

Report of the <u>France-Australe Bicentenary Expedition Committee</u>

Edited by P.F. Berry, S.D. Bradshaw, B.R. Wilson

RESEARCH IN SHARK BAY

REPORT OF THE FRANCE-AUSTRALE BICENTENARY EXPEDITION COMMITTEE

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FOREWORD

As part of the French contribution towards celebration of the Australian Bicentenary, a joint French-Western Australian scientific expedition was made to Shark Bay in July 1988, supported by the Governments of France and Western Australia.

A multidisciplinary team of eight natural scientists from the Musèum National d'Histoire Naturelle, Paris was accompanied by a similar number drawn from the Western Australian Museum, the University of Western Australia, Murdoch University and the Department of Conservation and Land Management. This team revisited the areas where early French navigators had landed and collected natural history specimens (St Allouarn in 1772, Baudin in 1801 and 1802 and de Freycinet in 1818), with a view to comparing the present situation at Shark Bay with the original French observations and descriptions.

On return to Perth a workshop was held in early August prior to departure of the French contingent, at which preliminary results of the expedition were reviewed and local scientists with past or current involvement in research at Shark Bay were invited to present papers. In view of the current interest in the natural history of Shark Bay it was decided to publish these papers, together with some others contributed by people unable to attend the workshop. (Papers presented at the workshop on preliminary research results have not been included.) Although this collection of papers is not a comprehensive review of research on the natural history of Shark Bay, it provides a timely summary of existing information in some fields and a basis on which to evaluate the need for future work. It is hoped that some of this may be undertaken in collaboration with French scientists.

The Expedition was funded by the French and Western Australian governments. The Museum National d'Histoire Naturelle provided generous supplementary funding for the publication. The Western Australian Fisheries Department provided a vessel and logistic support in Shark Bay. The hospitality of the Shark Bay Shire Council and the people of Denham is gratefully acknowledged.

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Archaeological research in the Shark Bay region, Western Australia: an introductory account

Sandra Bowdler*

Abstract

This paper summarises the results so far of an archaeological research project at Shark Bay. This project is directed towards an understanding of Aboriginal adaptations to this region in prehistoric times. So far, some 50 archaeological sites have been recorded, consisting mainly of unstratified shell midden scatters. One stone quarry site has been investigated in some detail, and small excavations have been carried out at two rockshelters. Dating of these, and one open midden site, demonstrate Aboriginal occupation of the region since mid-Holocene times only. Reasons why any very great antiquity of occupation of this area is unlikely are canvassed, and the possibility of environmental change during the Holocene is also discussed.

Résumé

Cet article résume les résultats obtenus jusqu'ici d'un project de recherches archéologiques dans la Baie des Chiens Marins. Ce projet vise à une compréhension des adaptations des Aborigènes à cette région à l'époque préhistorique. Jusqu'ici, quelques 50 sites archéologiques ont été recensés, consistant principalement en petites quantités de fumier de coquillages non stratifiés. Un site de carrière de pierre a été fouillé en détail, et de petites excavations ont été effectuées dans deux grottes. La datation de celles-ci et d'un site de fumier à ciel ouvert, démontre l'occupation Aborigène de la région depuis le Holocène moyen seulement. Les raisons pour lesquelles toute très haute antiquité de l'occupation de cette rèégion est improbable sont examinées minutieusement, et la possibilité de changement écologique pendant le Holocène est également traité.

Introduction

Aboriginal people have lived in the Shark Bay area since well before the advent of Europeans. Archaeological research has so far demonstrated that this occupation began at least 5000 years ago. We know from research elsewhere in Australia, including Western Australia, that the Aboriginal occupation of this continent began at least 40,000 years ago (e.g. Bowdler 1987). One of the questions to be addressed is whether the Shark Bay region has been only recently occupied relatively speaking, or whether further archaeological research will demonstrate a greater antiquity.

Aboriginal people still live in the Shark Bay area, but their way of life has changed greatly since the coming of the Europeans. Before that time, 200 years ago, Australia was occupied only by hunter-gatherers: people who subsisted off wild plants and animals. In Europe, the inhabitants began to practise agriculture not long after the end of the Pleistocene, and, by the time of the Romans, Europe

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was entirely inhabited by metal-using farmers. The Aborigines, by contrast, were able to adapt successfully to all the different environments of Australia without needing domestic plants or animals, nor tools made from anything other than stone, wood, shell and bone. This mode of life, which was highly systematic in its exploitation and use of land and resources, was successful for at least 40,000 years, but vulnerable to the impact of European colonists.

In the Shark Bay region, the first European explorers passed by in the seventeenth century A.D. In 1616, Dirk Hartog was the first European definitely known to have set foot on the west coast of Australia. He landed on the appropriately named Dirk Hartog Island, leaving behind an inscribed pewter plate nailed to a post (Henderson 1986:19). Other navigators, on voyages of discovery, followed, de Vlamingh in 1697 doing a plate switch. Few encounters with, or even observations of, Aboriginal people were made until the Baudin expedition of 1801-3, and Freycinet's return in 1818, described in detail in Marchant (1982). From these journeys, we have a few descriptions of items of material culture, such as spears, shields and clubs. Of a little more interest archaeologically are the relatively detailed descriptions of clusters of huts, suggesting quite substantial campsites used for more than an overnight stay (e.g. Baudin 1974:507).

In 1827-1829, the British established permanent settlements at King George Sound (the modern town of Albany) and Swan River (Perth). Thereafter, it was only a matter of time before land explorers and settlers moved in on Shark Bay. Grey (1841) passed through, without actually encountering any Aborigines, although he found evidence for their recent presence in the form of huts and fires. Further detailed mapping of the region was carried out in 1850 by Captain T.F. Gilman and in 1858 by Captain H.M. Denham (von Bamberger 1980:69).

During the 1850s, the first European land use of the region began, initially taking the form of the exploitation of the guano deposits on the islands and mainland. A small garrison was established on Dirk Hartog Island at this time, and in the early 1860s, the pearling industry began. This was of continuing significance in the region, particularly since Aboriginal men were taken on as labour on the cutters. It also introduced new ethnic groups to the region, Chinese pearlers and Malay contract labourers.

By the 1880s, all pastoral land had been taken up, the pearling industry had reached its productive peak, guano continued to be exploited, as also was sandalwood. Some Aboriginal people may still have been leading a traditional life, but we have no information on this point.

In 1904, the Queensland anthropologist W.E. Roth conceived the idea of establishing lock hospitals (hospitals specifically for patients suffering from venereal disease) for Aboriginal people from N.W. Australia in an isolated place. The Western Australian government immediately adopted this idea, "the unhappiest decision ever arrived at by a humane administration, a ghastly failure to arrest the ravages of the disease, and an affliction of physical and mental

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torture that it could not perhaps have been expected to forsee", Daisy Bates (1938:97) tells us. The hospitals were sited on Dorre and Bernier Islands for women and men respectively. Bates visited these institutions in 1910, and described the appalling plight of the inmates, Aborigines suffering from leprosy and venereal disease, brought from as far afield as Hall's Creek, Broome, Marble Bar and Lake Way. This "ghastly experiment" (Bates 1938:104) was abandoned in 1911. It is generally assumed that these bleak islands had not previously been occupied by Aboriginal people.

The local Aboriginal people meanwhile had become reasonably wellintegrated with the British, Chinese and Malay settlers, and their population was fairly stable through the early twentieth century (von Bamberger 1980:79). With the demise of the pearling industry during the 1930s and 40s, a new fishing industry had begun to emerge, which continues to this day.

It will be apparent that we know very little indeed about the traditional life and customs of the pre-European Aboriginal people of Shark Bay. It is not even clear whose territory the region was, whether the Nanda people or the Mulgana people (Brown 1912; Tindale 1974:249-50 and map; Bates 1985:58; von Bamberger 1980-65-7; Phillip Playford, W.A. Geological Survey, personal communication).

Only one piece of sustained anthropological research has been carried out in the Shark Bay region. Von Bamberger (1980) addressed the question of the socialisation of Aboriginal children in the Denham community. The Department of Aboriginal Sites of the Western Australian Museum has recorded information about Aboriginal sites of the historical period.

Archaeological research

Until very recently, very little archaeological research had been carried out in this region. A geologist, van de Graaff (1980), collected stone artefacts from surface sites on the Peron Peninsula and inferred long-distance raw material sources. Further collecting of stone artefacts from surface sites was carried out by Denis Byrne in 1980 (unpublished), as a student exercise (he was then employed at the University of Western Australia). Small mitigation surveys were carried out by Maynard (1981) in anticipation of the construction of Telecom masts at Monkey Mia and Wooramel. She located one surface site at each place of "minor archaeological significance".

I have carried out archaeological field work at Shark Bay in 1985, 1986 and 1987. Tha aim of this research is of a rather low level of inquiry, since we know so little about this region. The initial aims were simply to establish what kind of archaeological sites existed in the region, what kind of materials they might contain, and whether any were worth more intensive investigation, including excavation, to help us establish a chronology of occupation for the Shark Bay area, and perhaps provide us with some insights into the nature of the pre-European occupation.

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Some fifty archaeological sites have now been located, identified and recorded on the Peron Peninsula. Most of these are surface shell midden sites, comprising superficial scatters of stone artefacts, marine shell, and sometimes other faunal remains such as crab claws and mammal bones. Most directly overlook the shore or are very close to it, and they frequently occurr on weathered red dune sand. I have not located any inland sites, although I have been told by local identity Arthur Bassett that they exist; at the locations known to him however very dense scrub has so far made it impossible to relocate them. Interestingly, I have not found any sites at the south end of Hamelin Pool.

It is not clear whether these sites have always consisted of superficial scatters, or whether indeed they are eroded stratified sites. At some, it is possible to discern on occasional thin horizon in an erosion surface, which may contain midden material. Some other chronological clues exist however.

Shell found at these sites are usually the common marine species of baler, *Turbo* and oyster, the first of which is normally associated with sandy substrates while the last two are usually found on rocks. Occasional pearl oyster shells occur. Of particular interest is the occurrence of *Terebralia* shells. These animals normally live in mangrove environments, of which there are very few of any size along the Peron Pensinsula. The *Terebralia* shells are only found at some sites, but when they occur they are very abundant.

Other faunal remains include the bones of small macropods (two species, *Lagostrophus fasciatus* and *Bettongia penicillata*¹), birds and rodents, and small crab claws, which sometimes occur very numerously. Occasionally the remains of dugong and turtle are also found. The association of many of these remains (especially bird bones) with the sites are however somewhat problematical, given their unstratified nature.

Artefacts of stone are usually present and, at some sites, abundant. Raw materials include chert, silcrete and quartz. Artefact types include both backed blades and adze slugs. These are typical of a complex known as the Australian Small Tool Tradition, generally dated to within the last 4000 years.

At some sites, artefacts are found indicating an historical date. These include clay pipes, and also nineteenth century bottle glass flaked like stone artefacts. It may be noted that these artefacts do not occur at sites with *Terebralia* shells.

Some sites have been investigated in more detail. These include the test excavation of two rockshelter sites at Monkey Mia, controlled collections of artefacts, shell and other fauna from surface sites, and the investigation of a chert quarry site at Yaringa, near Gladstone.

The Yaringa quarry site was drawn to my attention in 1985 by geologist David McConachie (then of the Department of Geology, The University of Western Australia). It was thought worthy of more detailed attention for several reasons. On the one hand, van de Graaff's (1980) previous brief discussion did not mention

¹ Identified by Alex Baynes, Western Australian Museum

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it, nor envisage any such local significant stone sources. On the other hand, archaeological quarry studies have not been frequent until recently. Only during the 1980s have sophisticated methodologies been developed for the study of prehistoric lithic studies (e.g. Ericson and Purdy 1984), but there has been little application of these in Australia (McBryde e.g. 1984 being a notable exception).

Accordingly, in 1987 Allison Clark, an honours student in the Department of Archaeology, The University of Western Australia prepared a dissertation based on a detailed study of the Yaringa quarry. The initial aim of the study was to record, describe and characterise the quarry itself. The wider aim of her project was to investigate the connection between the distinctive honey coloured chert found in sites on Peron Peninsula and at the Yaringa quarry, in both petrological and archaeological terms.

Clark (1987:93-6) was able to elucidate techniques of stone exploitation, and other activities, at the quarry site itself. On petrological grounds, she was able to confidently identify the honey chert found at Peron Peninsula sites as originating at the Yaringa quarry. Further details as to the overall distribution of Yaringa chert in the Shark Bay region, and the nature of its curation and reduction at different sites and distances from the quarry, need further work and larger samples to establish.

With respect to the materials collected from open sites, on the one hand, stone artefacts have been used in Clark's (1987) study of Yaringa chert. On the other hand, it was thought useful to obtain a date for one of the sites with abundant *Terebralia* shells. The site selected for dating in this way was an extensive site at Eagle Bluff, which is virtually carpeted with *Terebralia*. A number of shell samples were collected, within arbitrarily chosen 1 x 1m squares. All the *Terebralia* shells from one of these squares was submitted for radiocarbon dating. The result is a date of 4690 ± 220 BP uncorrected, c. 4240 ± 255 corrected for the oceanic reservoir effect (Bowman 1985) whose significance is discussed further below.

In the low cliff which runs along behind the small settlement at Monkey Mia, a number of very small rockshelters occur. Two of these, not far from the settlement, appeared to be large enough to encourage human occupation, and to contain deposits which looked as though they might contain stratified archaeological materials. A single test pit measuring 1 x 1m was excavated in each.

In the first shelter (MM1), the largest and also nearest to the Monkey Mia settlement, the deposit was excavated to a depth of 104 cms. The deposit was fairly homogenous, of a red sandy nature. Excavation stopped because of large limestone boulders, and also cultural materials appeared to have petered out at this depth.

The contents included pieces of glass in the top 17 cms, stone artefacts to a depth of 96 cms, and bone and marine shell throughout. All these items were

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sparsely represented, with some clustering of artefacts between 73 and 50 cms, and bone between 50 and 61 cms. A summary is presented in Table 1.

Spit	Av.depth (cm)	Stone arte- facts (N)	Glass	Bonc (gms)	Shell (gms)	Date
1	<1	1	x	2.30	2.94	
2	6	1	x	1.63	5.77	
3	8	1	x	3.28	24.92	
4	17	2	x	8.11	25.74	
5	20			2.81	14.27	
6	23	6		8.4	11.51	
7	34	2		6.75	12.19	
8	43	10		9.85	40.74	
9	50	5		4.01	15.59	
10	55	1		40.49*	6.85	
11	61			31.82*	47.47	
12	87	1		5.81	14.27	
13		1		2.58	3.11	
14	92	1		2.05	1.27	650 ± 200
15	96	1		1.86	11.22	
16	104			3.34	20.96	

Table 1 Monkey Mia Rockshelter No. 1: Test Pit

*includes dugong

Table 2 Monkey Mia Rockshelter No. 2: Test Pit

Spit	Av.depth (cm)	Stone arte- facts (N)	Bone	Shell (gms)	Date (gms)
1	2	2	1.26*	0.04	
2	5		0.35*	1.19	
3	13			6.85	
4	24		0.1	0.49	
5	32		3.35*	0.54	
6	39	5	0.92	3.86	
7	52		2.76	17.65	
8	58	6	4.25	9.37	1100 ± 300
9	63	4	11.63	6.32	
10	75	3	6.45	51.93	
11	84	4	3.01	13.81	
12	90		1.94	14.8	
13	(95)		2.44	34.4	
14	101		2.56	95.74	
15	108		1.69	11.95	
16	119		5.73	18.04	
17	128		1.16	2.38	
18	133		0.31	1.63	

*includes rabbit

Most of the stone artefacts are small primary flakes or flake fragments, made of chert (43%), quartz (13%), and quartzite (45%). There were also three flakes with signs of secondary working or utilization, all of chert.

The faunal remains were not abundant, but represented a variety of animals. As well as numerous crab claws, there are bones of 3 species of small macropod (*Onychogalea lunata, Lagorchestes hirsutus, and Lagostrophus fasciatus*), four species of native rodent (*Leporillus apicalis, L. conditor, Rattus tunneyi, and Notomys sp.*), not specifically identified bird, fish and reptile, as well as dugong and turtle. There are also fragments of sea urchin and of eggshell. The marine shells included limpets, turban shells, baler shells, oysters, cockles and venus shells. No *Terebralia* were identified. There are also fragments of cuttlefish.

A radiocarbon date was obtained from charcoal at a depth of 92 cms below the surface. The result is 650 ± 200 BP.

In the second shelter (MM2), a very similar deposit was excavated to a depth of 133 cm. Stone artefacts were only found to a depth of 84 cms, although marine shell continued beneath this to the bottom of the excavation. Artefacts and bone were not as abundant in this shelter as in MM1, although the density of marine shell in the deposit is not dissimilar (Table 2).

The stone artefacts in MM2 consisted entirely of small primary flakes and flake fragments, with a higher proportion (83%) being of chert. The faunal remains include rabbit (*Oryctolagus cuniculus*) in the uppermost 32 cms, but otherwise represent some of the animals identified from MM1 (wallaby, *Leporillus apicalis, L. conditor, Notomys sp.*, fish and turtle). Crab claws, sea urchin and eggshell fragments were also noted. The marine shell species are similar to those of MM1, with again no *Terebralia*.

A radiocarbon date was obtained from charcoal from a depth of 58 cms below the surface. The result is 1100 ± 300 BP.

Discussion

The data gathered so far are exceedingly sparse, and some of them remain to be further analysed and dated. It is possible however to suggest a speculative sequence for Aboriginal occupation of the Shark Bay region, to be tested by further research and which draws to some extent on comparison with other information to the north and the south.

Of particular importance to considerations of past human behaviour in Australia is an understanding of past sea levels and associated environmental change. During periods of increased glacial activity during the Pleistocene, sea levels were lower, on a global basis. Detailed sea level curves have been calculated for the last 120,000 years (see especially Chappell and Shackleton 1986), which, in our current state of knowledge, comfortably brackets the period of human occupation in Australia. The continent of Australia (including the island of New Guinea) has, as its predominantly marsupial fauna attests, always been separated by a water barrier from southeast Asia and the rest of the world. Human colonists

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must always have had to make a water crossing to get here. The crossing would however have been lessened during times of lowered sea level. I have argued elsewhere (1977, in press) that colonists coming by water would probably have been well-adapted to exploiting the resources of the sea. Assuming that the earliest colonists clung to the coastal fringes, therefore, it follows that if they arrived at a time of lowered sea level, their earliest sites would have been submerged beneath rising seas, and remain so to this day.

The sea was some 6 metres higher than it is now 125,000 years ago. It dropped to some 60m below its present level 112,000 years ago, rose subsequently to about -20m 106,000 years ago, and fluctuated between these levels until the height of the last glacial event about 18 to 17,000 years ago which caused a maximum lowering to -130m. After that last severe glacial began to ameliorate, the sea rose relatively rapidly to reach its present position 6000 years ago (see Figure 1.).



Figure 1. Sea level change over the last 120,000 years (from data in Chappell and Shackleton 1986).

The oldest firmly dated evidence for the human occupation of Australia is the site of Upper Swan, near Perth, where stone artefacts in an old alluvial terrace of the Swan River are associated with charcoal dated to 38,000 years BP. Most of our firm evidence is rather more recent than this, very possibly due to the argument presented above, that many early sites are submerged. This argument is supported by recent evidence from archaeological sites in the northwest. A rockshelter on Koolan Island, just off the West Kimberley coast, has produced evidence of human occupation firmly dated to 26,000 BP (O'Connor in press). The site is not continuously occupied thereafter; there is a date from higher in the deposit of c.24,000 BP which is directly overlain by a date of c10,000 BP, suggesting a hiatus of both occupation and deposition. Significantly, the oldest date was obtained from marine shell. On the basis of a depth-age curve using the radiocarbon dates and the depths of the deposit from which they were obtained, O'Connor (in press) extrapolates a date for first occupation of the shelter of 30,000 BP. This corresponds with one of the times when the sea level rose bringing it close to Koolan rockshelter (see Figure 1). The hiatus between 24,000 and 10,000 corresponds with the retreat of the sea at the last glacial maximum. O'Connor (in press) interprets this sequence as evidence that people were living on the Pleistocene coastline, exploiting marine resources, and following the rising and retreating sea.

A closely similar sequence has been found in a rockshelter at North West Cape. In Mandu Mandu rockshelter there is evidence for human occupation and the exploitation of marine resources at 25,000 BP. This site has a more extended hiatus, between c.20,000 and 2500 BP, which however also encompasses the maximum retreat of the sea (Morse 1988b).

The fact that no evidence of human occupation prior to ca. 5000 BP has yet been found in the Shark Bay area may be due to the limited amount of research so far carried out. It may, on the other hand, be because the area was not in fact occupied during the Pleistocene. Or, drawing on the examples of Koolan Island and North West Cape, it may precede a considerable hiatus of such occupation which will make it difficult, if not impossible, to find in this particular area.

Koolan Island and North West Cape appear to have been occupied at times during the Pleistocene when the sea approximated its present position, while yet remaining some 40m lower then its present level. It may well be that the submarine topography around Shark Bay is such that the sea did not come very near its present position unless the level was higher than it was at anytime before 6000 and after 120,000 years ago. What is needed is a close inspection of hydrographic data for the area, to see where it might be profitable to look; at this stage, it would seem that the west coast of Dirk Hartog Island would be more likely to preserve evidence of Pleistocene occupation than Peron Peninsula. The ultimate difficulty however is the lack of known substantial rockshelter or cave sites which are likely to preserve sequences of an appropriate antiquity.

Turning to the Holocene evidence, at Shark Bay we have one open midden site with occupation and exploitation of what must have been quite dense mangrove stands dated to 4200 BP, and two rockshelters with occupation dated to c.1000 BP and 700 BP respectively. None of the evidence suggests very dense or intensive occupation. There are again similarities with other areas. Archaeology



Figure 2. Rockshelter 2, Monkey Mia.



Figure 3. Rockshelter 2, Monkey Mia: test pit section.

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Morse (1988a) has carried out a survey of the cliffs near the Zuytdorp wreck site just south of Shark Bay. She obtained dates from two shell midden sites, showing them to be c.4600 and c.4000 years old respectively. She concluded that Aboriginal occupation of the area was probably occasional only, in that the area has fewer and less accessible resources for human occupation than Shark Bay. Morse (personal communication) has also obtained dates for two open midden sites in the North West Cape area of c.5200 and 5000 BP. Some of these sites show extensive exploitation of mangrove resources.

Evidence is accumulating from other parts of northern Australia, and indeed Southeast Asia, that when the sea reached its present level, c. 7-6000 years ago, extensive stands of mangroves were established in estuarine areas, and that these provided important resources for Aboriginal communities (Woodroffe *et al.* 1985, 1988; Hope *et al.* 1985; Allen 1987). These mangrove swamps were however generally replaced between 5000 and 3000 years ago by open floodplains, and this is reflected in changes in archaeological sites (Allen 1987). Other evidence suggests that the early Holocene climate may have been somewhat moister and warmer than that of more recent times (Bowler *et al.* 1976).

The Shark Bay evidence so far would seem in accord with this pattern. One of the most extensive surface sites located, at Eagle Bluff, is abundant in *Terebralia* shells, of which a sample has been dated to c.4200 BP. Other sites which lack *Terebralia* shells appear to be both more recent and less extensive. The two rockshelter sites are dated within the best 1000 years, lack *Terebralia* shells, and show little evidence of intensive occupation. Sites demonstrably recent by virtue of the presence of flaked glass and clay pipes similarly lack *Terebralia* shells. Clearly however this pattern needs to be subjected to more rigorous testing, by a closer examination of more open sites, including the submission of samples for radiocarbon dating from an appropriate range of sites.

The question of the Pleistocene occupation of Shark Bay however is likely to remain an open question unless more substantial stratified sites can be located. Such sites would of course also throw more light on questions about the Holocene, since they allow so much greater chronological control of the data. The nature of the Shark Bay environment is however not encouraging to the hope of finding more such sites. It is in that case necessary for the archaeologist to wring the maximum amount of information possible from the sites that are available, unimpressive though they may be.

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Geology of the Shark Bay area, Western Australia.

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Abstract

Shark Bay is a shallow embayment bounded by peninsulas and islands, which are thought to be localized by subsurface Tertiary anticlines. Rocks exposed in the area consist of Cretaceous chalk, Tertiary sandstone and limestone, Pleistocene eolian limestone, eolian sandstone, marine limestone, and evaporites, and Holocene sands, beach-ridge deposits, and stromatolites.

The Pleistocene eolian limestone (Tamala Limestone) accumulated as enormous dunes on the western shoreline of the area during glacial periods of the Pleistocene, when the area was subject to extremely strong southerly winds. The linear development of the unit along the Zuytdorp Cliffs may be defined by a Quaternary fault.

The Hamelin Coquina is a beach-ridge deposit laid down around the hypersaline waters of Hamelin Pool and Lharidon Bight, and composed almost entirely of shells of the small bivalve *Fragum erugatum*, which thrives in the hypersaline conditions. Hamelin Pool became a hypersaline barred basin about 4,200 years ago, when the Faure Sill developed across its entrance, restricting inflow of open-marine waters from the rest of Shark Bay. Growth of stromatolites on the shallow sublittoral platform and intertidal zone of Hamelin Pool may have begun at about that time.

Hamelin Pool contains the most abundant and diverse stromatolites known in the world's oceans. They are believed to occur there because the hypersaline conditions have severely reduced or eliminated elements of the marine biota that would otherwise consume the stromatolite-building microorganisms or compete with them for ecological niches.

The three main types of benthic microbial communities that construct stromatolites at Hamelin Pool are termed pustular, smooth, and colloform mats. They are composed of distinct communities of cyanobacteria ("blue-green algae"), and microalgae. Pustular-mat stromatolites are confined to intertidal environments, smooth-mat stromatolites to lower intertidal and shallow subtidal environments, and colloform-mat stromatolites to subtidal environments (extending to depths of up to 4 m). The external morphology of the stromatolites is largely controlled by environmental factors, whereas biological factors are mainly responsible for differences in their internal fabrics.

The Hamelin Pool stromatolites are extremely slow growing, with measured growth rates of less than 0.5 mm per year, and they are consequently very susceptible to long-term damage by human activities. Many individual stromatolites are believed to be hundreds or even thousands of years old.

Résumé

Shark Bay est une baie peu profonde bordée de péninsules et d'îles que l'on pense être localisées audessus d'anticlinaux tertiaires en subsurface. Les roches qui affleurent dans la région consistent en craie du Crétacé, grès et calcaires du Tertiaire, calcaires et grès éoliens, calcaires marins et évaporites du Pléistocène, ainsi qu'en sables, dépots de levée de plage et stromatolites de l'Holocène.

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Les calcaires éoliens pléistocènes (Tamala Limestone) se sont déposés en vastes dunes sur la côte occidentale de la région durant les périodes glacières du Pléistocène, lorsque la région était sous l'influence de vents méridionaux extrêmement forts. Le développement linéaire de cette formation le long de Zuytdorp Cliffs peut être attribut à faille quaternaire.

Le Hamelin Coquina est une lumachelle déposée autour des eaux hypersalines de Hamelin Pool et de Lharidon Bight, et elle est composée presque entièrement de petits bivalves *Fragum erugatum*, qui abondent dans les conditions hypersalines. Il y a environ 4,200 ans, Hamelin Pool est devenu un bassin hypersalin suite à l'obstruction de son entrée par une barre sableuse, lorsque le Faure Sill se développa, restreignant les échanges d'eaux marines avec le reste de Shark Bay. Le développement de stromatolites sur la plateforme sublittorale peu profonde et dans la zone intertidale de Hamelin Pool a pu commencer à cette époque.

Les stromatolites de Hamelin Pool représentent les plus abondantes variétés dans les océans actuels. Leur développement peut être attribué aux conditions hypersalines qui auraient fortement réduit ou éliminé une partie du biotope marin qui qurait autrement détruit les micro-organismes constructeurs de stromatolites ou aurait été en compétition pour la niche écologique.

Les communautés microbiennes benthiques qui construisent les stromatolites de Hamelin Pool sont subdivisées en trois principaux types: pustuleux, lisses et botryoïdes. Elles sont composées de communautés distinctes de cyanobactéries ("algues bleues") et d'algues microscopiques. Les stromatolites pustuleux sont confinés aux milieux intertidaux, les stromatolites lisses aux milieux intertidaux inférieurs et néritiques peu profonds, et les stromatolites botryoïdes aux milieux infratidaux (s'étendant à des profondeurs allant jusqu'à 4 m). La morphologie externe des stromatolites est largement controlée par les facteurs écologiques, tandis que les facteurs biologiques sont principalement responsables des différences dans leurs structures et textures internes.

Les stromatolites de Hamelin Pool ont une croissance extrêmement lente, avec des taux de croissance inférieurs à 0.5 mm par an, et ils sont par conséquent vulnérables aux dommages causés à long terme par les activités humaines. On suppose que de nombreux stromatolites individuels sont âgés de centaines ou même de milliers d'années.

Introduction

Shark Bay is a shallow area of sea in the southern Carnarvon Basin, bounded to the west by Dirk Hartog, Dorre, and Bernier Islands, and Edel Land Peninsula, and divided into two arms by Peron Peninsula (Figure 1).

The Shark Bay area was almost unknown geologically until the mid 1950s, when West Australian Petroleum Pty Ltd conducted the first reconnaissance geological survey of the area (Johnstone and Playford 1955, Playford and Chase 1955), and drilled a series of holes on Dirk Hartog Island. Since then there has been a considerable amount of mapping and other research carried out in the area by geologists of the University of Western Australia, Geological Survey of Western Australia, and Baas Becking Geobiological Laboratory.

The Geology Department, University of Western Australia, commenced detailed studies of Holocene sedimentation in the Shark Bay area in the late 1950s (Logan 1959, 1961), and B. W. Logan and his co-workers have since published two comprehensive monographs on this work (Logan *et al.* 1970, Logan, Read, *et al.* 1974). The Geological Survey of Western Australia has studied the stromatolites of Hamelin Pool since 1968, and mapped the area during the





Figure 1. Generalized geological map of the Shark Bay area.

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1970s (Playford and Cockbain 1976; Playford 1980a, 1980b, Butcher *et al.* 1984; Denman *et al.*, 1985; van de Graff *et al.*, 1983; Hocking *et al.* 1987). The Baas Becking Geobiological Laboratory carried out detailed biological, sedimento-logical, and meteorological studies at Hamelin Pool during the late 1970s and 1980s (Bauld *et al.* 1979; Bauld 1984; Burne and James 1986; Walter and Bauld 1986; Skyring and Bauld in press), and further details of biological aspects of this work are being documented for publication.

Geomorphology

The peninsulas and islands which confine and divide Shark Bay consist of Pleistocene and Holocene dune deposits, which are thought to have accumulated on anticlinal ridges of Tertiary limestone (Figure 1). The hypothesis that the gross modern morphology is controlled by underlying folds was first proposed by Playford and Chase (1955), and was confirmed in the case of Dirk Hartog Island by a program of structure drilling for petroleum exploration (Butcher *et al.* 1984).

North-south promontories on the eastern side of Edel Land Peninsula (such as Bellefin Prong), and the associated inlets (such as Useless Inlet) are defined



Figure 2. The Zuytdorp Cliffs, adjoining Womerangee Hill. The type section of the Tamala Limestone is exposed at this locality, which marks the highest point along the cliffs (270 m above sealevel).

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by major longitudinal dune ridges and interdune valleys in the Pleistocene Tamala Limestone. These formed parallel to the strong prevailing southerly winds.

Similar north-south longitudinal dune ridges, in red sand over Peron Sandstone, occur on Peron Peninsula, and are also believed to be of Pleistocene age. The longitudinal dunes are connected by subordinate transverse dunes, and the interdunal depressions are occupied by playa lakes, known by their Aboriginal name as birridas. These are also believed to have originated during the Pleistocene.

The most striking geomorphological feature of the Shark Bay area, and one of the most remarkable features of the Western Australian coast, is the Zuytdorp Cliffs. These form a straight line of sheer cliffs, up to 270 m high, marking the western side of Edel Land Peninsula, and extending south for some 200 km to Kalbarri (Figure 2). They are named after the Dutch ship *Zuytdorp*, which was wrecked at the foot of the cliffs 60 km south of Shark Bay in 1712 (Playford



Figure 3. Map of the Hamelin Pool area showing sublittoral and intertidal-supratidal platforms and the Faure Sill, which restricts circulation between Hamelin Pool and the open ocean.

Geology

1960). The cliffs are composed of Pleistocene dune limestone (Tamala Limestone) and may be controlled by a fault, although it is not known whether this has moved during the Quaternary (Megallaa 1980, Butcher *et al.* 1984). Similar cliffs mark the west coast of Dirk Hartog Island.

Hamelin Pool forms the southeastern arm of Shark Bay. It is a hypersaline embayment, partially barred from the rest of the bay by a sand and seagrass bank, the Faure Sill (Figure 3). The water is hypersaline, with salinities up to nearly double that of the open sea, because tidal exchange is severely restricted by the shallow bank, rainfall is low, and evaporation is high. The hypersaline conditions are primarily responsible for the remarkable stromatolites and shell deposits (Hamelin Coquina) that occur around the margins of Hamelin Pool.

The most important control on the various types of stromatolites found in Hamelin Pool is the tidal range, but previous investigations have been made without the benefit of accurate tide data. As a result, the Geological Survey arranged for a tide gauge to be installed by the Department of Marine and Harbours (through Mr D.F. Wallace) at Flagpole Landing, Hamelin Pool, for



Figure 4. Tide data for Hamelin Pool obtained at Flagpole Landing in 1979-80 by the Department of Marine and Harbours. 4a. - Tide records for the period June 1979 to August 1980. 4b - Tide records for September 1979. 4c - Cumulative frequency curve for water levels at Flagpole Landing over a period of 416 days in 1979/80.

15 months from June 1979 to August 1980 (minus a 6-day gap in April 1980). Water levels were recorded every 15 minutes, giving some 40,000 pieces of information, which are synthesized in Figure 4a.

The main changes in water level at Hamelin Pool are linked to the weather. The approach of a low-pressure system causes the water level to rise, while a high-pressure system causes it to fall. In general the highest levels occur during winter, the lowest in summer. No cyclone passed through the area when the records were being obtained, but my own observations showed that Cyclone Hazel caused the water level at Flapole Landing to rise about 4 m above mean sealevel on 13 March 1979.

The tides at Hamelin Pool are classed as mixed semi-diurnal and diurnal, but are predominantly semi-diurnal (see record for September 1979, Figure 4b). The average daily tidal range is about 0.4 m (D.F. Wallace, pers. comm. 1981). The cumulative frequency curve (Figure 4c) shows the percentage submergence above and below mean sealevel for the period that the gauge was installed. The total extent of water-level change during the 416 days of observation was 1.6 m. A point 0.9 m above mean sealevel was submerged on only one day, one at 0.2 m above mean sealevel was submerged on 83 days (20% of the time), and so on down to a point of 0.7 m below mean sealevel, which remained submerged for 415 of the 416 days.

General geology

The surface geology of the Shark Bay area west of Hamelin Pool consists of Pleistocene and Holocene limestone and sandstone, largely covered by superficial sand (Figure 1). East of Hamelin Pool the area is largely covered by calcretised Cretaceous chalk, with some overlying Tertiary sandstone and calcarenite. Drilling has shown that the Shark Bay area is underlain by a thick sequence of Tertiary limestone, Cretaceous chalk, sandstone, shale, and Silurian sandstone, limestone, dolomite, and evaporites. Details of this subsurface sequence are outlined by Hocking *et al.* (1987); the surface geology only will be further discussed in this paper.

Cretaceous

The *Toolonga Calcilutite*, of Late Cretaceous age, is the oldest unit exposed in the area. It outcrops discontinuously along the east side of Hamelin Pool from Flint Cliff to Yaringa Station. The unit consists of white chalk and greenishwhite lime mudstone, usually altered to calcrete at the surface, and often containing abundant chert nodules.

Tertiary

The Eocene Giralia Calcarenite consists of greenish-grey calcarenite exposed at a few localities east of Hamelin Pool, overlying Toolonga Calcilutite. The Miocene Lamont Sandstone consists of silicified sandstone exposed in rocky headlands, such as Carbla Point, and a few other localities near the east shore of Hamelin Pool, overlying Toolonga Calcilutite.

Pleistocene

The *Peron Sandstone* is a unit of red colian sandstone, which is primarily exposed on Peron Peninsula. It is overlain by Tamala Limestone, and possibly interfingers with the lower part of that formation. The Peron Sandstone accumulated as a series of interlocking longitudinal and transverse dunes (Hocking *et al.* 1987).

The *Tamala Limestone* consists of a succession of eolian limestones, most of which accumulated during glacial periods of the Pleistocene, when sealevel was much lower than it is today. The unit is mainly developed on the Edel Land Peninsula, bounded to the west by the Zuytdorp Cliffs, which may be the physiographic expression of a Quaternary fault. The type section is at the highest point of these cliffs, adjoining Womerangee Hill (Figure 2), where its measured thickness is 270 m (Johnstone and Playford 1955). The total thickness of the Tamala Limestone in this area (extending below sealevel) probably exceeds 300 m, which is the thickest development known throughout the extent of the formation, from Shark Bay to the south coast of Western Australia. The prevailing southerly winds that formed the enormous dunes of the Tamala Limestone in the Shark Bay area during the low sealevel stands of the Pleistocene are thought to have been the strongest along the Western Australian coast at that time. They were considerably stronger than the prevailing southerlies in the area today, which are still the most powerful prevailing winds in Western Australia.

The *Dampier Limestone* is the oldest marine Pleistocene unit in the Shark Bay area, probably dating from the penultimate interglacial period, although it has yet to be accurately dated. It consists of shelly limestone laid down under waters of normal marine salinity. The *Carbla Oolite Member* is recognized within the Dampier Limestone on the shores of Hamelin Pool.

The *Depuch Formation* is a unit of calcarenite and calcirudite which occurs in narrow strips along the east side of the Edel Land Peninsula. It is believed to have formed by the erosion and reworking of older Pleistocene units.

The *Bibra Limestone* consists largely of beach-ridge deposits, with some tidalflat and coralline deposits, exposed along parts of the Shark Bay coastline. The unit contains an open-marine fauna, and is believed to have been deposited during the last interglacial period (ca. 120,000 years ago). Hamelin Pool was not hypersaline at that time, as shown by the open-marine fauna of the Bibra Limestone around its shores.

Evaporite deposits occur in birridas between Pleistocene dune ridges. They consist largely of gypsum, and have been mined at places on the Edel Land Peninsula. The deposits have not been accurately dated, but are believed to be Pleistocene. They are overlapped by Holocene dune ridges (Hamelin Coquina) on the east side of Hamelin Pool and have been inundated by the sea near the northwest end of Peron Peninsula.

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An interesting consequence of the inundation of Pleistocene evaporites is found on the west side of Hamelin Pool, north of Booldah Well. At this locality there are numerous circular ponds on the supratidal flats, up to about 20 m in diameter and 5 m deep, which are believed to be due to collapse following the subsurface solution of gypsum in a buried birrida deposit (presumably dissolved by groundwater flowing out from the land below the surface). The ponds ("blue holes") are filled with brine, and the water is replenished periodically following very high tides. The incoming water, although itself hypersaline, is less salty than the brine already in the ponds, and consequently it spreads out as a fresher surface layer, causing the ponds to become meromictic ("solar ponds").

The temperature of the brine below the hermocline rises by as much as 20°C. When the ponds are meromictic they are a bright blue colour - hence the name "blue holes". Stratification of the water is lost with time as the surface layer becomes more salty through evaporation, or mixing occurs as a result of wind action, and the ponds then become greenish in colour.

Holocene

Detailed information on aspects of Holocene sedimentation in the Shark Bay area is given in the monographs by Logan *et al.* (1970) and Logan, Read *et al.* (1974). Superficial Holocene sand, calcrete, and beach deposits occur extensively throughout the area, but the most interesting Holocene units are found around the shores of Hamelin Pool. These are the famous stromatolites and Hamelin Coquina, which are discussed in more detail than other features of Shark Bay geology in this paper.

Many elements of the open-marine fauna and flora found elsewhere in Shark Bay are unable to survive in Hamelin Pool because of its hypersalinity. On the other hand, some forms that can adapt to the high salinity are able to thrive there, due in part to the reduced abundance and diversity of competitors and predatory and grazing animals. The most conspicuous example of such a species is the small bivalve *Fragum erugatum*, which is by far the dominant mollusc in Hamelin Pool. This species also flourishes in Lharidon Bight, which is similarly hypersaline, but it is not so abundant elsewhere in Shark Bay. Its dead shells have accumulated in vast numbers on the shores of Hamelin Pool and Lharidon Bight, to form the Hamelin Coquina (Figure 5).

The Hamelin Coquina consists of a succession of beach ridges, in a belt up to 1 km wide and 4 m thick, around the shores of Hamelin Pool and Lharidon Bight. The beach ridges are composed almost entirely of single shells, uniform in size, of *Fragum erugatum*. The beach ridges consist of loose coquina along the modern shoreline, but become progressively more cemented to coquinite in the older beach ridges away from the coast. The loose shells have been excavated, for a variety of purposes, at several localities, especially Lharidon Bight. The partly lithified coquinite has also been quarried, principally near Boolagoorda and Carbla Point, for use as building stone in the Shark Bay area. Geology



Figure 5. Hamelin Coquina from the modern beach ridge at Carbla Point, showing shells of *Fragum* erugatum.

The oldest (furthest inland) beach ridges must have formed when the waters first became hypersaline following development of the Faure Sill. Preliminary radiocarbon datings by the Geological Survey (yet to be published) suggest that this was about 4,200 years ago, i.e. about 1,800 years after the sea rose to its present level at the end of the Flandrian Transgression.

Stromatolites are the other, and most famous, element of Holocene geology of Hamelin Pool; they are discussed in the following section.

Stromatolites

Introduction

The term stromatolite, as used in this paper, is applied to organosedimentary structures with vertical relief above the substrate, produced by sediment-trapping and/or precipitation resulting from the growth of benthic microbial communities, principally cyanobacteria.

Some authorities restrict the term stromatolite to laminated microbial bodies (e.g. Burne and Moore 1987), and according to their usage many of the Hamelin Pool forms would not be termed stromatolites, as they lack internal lamination in whole or in part. However, I see little advantage in adopting this restricted

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definition, and believe that the columnar and mound-shaped microbial structures at Hamelin Pool will continue to be known as stromatolites, in accord with common usage of the term among geologists and biologists.

The Hamelin Pool stromatolites have been the subject of a great deal of research, the principal publications being by Logan (1961), Logan, Hoffman, and Gebelein (1974), Playford and Cockbain (1976), Playford (1980a, 1980b), Golubic (1982, 1983, 1985), and Bauld (1984).

Why stromatolites occur at Hamelin Pool

Stromatolites are abundant, in a wide variety of forms, in Hamelin Pool, but are rare elsewhere in the world's oceans. There are two primary reasons why they are able to flourish at Hamelin Pool, both of which are linked to the hypersalinity of the water. Firstly it is clear that grazing animals, especially gastropods, which would consume the stromatolite-building cyanobacteria and microalgae, are very much reduced, and secondly there is a general paucity of thallophytic algae, such as seaweeds, which would otherwise utilize ecological niches now occupied by the stromatolites.

The Hamelin Pool stromatolites are regarded as modern analogues of the fossil stromatolites that occur widely in ancient rocks. Stromatolites are thought to have flourished during the Precambrian because of the lack of animal life and competing plants, but with the rise during the Phanerozoic of grazing and burrowing metazoans and higher marine plants, stromatolites became progressively less common in the world's oceans, until today they have almost disappeared. Thus, the conditions in Hamelin Pool, where most elements of the marine biota cannot survive, mimic conditions in the world's oceans during the early Palaeozoic.

Gross distribution

Stromatolites and associated stratiform cyanobacterial mats (formerly known as "blue-green algal mats") are growing today for some 100 km around Hamelin Pool (Figures 6-10). They cover wide areas of the intertidal zone and adjacent sublittoral platform, extending to water depths of at least 4 m. The stromatolites tend to grow together in linear belts, forming wave-resistant reefs.

Living intertidal forms are commonly backed along the shoreline by older dead stromatolites, which apparently grew when relative sealevel was as much as 1 m higher than today. These older dead forms are exposed above high-tide level, and are being actively eroded. They occur in some areas as a series of stepped terraces, which are best seen on the west shore of Hamelin Pool 4.5 km south of Booldah Well. The oldest stromatolites (from the highest terrace) at this locality have recently been radiocarbon dated as 1,000 to 1,250 years old (A. Chivas, written communication, 1988). Emergence and consequent death of these stromatolites may have resulted from recent uplift of the land in this area, perhaps associated with continued folding of the anticlines beneath the peninsulas (Playford 1980a).

Geology

Not all stromatolites in the intertidal zone and on the sublittoral shelf are living; a significant proportion are dead. Some died as a result of being overwhelmed with sediment, such as moving sand megaripples, and have since been uncovered. In many cases such exhumed stromatolites have been recolonized by living microbial mats, so that growth resumes. However, in other cases they have not been revived, even when in areas where conditions seem suitable for continuing growth, and it is not known why this is so.

The first paper to be published on the Hamelin Pool stromatolites claimed that they were restricted to the intertidal zone, and this concept was erroneously extended to the interpretation of ancient stromatolites (Logan 1961; Logan *et al.* 1964). However, subsequent investigations showed that subtidal stromatolites are widespread at Hamelin Pool (Playford and Cockbain 1976; Walter and Bauld 1986). Burne and James (1986) have further suggested that the present-day intertidal forms originated as subtidal stromatolites, which were stranded as a result of a relative fall in sea level. However, although this may be true in some cases, it is clear that many of the existing intertidal forms have grown wholly in the intertidal zone, as evidenced by their internal morphology and degree of cementation.

Stromatolite types

Nine types of microbial mats are recognized at Hamelin Pool, known as colloform, gelatinous, smooth, pincushion, tufted, pustular (mamillate), film, reticulate, and blister mats (Bauld 1984; Golubic 1985; Skyring and Bauld in press). Each of these has a characteristic microbial assemblage of cyanobacteria (one or more species), accompanied by microalgae in some mat types. The different mats occur in zones parallel to the shoreline, controlled primarily by their position within the tidal range.

Three of these mat types build columnar and mound-shaped stromatolites at Hamelin Pool: pustular, smooth, and colloform mats. The others form stratiform microbial mats, with little or no relief above the surface. The depth distribution, main biotic components, and morphology of the three stromatolite types are illustrated on Figure 6.

Pustular mat (mamillate mat of Golubic, 1985) forms small to large columns and mounds, up to 1 m wide and 40 cm high, in the intertidal zone (Figures 7, 8). It may also colonize the tops of smooth mat stromatolites as they grow higher in the intertidal zone. Pustular mat is built by the coccoid cyanobacterium *Entophysalis major*. This organism is thought to be a descendant of the Precambrian stromatolite-building cyanobacterium *Eontophysalis*, and this represents one of the longest-continuing biological lineages known (Golubic 1983).

Smooth mat constructs smaller stromatolite columns and mounds, mainly relatively small, in lower intertidal to shallowest subtidal environments (Figure 10). Smooth mat may also colonize the tops of colloform-mat stromatolites as

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Figure 6. Diagrammatic section illustrating the distribution in relation to sealevel of the Hamelin Pool stromatolites, their microbial mats, and their morphological characteristics.



Figure 7. Club-shaped pustular-mat stromatolites in the intertidal zone at Carbla Point.



Figure 8. Longitudinal pustular-mat stromatolites, elongate parallel to the direction of wave translation, 4 km south of Yaringa Point.



Figure 9. Mound-shaped colloform-mat stromatolites, up to 2 m across and 1 m high, in water about 2 m deep, 200 m offshore, and 100 m south of Carbla Point.



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Figure 10. Section through a small smooth-mat stromatolite and the calcrete foundation on which it grew, from Flagpole Landing. Note the relatively well-developed lamination and fenestral void system in the stromatolite, and the pseudo-stromatolitic (inorganic) lamination and bulbous form of the calcrete, which localized growth of the stromatolite.

they grow upwards into the intertidal zone. The principal agent of stromatolite construction is the filamentous cyanobacterium *Microcoleus chthonoplastes*; subdominant filamentous species are the cyanobacterium *Schizothrix* sp. and various flexibacteria (Bauld 1984, Golubic 1985).

Colloform mat forms large stromatolite columns and mounds up to 1 m high and several metres across (Figure 9) growing in subtidal environments, in water

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depths of up to 4 m (Playford 1980a; Walter and Bauld 1986). The microbial assemblage consists of a very diverse diatom flora and several species of cyanobacteria (J. Bauld, written communication 1989). The diatoms include some stalked forms, whose role in mat construction is at least as important as that of the cyanobacteria (J. Bauld, written comunication 1989). Macroalgae, especially *Acetabularia*, serpulid worms, and various other fauna are commonly attached to lithified surfaces of colloform-mat stromatolites (Bauld 1984; Golubic 1985; Walter and Bauld 1986).

Of the three stromatolite types, colloform-mat stromatolites contain the most diverse microbial flora and associated biota, and this is believed to be because they remain permanently submerged, under relatively constant salinity. The least diverse biota is found in high-intertidal pustular-mat stromatolites, which are exposed and subject to partial desiccation for prolonged periods each year.

Growth rates of stromatolites

The Hamelin Pool stromatolites grow very slowly by a process of accretion, through the trapping and binding of lime-sand and mud particles by a network of filamentous microorganisms, principally cyanobacteria. Some precipitation of calcium carbonate probably also occurs as a result of organic processes, and may play an important role in stromatolite cementation.

The growth rates of living stromatolites have been monitored over a period of 20 years, using non-corrosive nails placed as markers. This method has shown that the stromatolites are extremely slow growing, with maximum growth rates of less than 0.5 mm per year (Playford 1980a). Similar, but more precise, rates have recently been determined by carbon-14 analyses of stromatolites collected at Hamelin Pool, which showed long-term growth rates of about 0.3 mm per year (A. Chivas, written communication 1988). Field experimental data by Bauld and others (1979) have also shown that the highest primary productivity is found in subtidal colloform mat, and the lowest in intertidal smooth mat.

Most living intertidal forms seem to be virtually static, with growth balanced by erosion through wave action. The most active stromatolites are those in subtidal environments, although these are still subject to significant erosion during storms. A single storm may remove the growth of several years. The very slow growth rates indicate that some living stromatolites are probably hundreds, or perhaps even thousands, of years old. It seems possible that the commencement of stromatolite growth began some 4,200 years ago, when Hamelin Pool first became hypersaline.

The extremely slow growth rates of the stromatolites, their fragility, and susceptibility to damage by human activities, are well shown by wheel marks left more than 50 years ago by camel wagons pulled through living stromatolites near Booldah Well (Playford 1980a). These tracks are still so distinct that it would appear to a casual observer that they were made during the last year or two.
Clearly it will be several centuries before the damage at this locality will disappear through regrowth of the stromatolites.

Controls on stromatolite morphology

The morphology of the Hamelin Pool stromatolites is governed partly by environmental factors, and partly by the microbial communities that build them. The relationship between internal fabrics and microbial communities is illustrated on Figure 6. This shows that the best lamination occurs in smoothmat stromatolites (Figure 10), which also have the smallest fenestrae and smoothest external surfaces. Colloform-mat stromatolites are weakly laminated, with coarse fenestrae and irregular external surfaces, while pustular-mat forms are virtually unlaminated, and have very large fenestrae and irregular outer surfaces.

Further work needs to be done to more closely link details of the internal fabrics of the stromatolites with the microbial communities that build them. There is also a need to examine the processes involved in lithification of the stromatolites, and the extent to which the precipitation of cement is linked to organic versus inorganic processes. Lithification generally begins one or two centimetres below the living mat, but the mechanisms involved are not understood.

The principal environmental controls on stromatolite morphology are the wave-translation and prevailing wind directions, and the nature of the substrate (Playford 1980a).

Stromatolites at Hamelin Pool are commonly elongate in the direction of wave translation (Figure 8), apparently as a result of the scouring action of waves on the living mats. "Leaning" stromatolites near Carbla Point are inclined to the south, towards the prevailing wind, which is thought to have controlled growth in this direction, although the mechanism involved is not clear. Playford (1980a) also invoked wind-induced Langmuir circulation (paired helical vortices) in water to explain "seif" stromatolites on the west side of Hamelin Pool.

The nature of the substrate is a very important control on stromatolite development, as the stromatolites generally require a rocky substrate on which to grow. In various areas this consists of calcretised Cretaceous chalk (Toolonga Calcilutite), Tertiary silicified sandstone (Lamont Sandstone), and calcretised or otherwise lithified Pleistocene beach ridges and marine limestone (Bibra Limestone).

Stromatolites have grown principally around headlands rather than in bays, because the headlands have the required rocky substrate to initiate stromatolite growth. Where there is no rocky substrate, stratiform cyanobacterial mats tend to develop rather than columnar or mound-shaped stromatolites. On the east side of Hamelin Pool, headlands are localized by outcrops of Lamont Sandstone (such as at Carbla Point) or lithified Pleistocene beach ridges; on the west side they are commonly marked by similar lithified Pleistocene beach ridges. Stromatolites growing on such beach ridges occur in characteristic curvilinear belts, controlled by the lines of resistant ridges.

Conclusion

Shark Bay will continue to be an area of major interest to geologists because of its unique sedimentary environments, which include the habitat for the best developments of living stromatolites known from modern seas. Although there has already been considerable research conducted in the area, there is still a great deal remaining to be done, especially in relation to the growth and lithification of stromatolites and the history of Quaternary sealevel and climatic changes in the area.

The Tamala Limestone is a unit of considerable importance in coastal areas of southwestern Australia, but it has yet to be studied in any detail in the Shark Bay area, where the formation reaches its maximum development. The Tamala Limestone was probably laid down during several glacial periods of the Pleistocene, and a careful study of the unit at Shark Bay may provide a basis for its subdivision and for distinguisihing its various phases of deposition.

The relationships between the Tamala Limestone and Peron Sandstone also deserve further study, especially to determine the factors responsible for the accumulation of lime sand dunes on the one hand and siliceous sand dunes on the other. The associated birrida evaporite deposits also warrant research to determine the climatic conditions under which they accumulated.

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A Pleistocene molluscan fauna with Anadara trapezia (Deshayes) (Bivalvia: Arcoida) from the Dampier Limestone of Shark Bay, Western Australia.

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Abstract

A preliminary examination of fossil material from the Dampier Limestone at its type area, Broadhurst Bight, Shark Bay, records 95 molluscan species (56 bivalves, 39 gastropods). Up to nine of these, including the arcoid bivalve *Anadara trapezia* (Deshayes), are not known from the modern fauna of the area. The assemblage lacks normal trophic diversity and the hydrologic palaeoenvironment may have been a restricted one, influenced by freshwater discharge. Further study of correlative faunas and palaeoenvironments is indicated and there is a need for absolute age determination of emergent Pleistocene units in the area.

Résumé

Un examen préliminaire du matérial fossile de Dampier Limestone sur sa région typique, Broadhurst Bight, Baie des Chiens Marins, recense 95 espèces de mollusques (56 bivalves, 39 gastropodes). Jusqu' à neuf d'entre elles, y compris le bivalve arcoide Anadara trapezia (Deshayes), ne sont pas connues de la faune moderne de la région. L'assemblage manque de diversité tropihque normale et le paléomilieu hydrologique peut avoir été un milieu restreint, influencé par l'écoulement d'eau douce. Une étude ultérieure des paléomilieux corrélatifs est indiquée et une détermination absolue de l'âge des unités Pléistocènes émergentes est souhaitable dans la région.

Introduction

Stratigraphic studies (see Hocking *et al.* 1987 and references) of emergent Quaternary marine deposits in the Shark Bay area have drawn attention to the rich fossil assemblages, mainly molluscan, present there but to date no detailed examination of these has been undertaken.

The purpose of this paper is to provide a preliminary, annotated faunal list of the Mollusca of the Dampier Limestone in its type area, Broadhurst Bight (latitude 25°32'S, longitude 113°29'E), near the northern extremity of Peron Peninsula, Shark Bay. The material utilized in this study was collected by the writer during visits to the locality in November 1977 and December 1983 and is housed in the palaeontological collection of the Western Australian Museum. Catalogue numbers are as follows: WAM 79.1966-79.2071, 79.2121-79.2186, 84.1486-84.1495 and 88.1218.

The type section of the Dampier Limestone (Logan et al. 1970: 63-68; Hocking et al. 1987: 197) is a low (1 m) sea cliff of shelly limestone at the south end

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of Broadhurst Bight. The lower 0.3 m contains an abundance of large, frequently articulated bivalves and other molluscs. The only other macrofossils noted are occasional pieces of coral, not in growth position. The base of the formation is not exposed here but extensions up to 3 km southward show a disconformable contact with an erosion surface of the underlying Peron Sandstone.

The matrix of the shell bed comprises a pale brown, well-sorted, quartzose calcarenite with a rather weak, micritic cement. A strong calcrete layer caps the Dampier Limestone and lines numerous small solution pipes which descend into it. A well-cemented, thin, shelly-coralline rubble overlies the calcrete layer and occupies the solution pipes. This rubble appears to represent a Pleistocene depositional event younger than the "Dampier marine phase" of Logan *et al.* (1970) and may correlate with the Bibra Limestone (*ibid.*, pp. 68-73, 78-79).

A relative chronology of emergent Quaternary deposits at Shark Bay was established by Logan *et al.* (1970, p. 51, Table 2; p. 73, Table 6) but absolute ages were obtained only for the Holocene units and this remains the essential position. Results from electron spin resonance analysis by Hewgill *et al.* (1983) suggested a Late Pleistocene age for the Dampier Formation at its type section but these results require verification.

In the chrono-stratigraphic arrangement of Logan *et al.* (1970), the Dampier Limestone was assigned an informal "middle" Pleistocene age, from evidence of its contact relationships with older and younger units. This informal terminology has been followed by Butcher *et al.* (1984) and by Hocking *et al.* (1987). On the other hand, van de Graaff *et al.* (1983) and Denman *et al.* (1985) have assigned the Dampier Limestone to the Middle Pleistocene.

Evidence is accumulating (e.g., Broecker and van Donk 1970; Shackleton and Opdyke 1973; Stearns 1976; Chappell and Veeh 1978) that the "Last Interglacial" of the Late Pleistocene was a complex phenomenon, initiated around 128 thousand years ago by a major, transgressive-warming phase corresponding to substage 5e of the deep-sea, isotopic chronology (Shackleton and Opdyke, 1973; Bowen, 1978), followed by a sequence of lesser regressive-transgressive oscillations (substages 5d-a) and concluding about 75 thousand years ago. Subject to confirmation from absolute age determinations, it is suggested that both Dampier and Bibra Limestones derive from the "Last Interglacial", the former from substage 5e, the latter from a subsequent transgressive episode.

Systematic listing of molluscs from the Dampier Limestone at Broadhurst Bight, Shark Bay.

BIVALVES

Family Arcidae

1. Arca navicularis Bruguière, 1789. Figured Wells and Bryce, 1985: 148, figure 553.

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- 2. Anadara crebricostata (Reeve, 1844). About 38 narrow ribs on each valve.
- 3. Anadara trapezia (Deshayes, 1840). (Figure 1). About 23-26 ribs on each valve. Not now living at Shark Bay. Modern range is estuaries from central Queensland to southern Victoria with an isolated population at Albany, Western Australia. Figured Wells and Bryce, 1985: 148, figure 549.



Figure 1. Anadara trapezia (Deshayes). WAM 79.1996a, f. Southern end of Broadhurst Bight, Peron Peninsula, Shark Bay. Shell bed below prominent calcrete layer exposed on low coastal cliff. Map reference Denham (1546), G.M. 503724. Dampier Formation type section. A - paired valves showing LV exterior. B - LV interior. C- paired valves, anterior aspect. All X 1.

Family Mytilidae

- 4. Brachidontes ustulatus (Lamarck, 1819). Figured Wells and Bryce, 1985: 152, figure 556.
- 5. Septifer bilocularis (Linnaeus, 1758). Figured Wells and Bryce, 1985: 152, figure 559.

- Musculus nanulus Thiele, 1930. A minute species. Figured Thiele, 1930: 590, figure 70.
- 7. Modiolus philippinarum Hanley, 1843. Figured Wells and Bryce, 1985: 152, figure 562.
- 8. Modiolatus hanleyi (Dunker, 1882). An uncommon species.
- 9. Botula vagina (Lamarck, 1819). Figured Wells and Bryce, 1985: 152, figure 567.

Family Pinnidae

10. *Pinna* sp. cf. *P. bicolor* Gmelin, 1791. Fragments only, referred provisionally to this common species. Figured Wells and Bryce, 1985: 154, figure 571.

Family Ostreidae

11. Dendostrea folium (Linnaeus, 1758). A small to medium sized, thin-shelled oyster of irregular form, with radial folds and serrated commissure.

Family Pectinidae

12. *Chlamys australis* (Sowerby, 1842). Figured Wells and Bryce, 1985: 158, figure 583.

Family Spondylidae

13. Spondylus barbatus (?) Reeve, 1856. S. barbatus figured by Lamprell (1986: 48, pl. 16, figures 1a-c).

Family Lucinidae

- 14. Wallucina sp. aff. W. jacksoniensis (Smith, 1885). A small species, probably undescribed, which resembles the eastern Australian W. jacksoniensis.
- 15. Parvilucina (Bellucina) pisiformis (Thiele, 1930). A small species with cancellate sculpture, assigned to the genus Parvilucina Dall after Britton (1972). Figured by Ponder, 1978: 439, pl. 2, figures 3, 9.
- 16. *Divalinga* sp. A thin, orbicular shell with divaricate sculpture and finely crenulated margins.

Family Fimbriidae

17. *Fimbria soverbii* (Reeve, 1842). A rare species, recorded living in Western Australian waters south to about latitude 23°S but not known at Shark Bay. The Dampier Limestone specimen appears to be the most southerly record for the species. Figured by Nichol (1950: 85-86, figures 3, 5, 8) and by Wells and Bryce (1985: 163, figure 593).

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Family Ungulinidae

18. Felaniella sp. Small, thin, smooth shells with a roundly sub-angular marginal outline and two cardinal teeth in each valve.

Family Chamidae

19. Chama sp. A medium-size species with fine lamellose sculpture on each valve.

Family Lasaeidae

20. Melliteryx sp. aff. M. acupuncta Hedley, 1902. A minute, punctate species.

21. Lasaeid, genus and species undetermined. A minute species.

Family Carditidae

22. Megacardita turgida (Lamarck, 1819). Distinguished from the rather similar *M.incrassata* (Sowerby, 1825) by the more nodular rib sculpture. *M. incrassata* is figured by Wells and Bryce, 1985: 164, figure 595.

Family Crassatellidae

23. Eucrassatella pulchra (Reeve, 1842). Figured Wells and Bryce, 1985: 164, figure 598.

Family Cardiidae

- 24. Acrosterigma dupuchense (Reeve, 1845). Modern distribution is from Broome south to about latitude 23½°S but not known living from the Shark Bay area. This is the "Trachycardium flavum Linne" of the "Acropora-Trachycardium Assemblage" of Hagan (1970) and Hagan and Logan (1974). Figured and discussed in Wilson and Stevenson (1977: 85-87, pl. 5, figures 14-17) and in Wells and Bryce (1985: 166, figure 603).
- 25. Fragum (Fragum) carinatum (Lynge, 1909). (Figure 2). Living Indo-South West Pacific (Lynge, 1909) but not recorded from Australian seas. A synonym is Corculum (Fragum) bannoi Otuka, described from Taiwan (Otuka 1937). A small, robust species, distinguished by the strong single or double rib on the posterior shoulder and the angular outline. Museum collections show that in the late Middle to Late Pleistocene (isotopic stages 7 and 5), F. carinatum occurred, at times frequently, from Barrow Island south to Geographe Bay. No post-Pleistocene fossil is known from Western Australia but shells of the species have been reworked into the base of the Holocene Hamelin Coquina around Hamelin Pool, Shark Bay (WAM 80.382, 80.392).
- 26. Fragum (Fragum) unedo (Linnaeus, 1758). Figured Wilson and Stevenson (1977: 39, pl. 2, figures 19-22) and in Wells and Bryce (1985: 166, figure 610).
- Fragum (Lunulicardia) hemicardium (Linnaeus, 1758). Figured Wilson and Stevenson (1977: 46-48, pl. 2, figures 1-5) and in Wells and Bryce (1985: 166, figure 609).

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- Figure 2. Fragum (Fragum) carinatum (Lynge). WAM 87.594 (part). Yaringa Station, Shark Bay district, Western Australia. Large depression on western side of North West Coastal Highway. Map reference Wooramel (1746), KS 303257. Eroding slopes of Pleistocene shell bed overlying greenish Toolonga Calcilutite (Santonian). Upper row right valves; lower row left valves, all x 2.
- 28. Fragum (Afrocardium) erugatum (Tate, 1889). In some Shark Bay studies, e.g. Logan et al. (1970), the species has been referred to by its synonymous name Fragum hamelini Iredale, 1949. Distinguished from the similar-sized *F.carinatum* (Lynge) by its rounded posterior shoulder and less angular marginal outline. This species dominates the molluscan fauna of the modern, hypersaline Hamelin Pool and associated Hamelin Coquina beach ridges (Hocking et al. 1987) but is only a minor element in the Dampier Limestone at Broadhurst Bight. Figured by Wilson and Stevenson (1977: 49-51, pl. 3, figures 19-21) and by Wells and Bryce (1985: 166, figure 605).

Family Tellinidae

- 29. Tellina (Tellinella) virgata Linnaeus, 1758. Figured Wells and Bryce (1985: 172, figure 626).
- 30. *Tellina (Pharaonella) perna* Spengler, 1798. Figured Wells and Bryce (1985: 172, figure 627).
- 31. *Tellina (Pinguitellina)* sp. cf. *T. (P) robusta* Hanley, 1844. A small, roundlytriangular shell, closely comparable with this wide-ranging Indo-South West Pacific species.

- 32. Macoma (Scissulina) dispar Conrad, 1837). A small, thin shell bearing fine, oblique sculpture on the right valve only.
- 33. *Macoma* (s. l.) sp. An uncommon species of uncertain identity, not recognized in the modern fauna.
- 34. Exotica (Exotica) triradiata (H. Adams, 1870). A wide-ranging Indo-South West Pacific species, figured in Afshar (1969: 87-88, pl. 37, figure 1).

Family Semelidae

35. Leptomya psittacus (Hanley, 1883). A small shell with unequal, thin, white valves.

Family Veneridae

- 36. Antigona lamellaris (Schumacher, 1817). Figured Wells and Bryce (1985: 176, figure 645).
- 37. Dosinia (Pectunculus) sculpta (Hanley, 1845). A medium-sized shell with fine secondary radial sculpture at anterior and posterior ends. Figured Wells and Bryce (1985: 176, figure 635).
- 38. Dosinia (s. l.) biscocta (Reeve, 1850). A small shell with very fine secondary radials across the entire shell.
- 39. Gafrarium intermedium (Reeve, 1863). Small, robust shells with transverse ribbing over entire valves and divaricate sculpture on flanks and umbones.
- 40. Circe scripta (Linnaeus, 1758). Figured Wells and Bryce 1985: 178, figure 649.
- 41. Circe lenticularis Deshayes, 1853. Figured Wells and Bryce 1985: 178, figure 651.
- 42. *Tapes literatus* (Linnaeus, 1758). Figured Dance (1974: 267). Distinguished from the following species by its greater size (up to 11.3 cm long), more elongate form (length to height ratio of 1.6), finer sculpture and often-flamed colour pattern.
- 43. Tapes dorsatus (Lamarck, 1818). Figured by Fischer-Piette and Métivier (1971: 21-22, pl. 5, figures 6-9; pl. 6, figures 1-7); Shark Bay specimens most resemble their specimen in pl. 6, figure 5. The specimen attributed to *T.literatus* (Linnaeus) in Wells and Bryce 1985: 178, figure 647 appears to be *T. dorsatus*. The species has a stronger transverse sculpture than *T. literatus* and a length to height ratio of 1.4.
- 44. Irus irus (Linnaeus, 1758). Figured Fischer-Piette and Métivier (1971: 79-82, pl. 15, figures 12-14).
- 45. Marcia fumigata (Sowerby, 1853). The species inhabits estuaries and marine bays in south eastern Australia but is not known living from Western

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Australian seas. During the late Middle and Late Pleistocene, it was present throughout southern Australia northward to Shark Bay (WAM unpublished records). As *Eumarcia fumigata* (Sowerby), figured in Macpherson and Gabriel (1962: 352, figure 405).

- Paphia (Callistotapes) crassisulca (Lamarck, 1818). Figured Fischer-Piette and Métivier (1971: 41-42, pl. 11, figures 11, 12) Wells and Bryce (1985: 176, figure 638).
- 47. Callista (Costacallista) planatella (Lamarck, 1818). Figured Wells and Bryce (1985: 176, figure 639).
- 48. Pitar (Pitarina) citrina (Lamarck, 1818). A small to medium sized, rather inflated, robust shell with fine transverse sculpture; common.
- 49. *Clementia papyracea* (Gray, 1825). A large, thin rather fragile shell with weak transverse sculpture; uncommon.
- 50. Anomalocardia (Anomalodiscus) squamosa (Linnaeus, 1758). Figured Wells and Bryce (1985: 176, figure 644).
- 51. *Placamen berrii* (Gray in Wood, 1828). Shell robust, with about 23 low, transverse ribs in a height of 34 mm.
- 52. *Placamen gravescens* (Menke, 1843). Shell with about 17 raised transverse ribs in a height of 28 mm. Figured Wells and Bryce (1985: 176, figure 643).

Family Corbulidae

- 53. *Timoclea* (*Glycydonta*) sp. cf. *T.* (*G.*). *marica* (Linnaeus, 1758). Dampier Limestone specimens are very close to northern Australian (modern) specimens of *T. marica* but differ in sculptural details from representatives of the subgenus in the modern fauna of the Shark Bay area. *T. marica* is figured by Rippingale and McMichael (1961: 194, pl. 28, figure 8).
- 54. *Corbula (Corbula)* sp. cf. *C. (C.) stolata* (Iredale, 1930). Small robust shells with discrepant valves, the right transversely ribbed and larger than the left, which is smooth.
- 55. *Corbula* (s. l.) sp. A rare species, smaller than the preceeding and with more elongate valves.

Family Thraciidae

56. *Thracia alciope* Angas, 1872. A thin shell with smooth valves, the left longer and more compressed than the right; hinge edentulous.

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Family Trochidae

57. Euchelus atratus (Gmelin, 1791). Figured Wells and Bryce (1985: 44, figure 78).

- 58. Thalotia (Prothalotia) sp. cf. T. (P.) flindersi (Fischer, 1878). Small, trochoidal shell with spirally-sculptured whorls, stepped a little below the suture; umbilical fissure minute.
- 59. Calliostoma (Salsipotens) rubiginosum (Valenciennes, 1846) similare (Reeve, 1863). Figured Wells and Bryce (1985: 44, figure 88). A synonym is Calliostoma excellens Thiele, 1930 (Ponder, 1978: 429-432, pl. 2, figures 1, 2).
- 60. *Monilea callifera* (Lamarck, 1822). Figured Wells and Bryce (1985: 44, figure 81).
- 61. Solariella (?) sp. Minute shell with convexly-rounded whorls with light spiral and axial sculpture; umbilicus wide. Rare.

Family Turbinidae

62. Turbo (Marmarostoma) haynesi Preston, 1914. A small, robust shell with beaded spiral threads; operculum faintly pustulose, with a spiral rib and central boss.

Family Cyclostrematidae

63. *Elachorbis tatei* (Angas, 1878). Figured Ludbrook (1984: 64, figure 78c-g). A minute species.

Family Tornidae

64. Pseudoliotia micans (A. Adams, 1850). Figured May (1958; pl. 21, figure 8). A minute species.

Family Vermetidae

65. Serpulorbis sp. cf. S. sipho (Lamarck, 1818). An irregularly-coiled, vermiform, attached shell. S. sipho figured by Ludbrook (1984: 75, figures 21r, 79a).

Family Dialidae

- 66. Diala lauta A. Adams, 1862. Figured Ludbrook (1984: 78, figures 21k, 1, 68j; 78k; pl. 11e). A minute species.
- 67. Diala lirulata Thiele, 1930. A minute species with carinate whorls. Figured Thiele (1930: 574, figure 21).
- 68. Finella sp. A minute species with elevated spire and convex, plicate whorls.
- 69. Scaliola sp. A minute species with elevated spire and convexly rounded, smooth whorls.

Family Litiopidae

70. Alaba sp. aff. A. bowenensis (Laseron, 1956). A minute species with axial riblets on spire whorls, becoming fewer and stronger on the last whorl; spirally striate between axials and on base. Probably an undescribed species.

Family Cerithiidae

- 71. *Cerithium tenellum* Sowerby, 1855. A small shell with elevated spire, channelled sutures and a varicose aperture.
- 72. Rhinoclavis fasciata (Bruguière, 1792). Figured Wells and Bryce, (1985: 56, figure 134).
- 73. *Rhinoclavis bituberculata* (Sowerby in Reeve, 1865). Figured Wells and Bryce (1985: 56, figure 136).
- 74. Clypeomorus bifasciata (Sowerby, 1855). Small robust shells with strong granose spiral sculpture and two varices on the last whorl.
- 75. *Bittium icarus* (Bayle, 1880). Minute shells with four beaded spirals on each spire whorl.

Family Strombidae

76. Strombus (Doxander) campbelli Griffith and Pidgeon, 1834. Figured Wilson and Gillett (1971: 38, pl. 17, figures 9, 9a).

Family Muricidae

- 77. Morula fiscella (Gmelin, 1791). Emerson and d'Attilio (1981: 77-82, figure 9) figure a syntype of *Murex margariticola* Broderip, 1833, which is a synonym of *Murex fiscellum* Gmelin, 1791, the present species.
- 78. Lepsiella flindersi (A. Adams and Angas, 1863). The modern distribution is southern Australia north to about Fremantle; not recorded living in the Shark Bay area. Figured Wells and Bryce (1985: 92, figure 312).

Family Pyrenidae

79. Zafra vercoi (Thiele, 1930). A minute species. Figured Thiele (1930: 583, figure 57).

Family Buccinidae

80. Cantharus erythrostomus (Reeve, 1846). Figured Wells and Bryce (1985: 98, figure 343).

Family Nassariidae

 Nassarius albinus (Thiele, 1930). Figured Thiele (1930: 584, figure 58); Cernohorsky (1984: 106, pl. 16, figures 11-12).

Family Olividae

82. Oliva sp. A large specimen, resembling that figured by Wilson and Gillett (1971: 106, figures 1, 1a). Specific identify uncertain.

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Family Costellariidae

83. Vexillum (Vexillum) vulpecula (Linnaeus, 1758). The modern range of this Indo-South West Pacific species extends south to about Point Cloates (latitude 23°S) but is not known from Shark Bay and adjacent waters. Modern Western Australian specimens are assigned to the subspecies *jukesii* (A. Adams, 1851). Figured Wells and Bryce (1985: 110, figure 427).

Family Pyramidellidae

- 84. Cossmannica sp. Small shell with two columellar plaits and channelled suture; rare. Resembles S. subcarina Laseron (1959: 194, figures 24-26) from Queensland.
- 85. *Linopyrga* sp. Minute shell with single columellar plait and axially ribbed whorls; rare.
- 86. Syrnola sp. A. Minute shell with smooth elevated spire, a single columellar plait and thin peripheral colour band. Resembles S. pulchra Brazier, 1877, figured by Laseron (1959: 197, figure 38).
- 87. Syrnola sp. B. A minute, attenuate shell, assigned provisionally to this genus.
- 88. *Cingulina* sp. Small attenuate shell with strong spiral sculpture over entire spire and last whorl.

Family Ringiculidae

89. *Ringicula* sp. Minute, robust shells with strong columellar plaits, parietal callosity and outer lip.

Family Bullidae

90. Bulla ampulla Linnaeus, 1758. Figured Dance (1974: 221).

Family Hamineidae

This spelling of the family name (Hamineidae Pilsbry, 1895) follows Cernohorsky (1985: 63).

- 91. Atys sp. A minute, thin, involute, globose "bubble shell".
- 92. Cylichnatys campanula Burn 1978. Figured Burn (1978: 104-108, figures 11-17).
- 93. Liloa brevis Quoy and Gaimard, 1833). Figured Ludbrook (1984: 276, figure 68r).

Family Retusidae

94. Retusa sp. A minute, involute "bubble shell" with sub-parallel sides; apex umbilicate.

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Family Scaphandridae

95. Acteocina sp. A minute, cylindrical "bubble shell" with a distinct, raised apex.

Discussion

The study material comprises 95 mollusc species (56 bivalves, 39 gastropods), of which the greater part are familiars in the modern fauna of Shark Bay (see Slack-Smith, this volume). Exceptions to this include many of the small to minute species (e.g. lasaeid bivalves and opisthobranch gastropods), which are poorly represented in collections and, for the most part, scarcely known. Other exceptions include a group of nine species which, with varying degrees of probability, appear to be no longer living in Shark Bay waters. Further collecting may change these assessments but, for the present, this group may be characterized as follows:

Group Λ — species with recognized modern ranges north of Shark Bay;

Group B — species with recognized modern ranges south of Shark Bay;

Group C — species with no known modern range.

Group A	Group B	Group C
Fimbria soverbii Acrosterigma dupuchense Fragum carinatum Timoclea sp. cf. T. marica Vexillum vulpecula	Anadara trapezia Marcia fumigata Lepsiella flindersi	Macoma (s.l.) sp.

The above group of nine apparently-absent species constitutes about 10% of the Dampier Limestone assemblage recorded from the type area and, for such geologically-young material, represents a significant discrepancy from the modern fauna of the area. Oxygen isotope studies (e.g. Bé and Duplessy 1976) indicate that there have been two severe regressive low-temperature episodes, substages 4 and 2 of the terminal Pleistocene, since the time of deposition of the Dampier Limestone, which saw substantial northward displacements of the Subtropical Convergence Zone and severe cooling of surface waters in the southeast Indian Ocean, i.e., between Cape Leeuwin and Shark Bay. The post-Pleistocene transgressive-warming phase of the last 10 thousand years may represent no more than a partial restoration of temperature conditions prevailing in Shark Bay waters during substage 5e of the "Last Interglacial", the presumed time of deposition of the Dampier Limestone.

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		Bivalves			
Veneridae	18 :	species	Pin	nidae	1 species
Mytilidae	6 :	species	Osti	reidae	1 species
Tellinidae	6 :	species	Pect	inidae	1 species
Cardiidae	5 :	species	Spo	ndylidae	1 species
Arcidae	3 :	species	Ung	gulinidae	1 species
Lucinidae	3	species	Cha	midae	1 species
Lasaeidae	2 :	species	Car	ditidae	1 species
Corbulidae	2 :	species	Cras	ssatellidae	1 species
			Sem	elidae	1 species
			Thr	aciidae	1 species
		Gastropoo	ds		
Trochidae	5 spec.	Turbinidae	1 spec.	Nassariidae	1 spec.
Cerithiidae	5 spec.	Cyclostrematidae	1 spec.	Olividae	1 spec.
Pyramidellidae	5 spec.	Tornidae	1 spec.	Costellariidae	1 spec.
Dialidae	4 spec.	Vermetidae	1 spec.	Ringiculidae	1 spec.
Hamineidae	3 spec.	Litiopidae	1 spec.	Bullidae	1 spec.
Muricidae	2 spec.	Strombidae	1 spec.	Retusidae	1 spec.
		Pyrenidae	1 spec.	Scaphandridae	1 spec.
		Buccinidae	1 spec.		2

Table 1. Family representation in the study material according to species diversity is as follows:

The presence of *Anadara trapezia*, frequently as articulated pairs, in the study material should not pass without comment. The species is characteristic of shallow-water, sea-grass communities in typically-hyposaline, estuarine environments from central Queensland to southern Victoria (e.g., Macpherson 1966; Poore and Rainer 1974; Smith *et al.* 1975) and in southern Western Australia (Kendrick and Wilson 1959). The fossil record of the species (G.W.K., unpublished data) indicates that its modern, disjunct distribution is but a remnant of a much more extensive, maximal range during the Late Pleistocene, clearly a time when environments favourable to the species existed through the entire subtropical and temperate coastline of Australia.

Anadara trapezia is a common fossil in presumed Late Pleistocene deposits located near the mouths of the Wooramel and Lyndon Rivers of the Shark Bay region (WAM registered fossils 66.375, 70.2645). These occurrences, apparently correlative with those of the Dampier Limestone of Broadhurst Bight, may indicate a phenomenon regional in scope and consistent with higher and more sustained levels of river discharge during substage 5e of the Late Pleistocene than now prevail.

The palaeoenvironmental significance of *A. trapezia*, a species with a strong environmental signature, in regions such as Shark Bay, where it is no longer extant, warrants further study.

The restricted character of the Dampier Limestone (in its type area) macrofossil assemblage is indicated by its apparent lack of normal, trophic diversity

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(Table 1). Filter-feeding bivalves comprise over half of all known species and the great majority of gastropods belong to recognized herbivorous groups.

Substantially under-represented in terms of both species and individuals present, are the carnivorous/scavanger Neogastropoda, with some six or seven species and few individual specimens.

Occasional pieces of coral in the shell bed do not appear to have been in positions of growth and may have been transported. No echinoderms or other invertebrate groups are represented in the material to hand. Further consideration of the reasons for this apparent imbalance is deferred in view of the need to assemble data from other, correlative sources representing the "Dampier marine phase" of Logan *et al* (1970) around Shark Bay.

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Dynamics of phosphate in Shark Bay, Western Australia

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Abstract

Mass balances of carbon (C), nitrogen (N) and phosphate (P) for Shark Bay are briefly reviewed. P becomes depleted in the bay and appears to limit biomass. The net rate of P uptake in the bay is determined by sedimentation. Some preliminary data on concentrations of P and iron (Fe) in sediments are presented to distinguish differing mechanisms of P sedimentation.

Concentrations of both P and Fe in sediment decrease into the bay (7.59-0.65 μ mol P g-1 and 11.41-4.71 μ mol Fe g-1, respectively). 83-88% of total P in the sediments is inorganic P, 10-15% is organic P and 2% is adsorbed P. 90% of the inorganic P in Hamelin Pool sediments is in large shells and shell fragments. It is reasoned that if most of the P in sediments of the outer bay is also in larger fragments of calcium carbonate (CaCO₃), then the net rate of P uptake is directly related to the rate of community calcification of the bay and not necessarily to the rate of net community production, as stated earlier. Shark Bay remains as an important and exciting ecosystem to study interactions and mass balances of biologically labile materials.

Résumé

Les équilibres de masse de carbone (C), d'azote (N) et de phosphate (P) pour la Baie des Chiens Marins sont brièvement revus. Le P diminue dans la Baie et semble limiter la biomasse. Le taux net de levée du P dans la Baie est déterminé par la sédimentation. Certaines données préliminaires sur les concentrations en P et en fer (Fe) dans les sédiments sont présentées pour distinguer les mécanismes différents de sédimentation de P.

Les concentrations à la fois en P et en Fe dans le sédiment diminuent dans la Baie (respectivement 7.59-0.65 μ mol P g-1 et 11.41-4.71 μ mol Fe g-1). 83-85% de la totalité de P dans les sédiments est du P inorganique. 10-15% est du P organique et 2% est du P absorbé. 90% du P inorganique dans les sédiments de Hamelin Pool se trouve dans les grands coquillages et les fragments de coquillages. Nous pensous que si la majeure partie du P dans les sédiments de la Baie extérieure se trouve également d'ans de plus grands fragments de carbonate de calcium (CaCO₃), le taux net de levée du P est directement lié au taux de calcification de la communauté de la Baie et pas nécessairement au taux de la production nette de la communauté, comme on l'a formulé antérieurement. La Baie des Chiens Marins demeure un important et passionnant ecosystème pour étudier les relations mutuelles et les équilibres de masse des matériaux biologiquement labiles.

Introduction

Nearshore ecosystems are increasingly important as sites for studying marine biogeochemical cycles. Recycling and deposition of materials in nearshore

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benthic systems vary depending on the biological communities and the physical features of those ecosystems. Some coastal ecosystems trap terrigenous materials and other nearshore ecosystems act as sources or sinks of materials which are exchangeable with the sea. Understanding the dynamics of materials in coastal ecosystems is essential to predict and solve problems of coastal pollution, determine rates of cycling of anthropogenic compounds and even to quantify global elemental cycles.

P is a key compound in understanding the biological and geochemical processes in the world's oceans. P binds with C to form organic and inorganic components of plants and animals. There is little information on the interaction of C and P cycles in coastal ecosystems, especially in shallow tropical and subtropical seas. A major goal of my research in Shark Bay has been to identify some of the dominate biogeochemical processes that involve the interaction of C and P. Here I summarize earlier work, and present preliminary data indicating that the incorporation of P into $CaCO_3$ is the major sink for P in Shark Bay; I suggest that the net rate of P uptake in Shark Bay is not necessarily related to organic C production but may be directly related to the rate of calcification by the C:P ratio in shells.

Background

Shark Bay is a very large shallow basin. There is virtually no input of material from land; consequently nearly all of the material forming the sediments in the bay is a direct result of biological, chemical and physical processes operating within the bay over geological time (Logan and Cebulski 1970; Logan 1974). The salinity gradient in Shark Bay can be used to determine whether certain dissolved compounds in the water are produced or consumed within the bay. Concentrations of the major ions in seawater are too high to be affected by the activity of organisms, consequently salinity can be used to quantify physical processes such as the rate of evaporation of water and horizontal mixing. Even though biologically active compounds are recycled within the bay, perhaps many times, some compounds accumulate and form sediments. Sediments of Shark Bay include biogenic forms of C and P.

Estimates of net rates of organic and inorganic C, N and P uptake were made by constructing a water budget and by measuring the concentrations of those elements in sediments (Table 1; Smith and Atkinson 1983, 1984). The deposition of inorganic C as CaCO₃ shifts the pH of water in the bay about 0.15 pH units, from 8.25 in the oceanic region of the bay to 8.10 in Hamelin Pool. The shift in pH creates higher partial pressures of carbon dioxide gas (CO₂) in water than in air; thus CO₂ gas is released to the atmosphere. Shark Bay releases about as much CO₂ to the atmosphere each year as does the burning of petrol in all automobiles within Western Australia. N, as inorganic N compounds, is taken up in organic material. There is not enough N advecting or mixing into Shark

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Process	Rate	
Org C Prod	1.2	
Inorg C Prod	3.2	
CO ₂ gas evasion	2.0	
net N uptake	0.030	
oceanic N input	0.002	
net N-fix	0.028	
max N-fix	0.16	
net P uptake	0.0037	

 Table 1: Rates of net uptake and net production of C, N and P by Shark Bay (mmol m⁻² d⁻¹).

 From Smith and Atkinson (1983).

Bay from the Indian Ocean to support the net sink of organic N in the sediments. The extra N in the sediments is assumed to be created by N-fixation. An estimate of N-fixation rate for the bay is about 0.028 mmol N m⁻² d⁻¹ and this rate represents a low value for benthic systems.

P, which is removed from the water by the growth of organisms, is buried in the sediments as organic P and inorganic P (Figure 1; Atkinson 1987). Other than the Indian Ocean there are no major external sources of P into Shark Bay.



Figure 1: Concentration of dissolved P decreases into Shark Bay. (.) Hopeless Reach and Hamelin Pool, (+) Freycinet, (o) Lharidon. Reprinted from Atkinson 1987.



Figure 2: Total P in surface sediments versus the salinity at the sampling location. Symbols as in Figure 1. "C" represents the mean values for the core samples. Reprinted from Atkinson 1987.

Approximately ¼ of the P input from the Indian Ocean is by a slow net advection of water into the bay; the slow advection of water replaces water that evaporates. The remaining ¾ of the oceanic input is sustained by horizontal mixing down the gradient of P in the bay (Figure 1; Smith and Atkinson 1983). Horizontal mixing is created by reversing tidal currents.

An interesting result of earlier work is that the concentration of inorganic P and total P in the sediments decreases as the residence time or salinity of the water increases (Figure 2; Atkinson 1987). Presumably the decrease in the concentration of P in the sediments is a result of a decreasing input of P into the bay and a depletion of P in organic and inorganic matter (Atkinson 1987). The change in the C:P molar ratio of organic matter in sediments and autotrophs ranges from 100:1 in the oceanic part of the bay to 10,000:1 in Hamelin Pool (Atkinson 1987). This dramatic decrease in the concentration of P in the water,

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sediments, and autotrophs is an indicator that P limits the development of biomass in the bay. Because P limits biomass, factors ultimately controlling biomass can be elucidated by determining dominate mechanisms of P sedimentation. The large changes in the concentration of P in the water column and sediments is unique and is useful to study mechanisms of P sedimentation in shallow subtropical ecosystems.

In coastal sediments with high content of organic matter (10-20%), such as upwelling areas, the concentrations of P in sediment pore water determine the relative concentrations of P in different sediment components. As organic matter remineralizes in the sediments, P is released into interstitial pore waters, creating high concentrations of P. The interstitial P reacts with inorganic constituents in the sediment including clays, Fe, aluminium (Al) and Ca to form P containing minerals. P can be adsorbed or desorbed rapidly from particle surfaces. P minerals are eventually formed by long-term solid-state diffusion of adsorbed P into lattice structures of particles (Froehlich 1988). Some P can be lost from the sediment by diffusion or bioturbation to the overlying water column (Figure 3A). The sediments of Shark Bay do not have high concentrations of organic matter (only 0.5-2.0% by weight) and sedimentation of organic material is relatively low (Atkinson 1987). The bay is also shallow with strong tidal currents, so sediments get reworked by physical and biological processes. Under these conditions in



Figure 3: Possible dynamics of P in Shark Bay sediments. **3A**: Organic P (P_o) controls the inorganic P (P_i) sink via concentrations of interstitial P (P_p). P_p efflux to water (P_w). **3B**: P_i sink buffers P_p and P_w by adsorption and desorption from mineral surfaces (the dots). **3C**: P_i desorbs to P_p and P_w as shell fragments breakdown. See text for explanation.

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Shark Bay, high interstitial concentrations of P are unlikely; instead, the concentration of P in the water column may be buffered by resuspended particles from sediments. Fast adsorptive-desorptive reactions in concert with long-term solid-state diffusion of P into the lattice of particles could "control" the concentration of inorganic P in the water (Figure 3b). This mechanism is common in many estuaries and represents an inorganic control of concentrations of P in the water column (Froehlich 1988); the buffering exchange rates often depend on the size and mineralogy of the sediment particles. Another likely possibility for Shark Bay sediments is that most P is coprecipitated with CaCO₃ or $CaPO_4$ of shells, tests, and bones. When the shells are broken down to fragments over millenia, P is released back to the water column or readsorbed onto the smallest particles in the sediment (Figure 3c). In this latter scheme, the deposition of P is biogenically controlled, not physically or chemically controlled. It is biogenically controlled because inorganic P, the dominant sink for P, is created by organisms, and the amount of P in the sediments depends on the nature of shells and bones, not on the concentration of P in interstitial water or the concentration of the overlying water.

The preliminary data presented here indicate that Fe, Al adsorption reactions are not buffering the concentration of P in the water column but the P deposition is directly linked to CaCO₃ production by the C:P ratio of inorganic biogenic material.

Methods

I used three approaches to obtain data on the dominate mechanism of P deposition in Shark Bay.

One approach was to measure Fe and P in three cores, one core from the oceanic region of the bay, one from the metahaline region and one from the hypersaline (see "C" in Figure 2). If Fe and P covary, both vertically within each core and horizontally between cores, then it would be good initial indication that P might be precipitated as Fe minerals. Cores were collected by pushing a 8 cm diameter, 50 cm long PVC tube into the sediment. The core was removed from the PVC tube and sliced into 2 cm sections. Each section was frozen immediately in a field freezer.

Sections were dried in a laboratory at 60° C, ground to a fine powder and then extracted in 1N HCl. The supernatant of the extraction was filtered through GF/C filters. Fe was measured using Atomic Absorption Spectrophotometry and P was measured colorimetrically using the molybdate sulphuric acid reaction (Strickland and Parsons 1968).

The second approach was a serial extraction of the core samples to determine which chemical fraction contained most of the P. The extraction distinguished several chemical forms of P: 1) adsorbed P; 2) Fe- and Al- P; 3) organic P; and 4) inorganic P in CaCO₃. The serial extraction was briefly as follows (Biggs and Strom 1983). A 0.5 g sample of powdered sediment from a core was placed

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in a flask. The sediment was extracted in 0.5 N NaOH for 1 hour; this fraction represents Fe- and Al- bound P. The sediment slurry was filtered through GF/C filters; then the filtrate was analyzed for P colorimetrically after adjustment of the pH to 4-7. The sediment sample was then washed with citrate-diothionite solution. Any P adsorbed back onto CaCO₃ during the first step is remobilized in this step. The filtrate was also analyzed for P. This fraction also included any free Fe(OH)₂. The next two steps were acid extractions, 0.5 N and 1.0 N HCl, liberating CaPO₄ and CaCO₃, respectively. The remaining sediment was redried, oxidized at 550°C and then extracted in 1 N HCl. This last fraction represents organic P.

The third approach was to determine if the amount of P per gram of sediment changes as a function of the size of the sediment particles. If adsorption of P from the water column or interstitial water is significant, then the fine fraction would be expected to have larger amounts of P. Likewise, if desorption of P dominates, then the fine fraction would have the least P, and the larger shells and shell fragments would contain most P. A 8 cm diameter core was collected from Hamelin Pool on 29 December 1987, 1 km offshore from Boolagorda Station in 3 m of water. The core was separated into a top section (1-10 cm) and a bottom section (12-30 cm); the sections were frozen. In the laboratory each section of core was dried at 60°C. The dried sediment was then shaken through Edecot sieves of the following sizes: $0.25 \ \mu m$, $1.0 \ \mu m$, $3.35 \ \mu m$, and greater than $3.35 \ \mu m$. Subsamples from each size class were ground to a fine powder (0.2 mm screen) in a Culatti grinder and then extracted in 1N HCl for inorganic P.

Results

Fe decreased from 11.41 μ mol Fe g-1 (\pm 1.62) in the oceanic core, to 8.50 μ mol Fe g-1 (\pm 2.35) in the metahaline core and 4.71 Fe (\pm 1.29) in the hypersaline core. There were also significant vertical changes in the concentration of Fe within each core, which created large ranges and standard deviations (Table 2; Figure 4).

P also decreased from 7.57 μ mol P g-1 (\pm 0.43) in the oceanic core to 2.41 μ mol P g-1 (\pm 0.27) in the metahaline core and 0.65 μ mol P g-1 (\pm 0.10) in the hypersaline core. Unlike Fe, there were no significant vertical changes of P within each core. Consequently the ranges and standard deviations were relatively small (Table 2; Figure 4). Fe changed horizontally throughout the bay by 2.4 fold while P changed 11.7 fold.

Results of the serial extraction for all three cores showed that less than 2% of P was adsorbed, 10-15% was organic P and the remaining 83-88% of P was included in the acid soluble fraction as $CaPO_4$ and $CaCO_3$. These results are consistent with earlier results (Atkinson 1987).

Parameters	38 %∞	Cores 55 %	65 %00
Fe:			
mcan	11.41	8.50	4.71
sdev	1.62	2.35	1.29
n	16	15	12
max	15.88	12.50	7.08
min	9.21	5.14	2.83
P:			
mean	7.59	2.41	0.65
sdev	0.43	0.27	0.10
n	16	15	12
max	8.39	2.84	0.79
min	6.77	1.96	0.53

Table 2:	Total inorgani	c Fe a	nd P in	three cores:	oceanic re	gion, metahaline	region and hypersaline
	region. Values	in µ	mol g ⁻¹ .	Data are	shown in	Figure 1.	



Figure 4: Concentration of Fe and P in the inorganic fraction of Shark Bay sediments. (The oceanic core is 38%, the metahaline core is 55% and the hypersaline core is 65%, see Table 2.) Lines represent standard deviations of the means: "+'s" represent values for maxima and minima.

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	Wt (g)	%
Core (1-18 cm)		
0.0-0.25	29	6.4
0.25-1.0	108	24.0
1.0-3.35	142	31.6
3.35+	171	38.0
total	450	100.0
Core (18-33 cm)		
0.0-0.25	51	10.8
0.25-1.0	105	22.1
1.0-3.35	102	21.6
3.35+	215	45.5
total	473	100.0
Intertidal Sand		
0.0-0.25	68	22.0
0.25-1.0	183	59.4
1.0-3.35	10	3.3
8.35+	47	15.3
total	308	100.0
Beach Sand		
0.0-0.25	33	10.9
0.25-1.0	148	48.3
1.0-3.35	45	14.6
3.35+	80	26.2
total	306	100.0

Table 3: Amounts and proportions of sediment in each size class for Hamelin Pool core (mm).

Table 4: Acid soluble (1N HCl) and organic fractions in the Hamelin Pool core. Weights in mg.

	Initial	Acid		Organic	
Sample	WL.	Soluble Wt.	%	WL.	%
(1-18 cm)					
0.0-0.25	595.9	489.0	82.1	8.2	1.38
0.25-1.0	476.4	473.0	99.3	2.7	0.57
1.0-3.35	607.5	603.5	99.3	2.7	0.44
3.35+	471.5	469.3	99.5	1.7	0.36
(18-23 cm)					
0.0-0.25	498.3	424.5	85.2	6.1	1.22
0.25-1.0	515.2	510.5	99.1	2.8	0.54
1.0-3.35	492.8	489.6	99.4	2.0	0.41
3.35+	678.2	674.7	99.5	2.0	0.29

The size fractions of the Boolagorda core revealed the most interesting results. 40% of the sediment weight was comprised of shells greater than 3.35 mm and

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about 68% of the sediment was shell fragments greater than 1.0 mm. Most of the intertidal and beach sand, having been sorted by wave energy, were comprised of smaller particles (Table 3). 99% of the three larger size fractions (>0.25) was inorganic whereas 85% of the smallest size fraction (0.0-0.25 mm) was inorganic (Table 4). The smallest size fraction had more organic material than the largest size (1.3% compared to less than 0.6% organic matter; Table 4).

The exciting result was that over 80% of the total inorganic P in the core was in the shell fragments greater than 3.35 mm and over 92% of the total inorganic P was in fragments greater than 1.0 mm. Only about 1% of the total P in the sediment was in the smallest size fraction, less than 0.25 mm (Table 5). Consequently, the largest size fraction had 20 fold more P with respect to Ca than the smallest size fraction (Table 6).

 Table 5: Amount of P in each size fraction for the Hamelin Pool core. The weighted average concentration of P in the sediment is shown on the last line. Note that this concentration is similar to concentrations shown in Figure 2 for high salinities.

			μ mol P in	
Sample	μ mol P g ⁻¹	g	fraction	%
(1-18 cm)				
0.0-0.25	0.0314	28.9	0.91	0.65
0.25-1.0	0.0914	108.3	9.90	7.1
1.0-3.35	0.0992	142.3	14.11	10.1
3.35+	0.6742	171.1	115.3	82.2
average	0.311			
18-33 cm)				
0.0-0.25	0.0336	50.9	1.71	1.2
).25-1.0	0.0687	104.5	7.2	5.0
1.0-3.35	0.1813	101.9	18.5	12.9
3.35+	0.5359	215.3	115.4	80.8
average	0.302			

Labic of the and I in Hammin Loop core, weights are in panors	Table 6	i: C	a	and	P	in	Hamelin	Pool	core.	Weights	are	in	µmol g	1
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Sample	Ca	Р	P/Ca (ppm)
(1-18 cm)			
0.0-0.25	7.041	0.0314	4.5
0.25-1.0	10.487	0.0914	8.7
1.0-3.35	6.335	0.0992	15.7
3.35+	7.661	0.6742	88.0
(18-23 cm)			
0.0-0.25	7.310	0.0336	4.6
0.25-1.0	8.641	0.0687	8.0
1.0-3.35	8.370	0.1813	21.7
3.35+	4.716	0.5359	113.6

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Discussion

The preliminary results presented in this paper indicate that free Fe-P compounds are probably not a major sink for P. Even though concentrations of both Fe and P in sediment decreased from oceanic sediment to hypersaline sediments, that decrease can be simply explained by distance of the sediment, or site of deposition, from the oceanic source of new Fe and new P. Vertical changes in concentrations of Fe were not related to changes in P; likewise, horizontal changes in Fe (between cores) were 2.4 fold compared to changes in P of 11.7 fold. Further, results from the serial extraction revealed that there was little P in the Fe fraction. Nearly all P was bound in the CaCO₃ fraction. It is entirely possible that P could be bound as Fe compounds within shells (Sherwood et al. 1987), but vertical changes of Fe in each core without the concomitant changes in P indicates otherwise. The relationship between Fe and P in shells is not well understood and Shark Bay would be an excellent site to conduct further research on this topic.

Nearly all of the P in Hamelin Pool sediment was contained in larger shells and fragments of shells; this clearly indicates that the major source of P into the sediment is via biogenic CaCO₃, not by organic P compounds. As these shells breakdown, P must be lost by desorption back to the water column. If the sediments of the oceanic part of the bay also have more P in the larger fragments, then the ratio of P to Ca in the shells and bones of live organisms must decrease toward the inner bay to explain the horizontal decrease in concentration of inorganic P in the sediments. It is likely that most P is in the larger fragments of CaCO₃ throughout the bay because the relative proportions of adsorbed P, organic P and inorganic P did not change between oceanic sediment and hypersaline sediment. Changes in concentration of P in shells may be purely chemical, in which case the P to Ca ratio of shells from living animals is proportional to concentrations of P in water; or, it might be related to major shifts in the mineralogy of the shells, bones, and tests forming the sediment. This later case is entirely possible because of the large changes in species composition within the bay.

On the other hand, if the outer bay sediments have most P in the smallest size fraction, then adsorption of P may be the major reaction controlling the concentration of P in Shark Bay. Adsorption of P could be directly from the water column or from interstitial P.

If the outer bay sediments have most P in shell fragments, then the net rate of P uptake in Shark Bay is NOT related to net organic C production by the C:P ratio of organic material, as stated by Smith and Atkinson (1984), but would be directly related to the calcification rate of the system by the Ca:P ratio in shells etc. If this idea is shown to be correct then it would help explain why a number of tropical and subtropical systems that produce biogenic CaCO₃ become depleted in P.

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Shark Bay remains as an important and exciting site to answer questions about the relationships between the deposition of P and the net production of biogenic material by communities of benthic organisms. The bay will continue to serve as a model ecosystem to study the interaction of biogeochemical cycles in coastal subtropical ecosystems.

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Vegetation and flora of Shark Bay, Western Australia

G.J. Keighery*

Abstract

Shark Bay, despite being the site of some of the earliest studies made of the Australian flora, is still relatively poorly known. The region, because of the activities of early French collectors, is a major concentration of type localities for Western Australian plants.

The flora is greatly influenced by adjacent regions, numerous taxa are at the limits of their geographical ranges (both northern, 145 taxa, and southern, 39 taxa) and some (28) have differentiated into separate taxa. The high concentration of species at the limits of their ranges makes the area of immense phytogeographical significance both in an Australian and world context.

Résumé

La Baie des Chiens Marins, malgre qu'elle fût le site de certaines études antérieures effectuées sur la flore australienne, reste relativement peu connue. La région, à cause des activités des collectionneurs français précédents, est une concentration majeure de localités types de plantes d'Australie-Occidentale.

La flore est grandement influencee par les régions adjacentes, de nombreux taxa se trouvent aux limites de leurs habitats géographiques (à la fois au nord, 145 taxa, et au sud, 39 taxa) et certains (28) se sont différenciés en taxa séparés. La concentration élevée d'espèces aux limites de leurs habitats rend la région d'une immense portée phytogéographique à la fois dans le contexte australien et mondial.

Introduction

The Shark Bay Region occurs towards the southern margin of the Carnarvon Basin as defined by Hocking *et al.* (1987) on the northern margin of temperate Western Australia which has a warm dry Mediterranean climate. This paper considers the botany of the Shark Bay Region in the context of the Carnarvon Basin and the Carnarvon Botanical Region defined by Beard (1980) - Figure 1.

Botanical studies - historical

Dampier made the first plant collections in the region in 1699 only two years after the earliest Australian collections made by Vlamingh at the Swan River. Many other early explorers landed in the region but the first extensive botanical collections were not made until Leschenault de La Tour collected with the Baudin Expedition (1803) and Quoy and Gaimard collected with the Freycinet Expedition (1818). These collections were studied by Decaisne and Gaudichaud (1824) making Sharks Bay the type locality of numerous Western Australian plants.

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Figure 1. Map showing Carnarvon Basin and Carnarvon Botanical District.

Later significant early collectors in the region were Cunningham (with King in 1827) and Denham and Milne in 1850. These collections were studied by Bentham in compiling The Flora Australiensis. Mueller (1883) made use of all these early studies in his account of the region, as well as collections made by A. Forrest and himself.

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Over the next 50-60 years little work was done on the area botanically. With improved access to the area in the 1950s the region was the subject of more botanical studies both of a general and specific nature. None of these have been detailed enough to generate a comprehensive floristic list of the region let alone a full flora of the Carnarvon District. However sufficient botanical studies have been carried out in the region to give some indication of the composition and distribution of plants in the region.

Botanical studies - current

(1) Phytogeography

Beard (1980) in his phytogeographical map of Western Australia places the Shark Bay region as the changeover zone between the temperate South West and desert Carnarvon Phytogeographical Region (Figure 2). This boundary is largely based on the dominant vegetation formations, especially the presence or absence of hummock grasses (*Triodia* sp.) as a dominant component of vegetation structure.

Beard (1976a) left most of Edel Land, Peron Peninsula and the islands to the north (Dirk Hartog, Bernier and Dorre) in the desert, while recognizing their intermediate character. However, a boundary based on floristics, not habit and physiognomy is not as discrete. The Edel Land peninsula and islands have enough winter rainfall and long enough growing season to support some South Western species. This is further reinforced by Burbidge and George (1978) for Dirk Hartog Island who noted that the majority of species listed for the island are south western or have strong southern affinities, and the vegetation formations themselves were mainly related to heath formations further south. Similarly Bernier and Dorre Islands (Royce 1962; Prince *et al.* unpub. data) which have more desert species are still somewhat intermediate in floristics and physiognomy.

Based on the floristic data the boundary between the South Western and desertic Carnarvon Region should be between the two peninsulas and include Dirk Hartog, Bernier and Dorre Islands (Figure 2) in the South Western Region.

(2) Vegetation Studies

The dominant vegetation of the entire Carnarvon district has been mapped by J. Beard at a scale of 1:250,000. These dyeline maps (held at the Geography Department, University of Western Australia) were compiled into single maps at scale of 1:1,000,000 and published in Beard (1976a).

The Shark Bay Region was mapped and documented separately at a scale of 1:250,000 by Beard (1976b).

Vegetation and flora

Subsequently the entire region was mapped at a scale of 1:250,000 on a land system basis (a combination of vegetation and geomorphology) for rangeland management by Payne *et al.* (1988). In this study 89 land systems were defined, 19 of which occurred in the Shark Bay Region, 7 of these being confined to this region (Birrida, Cullawarra, Edel, Inscription, Peron, Taillifer and Tamala). These endemic land systems require more detailed floristic study, to complement the vegetation data already obtained at their monitoring sites.



Figure 2. Boundary of south west botanical province.

(3) Floristics

As indicated previously little research has been carried out on the floristics of areas in the Carnarvon Basin.

Non vascular plants are perhaps the least documented. A list of Lichen species can be obtained from Sammy (1985), but no information is available on mosses or fungi.

Vascular plants present in the Carnarvon Botanical District are enumerated in the revision of the Descriptive Catalogue of Western Australian Plants (Keighery, in press - publishing date 1990). At a smaller scale many vascular plants have been mapped using a grid scale of 1:250,000. These include the Ferns, Gymnosperms and Monocotyledons (reference list and summary in Keighery 1984), *Acacia* (Maslin and Pedley 1981), *Eucalyptus* (Chippendale and Wolfe 1981), the families Goodeniaceae (Keighery 1983) and Asteraceae (Keighery 1988).

Species lists with vegetation data exist for North West Cape (Keighery 1987); Kennedy Ranges (Newby, unpub.); Bernier and Dorre Islands (Royce 1962) and Dirk Hartog Island (Burbidge and George 1978).

A few detailed site based floristic studies have been undertaken at Lake Macleod (north of Carnarvon) by Tyler (1988) and for three small islets in Shark Bay by Abbott (1981). Immediately south of the region studies have been undertaken in Coolomia Nature Reserve (Hopper, unpub.) and the Nerren Nerren region (Burbidge *et al.* 1980). Payne *et al.* (1988) have set up numerous monitoring quadrats for pastoral appraisal. These are based on perennial plants and form a positive basis for updating into complete floristic sites.

For this paper a search was undertaken at the Western Australian Herbarium for all known records of vascular plants recorded in the Shark Bay Region. This list was augmented by literature searches and field collecting during the Bicentennial Expedition, and is presented as Appendix I.

This list represents the known flora of the region to the end of 1988, when it comprised 673 taxa, 621 native and 52 naturalised. This is a diverse flora for a semi-arid region of low topographic relief. Major families represented are the Poaceae, Chenopodiaceae, Myrtaceae, Goodeniaceae and Asteraceae; reflecting the temperate and desert interface that Shark Bay is. Reasons for the composition and richness of the flora are expanded in the following section.

Analysis of current data

(1) Endemics of the Region

The Carnarvon Phytogeographical Region currently contains 40 known endemics and another 19 near endemics. This number is conservative as many


Figure 3. Nodes of endemism in the Carnarvon Basin.

groups require further study and revision, for example Table One lists the known endemics for North West Cape. Of the 11 endemics, four were named in the period 1963-7 after a collecting expedition, but six still have not been formally described.

The known endemics concentrate in 7 regions (Figure 3) which correspond with climatic and geographical zones. The richest of these areas are the ranges of the North West Cape with 11 endemics and the Tamala Sandplain with the same number. Other significant areas are the Nerren-Nerren Sandplain (5 endemics), the Carbla Plateau (2 endemics) and the coastal zone around Shark Bay. This last area is of interest as it contains 2 endemics (an unnamed subspecies of sandalwood, *Santalum spicatum*, and an unnamed *Plectrachne*) and possibly more (*?Trachymene elachocarpa*). Another 13 species are confined within the general boundary of the Carnarvon Basin. Considering



Figure 4. Diagrammatic representation of the sand dune systems of the Carnarvon Basin.

the large number of recently discovered and poorly known endemics in the region further study of the region could easily increase the level of endemism.

The near endemics are confined to the Sand Dune System (Figure 4) that extends from Kalbarri, south of the Region to the North West Cape within the Region. These Dunes are a unique feature of the Carnarvon Basin and are poorly known and largely outside the current reserve network.

(2) Composition of the Flora

The region contains a diverse range of species due to the variety of habitats within the region, the number of desert species that reach to the coast here and the large number of northern and southern species whose geographical ranges end in the region. Considering each of these factors:

(a) Habitats

The presence of large salt lakes, alluvial flats, birrida lakes, arid range systems and a rapidly changing climatic regime has led to a diverse annual flora. The families Poaceae (Keighery 1984), Amarantaceae (Keighery and Marchant 1982), Goodeniaceae (Keighery 1983), and Asteraceae (Keighery 1988) all containing numerous annual taxa are species diverse in the region, compared to other desert areas adding markedly to the diversity of the flora.

(b) Desert species

A large number of central desert taxa reach their western range limits in the Carnarvon Basin, and do not penetrate the temperate region further south. This desertic element is added to by numbers of semi-arid and arid taxa of southern affinities (i.e. those centred in the Austin, Ashburton and Coolgardie Phytogeographical Regions) which also occur in the Carnarvon Basin.

(c) Range ends

The number of taxa that reach the ends of their geographical range in the Shark Bay Region is a major feature of the region's flora. This can be easily seen in the maps of the Fabaceae presented in Keighery (1981, 1984) where the tropical genera *Crotalaria*, *Sesbania* and *Tephrosia* end in this area, as do the temperate genera *Bossiaea*, *Bugesia*, *Oxylobium* and *Pultenaea*.

Similar trends can be seen in *Acacia* (Maslin and Pedley, 1981) where 17 species reach their northern limits in the Region and 8 their southern limits. This also happens with species of *Ficus* (Keighery and Brighton 1982 - tropical genus). *Triodia* and *Plectrachne* (Poaceae, Keighery and Brighton 1983) and *Eucalyptus* (Chippendale and Wolfe 1979).

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These factors, the diverse climatic and habitats present in the Carnarvon Basin have led to an unusual and diverse flora that is unique for an arid region of Western Australia.

Future directions

A major biological survey of the Carnarvon Basin is planned by the CALM Biogeography Program during 1990-1995 (CALM 1988). This survey will study vertebrates and plants in major geological zones of the basin and recommend conservation priorities.

Detailed floristic studies should be undertaken on the flora of North West Cape, the Shark Bay Peninsulas (Edel and Peron), the Tamala Sandplain, the sand dune systems (including the Kalbarri outliers) to enable a clearer understanding of the composition, relationships and phytogeographical placement of these important regions.

These studies must be integrated with the land units defined by Payne et al. (1988) which provide a convenient framework in which to place floristic studies.

During, and after these surveys it is desirable to stimulate taxonomic studies on the many poorly known groups present in the region. A flora of the region should be the long term goal of such studies.

Table 1 North West Cape Endemics	
MONOCOTYLEDONS	Date named
Dasynogonaceae	
Acanthocarpus rupestris A.S. George	1985
DICOTYLEDON	
Proteaceae	
Grevillea calcicola A.S. George	1967
Grevillea stenobotrya ssp. nov.	
Grevillea variifolia C.A. Gardn. et A.S. George	1963
Mimosaceae	
Acacia sp.	
Fabaceae	
Dabiesia sp.	
Daviesia sp.	14 C
Stackhousiaceae	
Stackhousia umbellata C.A. et A.S. George	1963
Sterculiaceae	
Brachychiton sp.	-
Myrtaceae	
Pileanthus sp.	
Convolvulaceae	
Ipomaea yardiensis A.S. George	1967

Discussion

The flora of the Shark Bay region can only be understood in the context of the adjacent regions. To the south is temperate Western Australia, and on all other sides is the desertic Carnarvon region.

The Carnarvon region is unique for any desert region in Western Australia because of its diversity of annual taxa and range ends (both northern and southern central desert taxa and desert taxa of southern affinities) occurring in a general background of more widespread species.

Shark Bay is a subset of these influences, especially containing numerous temperate taxa at their northern limits and being the type locality of many Western Australian species. At least 28 taxa are endemic to the region, and these require further survey.

Appendix 1

Vascular plants recorded from the Shark Bay area.

* naturalized alien

Area recorded:

- 1: Bernier and Dorre Islands
- 2: Dirk Hartog Island
- 3: Edel Land
- 4: Peron Peninsula
- 5: Tamala-Hamelin Stations

Comments:

Northern limit: a south-western species at the northern limit of its range.

Southern limit: a northern or coastal desert species at the southern limit of its range.

Western or north-western limit: a widespread temperate desert species reaching the sea only in this area.

Statistics

Number of taxa recorded: 673 Monocotyledons: 115; 100 native, 15 naturalized Dicotyledons: 558; 521 native, 37 naturalized

Endemic taxa (Shark Bay Region): 28 Northern limit: 145 Southern limit: 39 Western limit: 31

TAXON	COMMENT	1	2	3	4	5
FERNS						
Ophioglossum lusitanicum						
ssp. coriaceum		x	x			x
Marsilea mutica						x
GYMNOSPERMS						
Callitris columellaris					х	х
MONOCOTYLEDONS						
TYPHACEAE						
Typha domingensis	Hamelin Pool					х
POTAMOGETONACEAE						
Potamogeton pectinatus	Hamelin Pool					х
Ruppia polycarpa			х	\mathbf{x}		
R. tuberosa				х		
ZANNICHELLIACEAE						
Lepilaena sp.		10			x	\mathbf{x}
POSIDONIACEAE						
Posidonia angustifolia			x	x		
P. australis			\mathbf{X}	x		
P. sinuosa		x	х	х		
P. coriacea			х	х		
CYMODACEAE						
Amphibolus antarctica		x	х	x	х	
A. griffithii		x	х	х	х	
Cymodocea angustata				x	х	
C. serrulata				x	х	
Halodule uninervis					х	
Syringodium isoelifolium					x	
NAJADACEAE						
Najas marina			х			
JUNCAGINACEAE						
Triglochin calcurapa		x	х			
1. centrocarpa						х
1. mucronala		10 100	x			x
1. tricnopnora		x	x			
HYDROCHARTAGEAE		100				
Halophila ovalis		x		12.57	221	
POACEAE			x	x	X	
Amphibogon caricinus						
A turbinatus	porthern limit					x
* Avena harbata	norment mint		v			x
Bothriochlog guartiana		8	х		×r ::	x
*Briza minor			v		х	
Bromus arenarius		×	л			
*B diandrus		N N		v		v
*Cenchrus ciliaris		`	v	~	v	A
*C. echinatus			x		^	
*C. setigera		x	x			
Chrysopogon fallax		x				х

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TAXON	COMMENT	1	2	3	4	5
Cymbypogon ambiguus		x				
C. obtectus					X	
*Cynodon dactylon			х			
*Bromus hordeaceus			x			
Danthonia caespitosa		1				x
D. racemosa		x				
Dicanthium affine						x
*Ehrharta breviflora		x	х			х
*E. calycina						x
Enneapogon caerulescens		x	х			
E. pallidus						x
Eragrostis dielsii			х			x
E. ? brownii			х			
E. falcata		x				
E. sp. (?setifolia)					x	
E. mucronata			X			
Eulalia fulva		x	x			
*Hordeum leporinum		1 1	x			x
*Lolium loliaceum			x			
*Lophochloa pumilla		x				
Monachather paradoxa						×
Paractaenum novae-hollandiae		x	N			×
Paspalidium clementii		×	N			
P. gracile			N			×
P tabulatum				x	x	
Plectrachne bromioides	northern limit			0		×
P danthonioides	northern limit			S.	×	x
P drummondii	northern limit	1	N	×	<i>,</i> ,	~
P so	Pendemic	1	×	~		~
*Polybogon monspeliensis	. cracenic		~	~		
*Poa appua			×		А	
Setaria dielsii		×	A	~		
S perticillata				A.		
S. 7 surgens		A	A			
Shiniley Impilalius		×	v	×.	A V	
Spinifex tongijonus Sporobolus zirginizus			X	x	х	
Stiba crimita			X			
Supa Crinia S alagantissima	northorn limit	x	x			12
5. elegantissima Thomada australia	погшеги шти		х			x
Tracine australianus						X
Tragus australianus *Tricatoria oristato			122		X	
Triselaria cristala Triselaria televisearenta	actual come Director		х			
CVDED ACE AE	southern limit	X	x	x		
Dello and dia handrata						
Carbarus bilas		x		247		
Cyperus oijax	and have the state		1990	x		
C. outoosus	southern limit	1	X	x		
C. Daginatus	and the second second	1			x	
Gannia lanigera	northern limit	1		х		X
Isolepis cernula	northern limit	1	x			

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TAXON	COMMENT	1	2	3	4
Mesomelaena pseudostygia	northern limit	1		x	
RESTIONACEAE					
Lepidobolus preissianus	northern limit	1	х		
Ecdeiocolea monostachya	northern limit				
Loxocarya flexuosa	northern limit	1	х		
CENTROLEPIDACEAE					
Centrolepis humillima	northern limit	1	х		
JUNCACEAE					
Juncus bufonius	?northern limit	x	x		
DASYPOGONACEAE					
Acanthocarpus preissii		x	х	х	x
A. robustus	southern limit		x		
A. verticillatus	southern limit	x	x	х	
PHORMIACEAE					
Dianella revoluta var. divaricata		1	х	х	
ANTHERICACEAE					
Corynotheca micrantha var. micrantha		1	х	х	
C. pungens					
Laxmannia sessiliflora ssp. sessiliflora	northern limit				
Dichopogon tyleri	southern limit		х		
Murchisonia volubilis	southern limit				
Thysanotus exiliflorus	western limit				
T. manglesianus					
T. patersonii		x	х		
T. speckii	northern limit	x	x		
Tricoryne sp.	?endemic		x		
ASPHODELUS		1			
*Asphodelus fistulosus		x		x	x
Bulbine semibarbata				х	
DIOSCOREACEAE					
Dioscorea hastifolia					
COLCHICACEAE					

5

x

х

x

х

х

x

x

x

х

х

х

х

х

x

х

x

х

х

x

х

х

х

x

х

х

х

x

х

	72				
A. helmsii	northern limit		х		
Allocasuarina acutivalvis	northern limit				
CASUARINACEAE					
DICOTYLEDONS					
Lyperanthus nigricans	northern limit				
Eriochilus dilatatus	northern limit		х		
ORCHIDACEAE		+			
Hypoxis sp. (?glabella)	northern limit				
HYPOXIDACEAE					
C. stylidioides	northern limit				
C. candicans ssp. flavifolia	northern limit				
Conostylis aculeata ssp. septentrionora	northern limit	1			
Anigozanthos manglesii ssp. quadrans	northern limit				
HAEMODORACEAE					
W. tenella	northern limit				
W. odorata	southern limit	x			
W. monantha	northern limit		x		
Wurmbea inframedia					x
COLCHICACEAE		1			
Dioscorea hastifolia					
DIOSCOREACEAE				275	
Bulbine semibarbata				x	
*Asphodelus fistulosus		x		x	x
ASPHODELUS	. cuccume	1	~		
Tricoryne sp	Pendemic	^	x		
T speckii	northern limit	x	x		

Vegetation and flora

TAXON	COMMENT	1	2	3	4	5
MORACEAE						
Ficus platypoda var. minor	southern limit	x				
URTICACEAE						
Parietaria debilis		x	х	X		х
PROTEACEAE						
Adenanthos acanthophyllus	endemic					x
Banksia ashbyi					x	x
B. prionotes	northern limit					x
B. sceptrum	northern limit					x
Conospermum stoechadis	northern limit					x
Grevillea candelabroides	northern limit					x
G eriostachya						×
G. roversoniana	endemic					×
G. stepothylla	Childrine		×			2
C. stenopnytu C. stenomera	northern limit		A.			×
C stenobotrya seb pop	southern limit					~
C. thelemoniana sch. hinaster	southern limit				A	N
G. inclemantana ssp. pinasier	andomic					X
Hakea ? sp.	rendemic		х			
P. stehophylia	in multiple line is				X	x
Petrophile semijurcala	northern limit					X
SANTALACEAE	1 12 2					
Anthobolus Joveolatus	northern limit					X
Exocarpus aphyttus		X	X	X	X.	N
E. sparteus						X
Leptomeria preissiana	northern limit					N
L. spinosa	northern limit		X			
Santalum acuminatum	north-western limit					N
S. spicatum						х
S. spicatum ssp. nov.	endemic	х	х		x	
OLACACEAE						
Olax aurantia						x
LORANTHACEAE						
Amevema benthamii	western limit				x	
A. linophylla	in concerne minine		x		<u>a</u>	
A. maidenii			^			×
A miraculosum	northern limit					~
A preissii	invitient initi		v			~
A miquelii			A			
Insiana murrani				-	X	х
POLYCONACEAE				х		
*Emay australia						
Maddan hadia alterna			x			
Muentenbeckia aapressa						X
w. cunningnamit					X	
"Rumex vesicarius					X	
CHENOPODIACEAE						
Atriplex bunburyana		х	х		x	
A. cinerea			X	X	X	
A. codonocarpa				х	X.	
A. isatidea				X	X	

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TAXON	COMMENT	1	2	3	4	5
A. paludosa ssp. baudinii					x	x
A. paludosa ssp. moquiniana	northern limit	x	x		х	х
A. semilunaris					x	x
A. vesicaria ssp. incompta					х	х
A. vesicaria ssp. variabilis		x	x			
Chenopodium gaudichaudianum			x			
C. melanocarpum		x	х			
*C. murale		x	х	х		
Dysphania plantaginella		x	х		х	
D. sphaerosperma			x			
Dissocarpus paradoxus					x	x
Enchylaena tomentosa		x	x			
Didymanthus roei					x	x
Eriochiton sclerolaenoides					x	
Halosarcia doleiiformis						x
H. halocnemoides ssp. halocnemoides		x	х			x
H. halocnemoides ssp. tenuis			100			x
H. indica ssp. bidens			x			
H. indica ssp. leiostachva					x	x
H. peltata			x		15	
H. pergranulata			x			
H pruinosa			<u> </u>			×
H blervgosberma ssb blervgosberma						Ŷ
Maireana abbressa					x	x
M. atkinsiana					A	v
M carnosa					v	×
M. georgei					~	~
M. Janosa					A V	
M, attosa M, oppositifolia		8			÷	^
M. blanifolia				v	л У	
M. platycarda				А	X	v
M. polyblervaia					х 	X
M. stipitata		2			x	х
M. tomentosa					x	
M. tomentosa Nechassia astrocarba					x	
Ostacentum eccolterum var eccolterum	Dungtown limit			162	x	
Salsola kali	western minit			х	х	
Sarcocornia blackiana			\mathbf{x}			
S. quinqueflora ssp. quinqueflora						х
Rhagodia latifolia ssp. latifolia	northern limit	x	х			
R. preissii ssp. obovata	northern limit	x	х			
Sclerolaena diacantha		1 1 1 2 2 2			х	x
S. eurotioides						x
S. recurvicuspis						x
S. tridens						x
S. uniflora			x			
Threkeldia diffusa			x			x
AMARANTHACEAE Amaranthus ballidiflorus					224	
ananantinas particujionas		X			X	

TAXON	COMMENT	1	2	3	4	5
Hemichroa diandra					x	
Ptilotus aervoides						X
P. alexandri	endemic		х	х		
P. chamaecladus						
P. divaricatus var. divaricatus		x	x	x	x	
P. divaricatus var. rubrescens	endemic					х
P. drummondii						x
P. exaltatus			х			
P. gaudichaudii var. gaudichaudii		x	х		х	х
P. gaudichaudii var. parviflorus	northern limit		x			x
P. grandiflorus var. grandiflorus						х
P. helichrysoides		x				
P. obovatus var. obovatus		x	х	х	х	x
P. obovatus var. laurifolius	endemic					х
P. stirlingii var. pumilus	endemic					x
P. villosiflorus		x	х	х	х	х
NYCTAGINACEAE						
Boerhavia burbidgeana	southern limit	x				
B. coccinea			x			
Commicarpus australis	southern limit				x	X
GYROSTEMONACEAE						
Codonocarpus cotonifolius					x	X
Gyrostemon ramidosus		x	х			x
AIZÓACEAE		1.000				
Carbobrotus aff, rossii		x	X	X	x	
C. virescens				x		X
Gunniobsis rubra	northern limit					x
G. septifraga					X	
Glinus lotoides				x		
Macarthuria intricata	endemic					X
*Mesembryanthemum crystallinum		x	x	x		
Sesuvium portulaccastrum		x			x	
Tetragonia diptera	?endemic	x	x	X	X	
T implexicoma		x		x		
T tetragonioides				x		
Trianthema turdivitolia				07	x	
PORTULACACEAE						
Calandrinia corrigioiloides	northern limit					x
C papillata			x			
C. populata			x			
CARVOPHYLLACEAE						
*Cerastium alomeratum			x			
*Silene gallica pay anglica			x		N	
*Polycarbon tetrabhyllium			x			
*Spergularia diandra						x
*S ruhra			x			4
RANUNCULACEAE			A			
Clematic microphylla		N	x			v
caemano maroprojua		1	~			A.

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TAXON	COMMENT	1	2	3	4	5
LAURACEAE				10 11		
Cassytha aurea			х			х
C. filiformis		x			х	x
C. nodiflora					х	х
C. pomiformis	northern limit					х
C. racemosa forma racemosa	northern limit					х
C. racemosa forma pilosa						x
PAPAVACEAE						
*Argenome ochroleuca			х			
CAPPARACEAE						
Capparis spinosa var. nummularia		x	х			х
EMBLINGIACEAE						
Emblingia calceoliflora						х
BRASSICACEAE						
*Brassica juncea						х
*B. tournefortii			х		х	х
Cakile maritima			x			
*Hymenobolus procumbens			х			
*Diplotaxis muralis			x			
Lepidium foliosum					х	
L. biplicatum			х	х		
L. linifolium			x			
L. lyratogynum				x		
L. phlebopetalum						x
L. platypetalum	western limit					x
L. rotundum	northern limit		x			x
Menkea ? australis						x
*Rhaphanus raphanistrum						х
*Sisymbrium erysimoides			x			x
*S. irio		x			х	
*S. orientale			x			x
Stenopetalum ? pedicellare						х
S. robustum	northern limit					x
S. sphaerocarpum			х			
DROSERACEAE						
Drosera stolonifera ssp. humilis	northern limit					x
CRASSULACEAE		1				
Crassula colorata var. colorata		x	x			x
C. colorata var. tuberculata						x
PITTOSPORACEAE						
Billardiera bicolor var. lineata						х
Bursaria occidentalis					x	х
Cheiranthera preissiana var. preissiana	northern limit					x
Pittosporum phylliraeoides						
var. phylliraeoides		x	x	x	x	
CUNONIACEAE						
Aphanopetalum clematideum	northern limit		x			x
STYLOBASIACEAE		5				
Stylobasium spathulatum		x			\mathbf{x}	
S. australe		1				х

Vegetation	and	flora
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TAXON	COMMENT	I	2	3	4	5
MIMOSACAEAE						
Acacia ambyllophylla	northern limit				х	
A. bivenosa	southern limit	х	x			
A. brachystachya	north western limit				X	х
A. coriacea	southern limit	X	x			x
A. farnesiana	southern limit				х	х
A. grasbyi	western limit					х
A. idiomorpha	northern limit		х			
A. latipes	northern limit					х
A. leptospermoides	northern limit		X			
A. ligulata	western limit		х	х		
A. longispinea	northern limit					х
A. microcalyx	western limit					x
A. ramulosa				х	X	
A. roycei	endemic					x
A. sclerosperma		N				
A. spathulifolia						X
A. tetragonophylla			X			x
A. victoriae						х
A. xanthina	northern limit					x
A. xiphorphylla	southern limit					х
A. sp.	?endemic		X			
A. rostellifera	northern limit	X				
A. congesta	northern limit					X
CAESALPINACEAE						
Cassia chatelainiana			X			X
C. nemophila var. nemophila					X	x
C. nemophila var. platypoda						X
C. phyllodinea						x
C. sturtii						X
Labichea cassioides					x	x
Petalostylis labicheoides						x
FABACEAE	1					
Aotus ? phylicoides	northern limit					x
Bossiaea walkeri	northern limit				X	
B. spinosa	northern limit		x			
Brachysema aphylla	northern limit					X
B. daviesioides	northern limit					х
B. macrocarpum	southern limit	x	х			
Chorizema ericifolium	northern limit		х			X
Daviesia sp.	?endemic		x			x
Glycine tabacina			x		X	
Indigofera ? australis						X
I. boviperda			х		X	
I. georgei		x			X	
I. monophylla		925 9			x	
Lotus australis		X				
L. cruentus						
*Meliolotus indica			х			

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TAXON	COMMENT	1	2	3	4	5
*Medicago polymorpha		1	x			
Mirbelia ramulosa		x	x			x
Psoralea cinerea						х
Swainsona beasleyana ssp. elegantoides			х			
S. canescens var. canescens						
S. elegans						
S. kingii ssp. kingii						
S. phacoides						
S. pterostylis						
GERANACEAE						
Erodium angustilobum		х	х			х
*Erodium aureum			x			
*Erodium cicutarium		S	х		х	х
Erodium cygnorum		x	x			x
OXALIDACEAE						
Oxalis perennenans		x	x			x
ZYGOPHYLLACEAE						
Nitraria billardierei		x	x		x	
Tribulus platyptera	?southern limit	100			x	
T. occidentalis			x			
T. forrestii			280	x		
T. terrestis					x	x
Zygophyllum ammophilum			х			
Z. aurantiacum			x			
Z. apiculatum		x				
Z. fruticulosum		x	x		x	v
Z. eremaeum	western limit	x				100
Z. tesquorum					x	
RUTACEAE					~	
Boronia crenulata var. gracilis	northern limit					v
B. purdieana	northern limit					x
Diplolaena grandiflora		x	x			x
D. microcephala	northern limit		x			x
Geleznowia verrucosa	northern limit		x			x
POLYGALACEAE	northern mint		~			~
Comesperma integerrima	northern limit					x
C. scoparia	northern limit				x	
EUPHORBIACEAE						
Adriana tomentosa	southern limit				x	x
Beyeria cinerea			x		x	x
B. cyanescens	?endemic	x	x			~
Euphorbia alsiniflora	western, southern					
	limit	x				
E. atoto					x	
E. australis	western limit	x				x
E. boopthona	western limit	x				
E. drummondii	western limit	x			x	
E. myrtoides	western limit	x	х		**	
E. sharkoensis	southern limit		x			

TAXON	COMMENT	1	2	3	4	5
E. tannensis ssp. eremophila	western limit	x		-		x
Monotaxis lurida	northern limit	11.1				x
Poranthera microphylla			X			
Phyllanthus calycinus	northern limit	x				
P. fuernrohrii	southern limit	x				
*Riccinus communis		1.000	х			X
Sauropus crassifolius			x			
STACKHOUSIACEAE						
Stackhousia muricata						X
S. pubescens						x
S. viminea		x	x			
SAPINDACEAE						
Diplopeltis huegelii var. subintegra	northern limit					х
D. intermedia var. intermedia						x
D. petiolaris	northern limit					x
Dodonaea aptera	northern limit		X			
D. inaequifolia	northern limit	x	x		x	x
D. viscoca ssp. angustissima	northern limit	100	59		1.17	x
Heterodendron oleifolium var.						
oleifolium	western limit	x	x		X	
RHAMNACEAE		100	12			
Cryptandya lencophyacta						x
C. mutila	northern limit	×				
C. nudiflora	endemic	x				
Spyridium divaricatium	endemic		x			
STERCULIACEAE						
Commerconia agudichaudii	northern limit					
Brachychiton aragorii	Augstern fimit		2			
Chichanotia laditolia	northern limit				Y	
Hamafordia anadrinabiis	northern mint		X			X.
Keraukania bermanniifolia			A.			X
K interritolia			X			x
Lasiobatalum obbositifolium	northorn limit	1				x
Rulingia conversos par borgalis	northern limit	A	X			
R Inteiflore	norment min		A			
R. dansiflora	northern limit		X			x
R. walsitolia yay howalis	northern limit					x
THIACEAE	normeni unin			х		
Triumfette abbendiculate		1				
		x				
Clamaticismic angustissima	northern limit					2.0
MALVACEAE	northern mint	1				х
MALVAGEAE Huddhu mutaatalahuu	1200.04	1 122				
	western minit	X				
A. exonemum	southern limit	X	22			
A. geranioiaes	southern limit	X	x			X
A. oxycarpum	southern timit	1	x			X
A timeniana		X	x			2.527
A. prinoniana		X	x			X
"Lavalera cretica		1	X			

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TAXON	COMMENT	1	2	3	4	5
Hibiscus aff. coatesii						x
Hibiscus sturtii var. truricatus	western limit	x				
Lavatera plebeia						
Lawrencia densiflora				х	х	
L. viridigrisea			х	x		
*Malva parviflora						х
Sida calyxhymenia			x			
S. corrugata			x			
S. kingii					x	
S. fibulifera	?southern limit	x				
DILLENIACEAE						
Hibbertia acerosa	northern limit					x
FRANKFNIACFAF	northern mint					A
Frankenja cinerea	western limit	1	v			
F confuse	western limit		A			
E bauciflora	western mint				x	
F. seloca	mostore limit	x	X	x	x	627
THVMELAEACEAE	western mint					X
Dimelas allainna	12		0.8	RG1		
Pimelea giigiana Di laborarritarra esta laborarritarri	northern limit	1	x	x		
P. lenmanniana ssp. lenmanniana	northern limit	9.83				x
P. microcephala var. microcephala		x	x		X	
MYRIACEAE						
Baeckea pentagonantha			х			х
Beaufortia dampieri	northern limit	x	х			х
Calothamnus formosus ssp. formosus	endemic					х
C. quadrifidus	northern limit				х	х
C. kalbarriensis	northern limit					х
Calytrix brevifolia	northern limit		x		х	x
C. strigosa	northern limit	x			х	
Eucalyptus decipiens						x
E. beardiana	northern limit					х
E. dongarraensis		x	х			
E. eudesmoides						x
E. fruticosa	southern limit	x	x			
E. mannensis		1				x
E. gittinsii						x
E. jucunda					x	
E. oraria		x	x			
E. redunca					v	
E rovcei	endemic				•	v
E oldfieldii	northern limit					A
Lamarchea hakeitolia wax hakeitolia	endemic					x
Malleostemon bedynculatus	northern limit				X	x
Malalayca cardiophylla	normern mint	1				x
Metaleucu cululophytta M_aleutherostachua			x			x
M. holosariosa	manufactor 12 miles					x
M. humali	northern limit		x			
M. huegeln	northern limit	x		x	x	
M. lanceolata	northern limit		х			
M. leiopyxis	northern limit					х

Vegetation and	d flora
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TAXON	COMMENT	1	2	3	4	5
M. ? leptospermoides	northern limit					
	or endemic		x			
M. aff. nesophila	northern limit					
A	or endemic			x	x	
M. ? oldjieldii	northern limit					
M	or endemic					х
M. scabra	and have the set				082	x
M. uncinala M. 2 superalaria	northern limit				x	
M. E urceoutris	normern mint or					
Micromatic halfigary	endenne					x
Micromyrius peuigera M. raamposa						
M. tacemosa Dilamthus limasis	anothers limit					
P sh	southern mint	x	X			
r. sp. Scholtzia lablantha				x	122	x
Schouzia tepianina Scoligandza					x	х
S. onganara S. amballilara					x	
S. unbeuijeia	Jandomia		20		x	
5. sp. Thrablomana haachaacaa	rendenne		x			
Thryptomene baeckeacea					923	x
LIALOPACACEAE					X	X
Clichrogram any any any	northorn limit					
Consentional you attretum out, attretum	northern limit					x
G. Judoscens Haloragis gossai	northern mint					x
H (vigonocarba			X			
APIACEAE		А	х			
Dawaw alochidiatus						
Neosciodium glochidiatum	northern limit		X			X
Trachomana alachocarba	endemic	×	×.			x
T ornata	cindenne	л	~			A N
T. bilosa		v	×			X
Illdinia ceratocarba		~	^		~	
PRIMULACEAE					A	
*Anagallis argensis par argensis					×	
*A arvensis var caerulea			x		A	×
Samolus junceus			•		N	x
S repens vor repens			×		A	~
S. repens var floribundus			~		v	
PLUMBAGINACEAE					~	
Muellerolimon salicorniaceum				v		
OLFACEAE				~		
lasminum calcareum	?southern limit	x	x			
LOGANIACEAE		100	A			
Logania aff. vaginalis	southern limit		x			x
GENTIANACEAE			a			A
*Centaurium erythraea						v
ADOCVNACEAE						~
Alwia huvitolia				v	×	
myata ottatjona				А	~	

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TAXON	COMMENT	1	2	3	4	5
ASCELEPIDACEAE		1				
Cynanchum floribundum		E.	х			
Gymnanthera nitida						
Leichardtia australis					x	
Rhyncharrhena linearis				х	х	x
Sarcostemma australe		x	x			
CONVOLVULACEAE						
Bonamia rosea						x
Convolvulus erubescens		x			x	x
Porana sericea		x	х		х	x
Wilsonia humilis				х		
CUSCUTACEAE						
Cuscuta australis						x
BORAGINACEAE						
Halgania littoralis	northern limit	x	х	х		
H. viscosa			x		х	
Heliotropum curassavicum						x
H. undulatum		x				
Trichodesma zeylanicum var.						
zeylanicum		x	х			
CHLOANTHACEAE						
Cyanostegia lanceolata	northern limit					x
Dicrastylis cordifolia	western limit		х			
D. fulva	northern limit	8	х			x
D. linearifolia	northern limit	1				x
D. micrantha	northern limit	1				x
Lachostachys eriobotrya	northern limit					x
Newcastelia chrysophylla	northern limit					x
Pityrodia atriplicina	northern limit		х			x
P. cuneata	northern limit	x		x	х	
P. glabra	endemic	}				x
P. hemigenioides	northern limit		х			
P. loxocarpa				х		
P. oldfieldii	northern limit					x
P. panniculata	southern limit				x	x
AVICENNIACEAE						
Avicennia marina		1			x	
LAMIACEAE	N 1	8				
Hemiandra sp. (JSB 7059)	rendemic					x
H. macrantha	northern limit					x
H. sp.	northern limit	1				x
"Salvia veroenacea Westningia daughiani						x
Westringia aampieri		x	x	x	x	122
Esemophia pantonii	western limit	1				x
E. platycatyx						x
E. prerocarpa E. 2 complete	worten limit					x
E. : serruana E. subfloccosa	western filmit					2
L. subjuccosa	x					
myoporum auscentens			x			

TAXON	COMMENT	1	2	3	4	5
M. insulare		x	x	x	x	
M. deserti		x	х		х	
M. tetrandrum		x				
SOLANACEAE						
Anthocercis littorea	northern limit		x		х	x
A. intricata	northern limit					х
Dubosia hopwoodii					х	
Anthotroche walcottii	northern limit		х			
Lycium australe					x	
*L. ferocissimum						x
Datura leichhardtii					x	
*Solanum americanum			х			
S. hesperium	northern limit		x		х	
S. lasiophyllum		x	x	x	x	X
*S. nigrum						х
S. oldfieldii	northern limit					x
S. orbiculatum ssp. orbiculatum		x	x			
*Nicotiana glauca			x		x	
N. occidentalis ssp. obliqua	western limit				x	x
N. occidentalis ssp. hesperis	NUMBER OF STREET, STRE	x	х		x	
SCROPHULARIACEAE						
Morgania floribunda						x
Stemodia viscosa						x
MYOPORACEAE						
Eremophila clarkei	imprecise locality		х			?
E. decipiens						
E. glabra			x			
E. leucophylla	western limit					x
E. macklinyai	western limit				х	
E. maculata var. brevifolia				x		
E. maitlandii	southern limit			x	х	
E. oldfieldii	northern limit		х		х	x
PLANTAGINACEAE						
Plantago drummondii	northern limit	х				
P. sp. (Cranfield 2583)	1 other collection					
	Yaringa Stn.				х	
RUBIACEAE						
Opercularia spermacocea	northern limit		х			
O. vaginala	northern limit	x				
CUCURBITACEAE						
Mukia maderaspatana	southern limit				х	
CAMPANULACEAE						
Wahlenbergia gracilenta			х			
LOBELIACEAE						
Lobelia heterophylla				х	х	х
GOODENIACEAE						
Dampiera altissima						x
D. incana var. incana		x	х	х		
D. incana var. fuscescens	northern limit					x

TAXON	COMMENT	1	2	3	4	5
D. lindlevi	northern limit				x	
D. spicigera	northern limit				10.00	x
Goodenia berardiana		x	x			120
G. cornnocarba	southern limit	x				X
G. mimuloides	northern limit	x				122
G. ochracea	endemic	x				
G. pinnatifida	north-western limit	220				X
G xanthosperma	north-western limit			x		
Lechenaultia linearoides	endemic subspecies		x			X
L. subcymosa	southern limit		x			
Scaevola anchusifolia				X		x
S. crassifolia	northern limit	x	x	x		x
S. depauperata	western limit			~		x
S. dielsii			X			
S. elobulitera						x
S. holosericea		X	x			
S. paludosa		225	x			
S. parviflora				x		
S. porocarva				x		
S. spinescens		X	х	x	x	x
S. tomentosa		x	x	x	x	x
Velleia cycnobotamica	northern limit	550		221		x
ASTERACEAE						
Actinobole condensatum	northern limit	x	x		x	x
A. drummondiana	southern limit				x	x
A. oldfieldiana						x
Angianthus acrohyalinus	southern limit	x	х	x		x
A. cunninghamii	To a strate a construction of the strategy of	x	x	x	х	x
A. microcephalus	western limit		x		x	x
A. milnei			x			x
A. tomentosus	northern limit		x			x
*Arctotheca calendula			х			
*Bidens bipinnata		x	x			
Brachycome cheilocarpa					х	
B. ciliaris		x	х	X	x	x
B. ciliocarpa	5					x
B. iberidifolia		X	х			x
B. latisquamea	southern limit		x		x	
Calocephalus brownii				X	х	
C. multiceps				x		
C. francisii			x			x
Calotis multicaulis			x			x
Centipedia cunninghamii					x	
C. minima					x	
Cephalipterum drummondii			х			
*Centaurium melitensis			x			
Chrysocoryne pusilla	northern limit	x				
Chthonocephalus pseudevax						x
C. tomentellus	endemic				x	x

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TAXON	COMMENT	1	2	3	4	5
Cotula cotuloides			x			
Calocephalus multiceps					х	
Gilruthia osbornei						х
Gnaphalum ? indutum/	northern or					
polycaulon (ASW 10549)	southern limit	x				
Gnephosis macrocephala			x			
G. gynotricha						х
G. pusilla		x	х			
G. skirrophora		100	x			
G. ? tenuissima			x			
Helichrysum aversii	western limit					X
H. condensatum	northern limit	×	x			×
H. craspedioides		-				Ŷ
H humboltiunum	western limit					~
H hydrospermum	porthern lippit		~		A	
H splendidum	norment min				х	x
H tenellum					2:37	x
Hybochaeric alabra					х	
Milletin mugatiditelin		.126	x			X
Miniona myösönäijönä		x	x		X	
Myriocephatus guerinae		1.1.1.4				x
Oteria axillaris		x	x			
O. pimelioides			x			
O. revoluta	127 127 12	X				
O. sp. (ASG 11568)	?endemic		x	x		
Pluchea rubelliflora	southern limit	X	х			
Podolepis canescens	northern limit		x	x	x	x
P. gardneri		X				
*Pseudognaphalium luteoalbum		x		x		
Pogonolepis stricta			X			х
Podotheca angustifolia			x		x	x
P. gnaphalioides	northern limit		х		x	
Schoenia cassiniana		0				х
Senecio glossanthus		x	x			x
S. gregorii					х	
S. lautus ssp. lautus		x	x	x	x	
S. lautus ssp. maritimus				x		
S. lautus ssp. dissectifolius		x		x		
*Sonchus oleraceus		x	x	x	x	x
Streptoglossa liatroides						Ŷ
*Urospermum picroides						v
Vittadinia cervicularis var cervicularis	northern limit		*			~
V cervicularis var oldfieldii	northern limit		л			
Waitzia citrina	norment mint		32			X
W commbosa			x			
W. podolonis			X	-		122
w. podotepis				X		x

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The marine algae of Shark Bay, Western Australia

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Abstract

One hundred and fifty-three species of marine algae are reported from Shark Bay, Western Australia, comprising 102 species of Rhodophyta, 27 species of Chlorophyta and 24 species of Phaeophyta.

Résumé

Cent cinquante-trois espèces d'algues marines vivant dans ea Baie des Chiens Marins, Australie-Occidentale sont répertoriées, comprenant 102 espèces de Rhodophycées, 27 espèces de Chlorophycées et 24 espèces de Phéophycees.

Introduction

The early French exploration of Shark Bay saw a number of algae collected, many of which were new species and were subsequently described in various publications (e.g. *Acetabularia calyculus* Lamouroux in Quoy & Gaimard, 1824). Unfortunately a complete flora of the area was never published, and it is only recently that there has been an upsurge of interest in the marine plants of the area. Recent publications have been concerned with the seagrasses (Walker 1985; Walker *et al.* 1988; Walker & McComb 1985, 1988), the seagrass epiphytes (Harlin *et al.* 1985; Kendrick *et al.* 1988; Walker & Woelkerling 1988) and the benthic algae (Kendrick *et al.* 1990). This paper collates all of the species recorded in those works and gives a reference to a recent description and illustration to aid in identification.

Materials and methods

Surveys of Shark Bay were made using SCUBA and snorkel during March, June, August, October and December 1982, September 1984, August 1985, July 1986, July and August 1988. All samples of algae were preserved in 6% formalin in seawater. Voucher specimens of all species collected were deposited in the herbaria at Murdoch University and The University of Western Australia.

Results and discussion

Although seagrasses dominate the sedimentary environments of Shark Bay, macroalgae are found on the rare subtidal rock platforms, on extensive sandflats

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that dominate the shallows of the bay, or as epiphytes on seagrasses, other algae and mangroves. In addition many species survive as drift algae amongst the seagrass beds. Tropical species predominate. The Rhodophyta are represented by the greatest number of species, but these tend to be largely inconspicuous epiphytes. Members of the Chlorophyta are most abundant with *Penicillus nodulosus* (Lamouroux) Blainville and *Polyphysa peniculus* (R. Brown *ex* Turner) C. Agardh the most common species. *Polyphysa peniculus* dominates the high salinity area south of the Faure Sill. The brown algae *Hormophysa cuneiformis* (Gmelin) Silva and *Dictyota furcellata* (C. Agardh) J. Agardh were also common in high salinity areas (Allender and Smith 1978). Species richness was lower in high salinity regions for both benthic (Kendrick *et al.* 1990) and epiphytic algae (Kendrick *et al.* 1988).

Species list of algae found in Shark Bay, W.A.

(E epiphytic; B benthic)

CHLOROPHYTA

CAULERPALES

Caulerpaceac

- B Caulerpa cupressoides (Vahl) C. Agardh. Taylor 1960: 147, pl. 14, figures 3, 4, 6, pl. 15, figures 1-4, pl. 18, figures 11-13.
- B C. lentillifera J.Agardh. Cribb 1958: 213, pl. 4, figures 1-4, pl.3, figures 1-17.
- B C. papillosa J. Agardh. Womersley 1984: 270, figures 91C, 92E.
- B *C. racemosa* var. *clavifera* (Turner) Weber-van Bosse. Taylor 1960: 151, pl. 18, figure 3.
- B C. racemosa var. uvifera (Turner) Weber-van Bosse. Taylor 1960: 151, pl. 18, figure 4.
- B C. sertularioides (Gmelin) Howe. Taylor 1960: 144, pl. 13, figures 1-7.

Udoteaceae

- B Halimeda incrassata (Ellis) Lamouroux. Hillis-Colinvaux 1980: 93, figure 22.
- B H. simulans Howe. Hillis-Colinvaux 1980: 103, figure 26.
- B H. tuna (Ellis & Solander) Lamouroux. Hillis-Colinvaux 1980: 122, figure 35.
- B Pencillus nodulosus (Lamouroux) Blainville. Gepp & Gepp 1911: 86, pl. XX, figures 172-175.
- B Udotea argentea Zanardini. Gepp & Gepp 1911: 125, figures 21, 22C, 22D, 57-60.

DERBESIALES Bryopsidaceae

B Bryopsis plumosa (Hudson) C. Agardh. Womersley 1984: 282, figures 96C, 97A.

CODIALES

Codiaceae

- E B Codium spongiosum Harvey. Womersley 1984: 228, figures 75E, 76F.
 B C. duthieae Silva in Silva & Womersley. Womersley 1984: 235, figures 77F, 78G.
 - B C. harveyi Silva in Silva & Womersley. Womersley 1984: 236, figures 79A, 80A.

DASYCLADALES

Polyphysaceae

- B Acetabularia calyculus Lamouroux in Quoy & Gaimard, Womersley 1984: 295, figures 101B, 102B-D.
- B Polyphysa peniculus (R. Brown ex Turner) C. Agardh. Womersley 1984: 296, figures 101C-E, 102E-G.

CLADOPHORALES

Cladophoraceae

- E B Chaetomorpha valida (Hooker & Harvey) Kuetzing. Womersley 1984: 178, figures 56B, 57D.
 - B Cladophora feredayi Harvey. Van den Hoek & Womersley 1984: 196, figures 62C, D, 63D, E.
- E *C. valonioides* Sonder. Van den Hoek & Womersley 1984: 196, figures 64A, 65A, B.
 - B Cladophora sp.
 - B *C. vagabunda* (Linnaeus) van den Hoek. Van den Hoek & Womersley 1984: 202, figures 64E, 65G.
 - B Rhizoclonium sp.

Anadyomenaceae

E B Microdictyon umbilicatum (Velley) Zanardini. Womersley 1984: 217, figure 72.

ULVALES

Ulvaceae

- B Enteromorpha clathrata (Roth) Greville. Womersley 1984: 157, figures 50A, 51B, C.
- E B Enteromorpha intestinalis (Linnaeus) Nees. Womersley 1984: 161, figures 50D, 51G, H.

B Ulva australis Areschoug. Womersley 1984: 141, figures 44B, 45D-F.

E B Ulva lactuca Linnaeus. Womersley 1984: 141, figures 44A, 45A-C.

PHAEOPHYTA

SPHACELARIALES

Sphaceleriaceae

E B Sphacelaria rigidula Kuetzing. Womersley 1987: 166, figures 51D, 54A-G.

E B S. tribuloides Meneghini. Womersley 1987: 160, figures 45G, 52A-C.

ECTOCARPALES

Ectocarpaceae

- E B *Ectocarpus siliculosus* (Dillwyn) Lyngbye. Womersley 1987: 33, figures 2D, 5A-E.
 - B Hincksia sp.

SCYTOSIPHONALES Scytosiphonaceae

- E B Colpomenia sinuosa (Mertens ex Roth) Derbes & Solier. Womersley 1987: 297, figures 107A, 108E, F.
- E B *Hydroclathrus clathratus* (C. Agardh) Howe. Womersley 1987: 300, figures 109A, 110A, B.

DICTYOTALES

Dictyotaceae

- E B Dictyota furcellata (C. Agardh) J. Agardh. Womersley 1987: 196, figures 65C, 66A-C.
- E B D. dichotoma (Hudson) Lamouroux. Womersley 1987: 194, figures 64H-M, 65A, B.
 - B D. ciliolata Kuetzing. Taylor 1960: 223, pl. 32, figure 3.
 - B Dictyopteris plagiogramma (Montagne) Vickers. Allender & Kraft 1983: 103, figures 17A, B, 18A, B.
 - B Dictyopteris sp.
 - B Lobophora variegata (Lamouroux) Womersley. Womersley 1987: 253, figures 91F, G, 92A.
 - B Padina sanctae-crucis Boergesen. Womersley 1987: 219, figures 74A, 75H-J.
- E B Padina sp.
 - B Stypopodium flabelliforme Weber-van Bosse. Allender & Kraft 1983: 96, figures 11D, F, 12.

FUCALES

Cystoseiraceae

- E B Caulocystis uvifera (C. Agardh) Areschoug. Womersley 1987: 359, figure 129A.
- E B Cystoseira trinodis (Forsskål) C. Agardh. Womersley 1987: 357, figures 128B, 131E, F.
- E B Hormophysa cuneiformis (Gmelin) Silva. Womersley 1987: 356, figures 128A, 131C, D. (as H. triquetra).
 - B Platythalia angustifolia Sonder. Womersley 1987: 404, figures 150A, 155B.

Sargassaceae

- E B Sargassum decurrens (R. Brown ex Turner) C. Agardh. Womersley 1987: 421, figures 157A, 160A.
- E B S. flavicans (Mertens) C. Agardh. J. Agardh 1889: 82, t.25, figure 3
 - B S. spinigulerum Sonder. Womersley 1987: 442, figures 166A, 168D.
- E B S. varians Sonder. Womersley 1987: 426, figures 159A, 160E.
 - B S. verruculosum (Mertens) C. Agardh. Womersley 1987: 426, figures 159B, 160F.

RHODOPHYTA

ACROCHAETIALES

Acrochaetiaceae

- B Audouinella daviesii (Dillwyn) Woelkerling 1971: 28, figures 67, 22.
- E A. microscopica (Naegeli) Woelkerling 1971: 33, figure 10.

NEMALIONALES

Liagoraceae

E B Liagora sp.

Galaxauraceae

- B Galaxaura collabens J. Agardh. Kjellman 1900: 46, pl. 2 figures 19-24, pl. 3, figure 1, pl. 20, figure 15.
- B G. obtusata (Ellis & Solander) Lamouroux. Papenfuss et al. 1982: 418, figures 14-16, 27, 39.
- B G. rugosa (Ellis & Solander) Lamouroux. Papenfuss et al. 1982: 421, figures 17-19, 29, 40, 41, 45.

BONNEMAISONIALES

Bonnemaisoniaceae

B Asparagopsis taxiformis (Delile) Trevisan. Cribb 1983: 28, pl. 4, figures 1-2.

GELIDIALES Gelidiaceae

- B Gelidiella acerosa (Forsskål) Feldmann & Hamel. Cribb 1983: 29, pl. 6, figure 1.
- B Gelidium pusillum (Stackhouse) Le Jolis. Fuhrer et al. 1981: 14, pls 55, 56.
- B Pterocladia capillacea (Gmelin) Bornet in Bornet & Thuret. Fuhrer et al. 1981: 42, pl. 57 (as P. pinnata).

CORALLINALES Corallinaceae

- B Amphiroa anceps (Lamarck) Decaisne. Jaasund 1976: 79, figure 160.
- B Amphiroa sp.
- E Haliptilon roseum (Lamarck) Garbary & Johansen. Johansen & Womersley 1986: 551, figures 1-6.
- E B Jania micrarthrodia Lamouroux 1816: 271, t.9, figure 5.
- E Jania sp.
- E *Fosliella cruciata* Jones & Woelkerling 1984: figures 1,2,4,20. Harlin *et al.* 1985: figures 4, 11.
- E F. cymodoceae (Foslic) Jones & Woelkerling 1984: figures 3,6-13. Harlin et al. 1985: figures 7, 13.
- E *Pneophyllum caulerpae* (Foslic) Jones & Woelkerling 1984: figure 18. Harlin *et al.* 1985: figures 3, 8-10.
- *Melobesia membranacea* (Esper) Lamouroux, Chamberlain 1984: figures 17, 19.
- E B *Metagoniolithon stelliferum* (Lamarck) Weber-van Bosse. Ducker 1979: 83, figures 1-3.
 - B Neogoniolithon sp.

GIGARTINALES

Dicranemaceae

E Dicranema revolutum (C. Agardh) J. Agardh. Kraft 1977: 223, figures 1-3, 12, 13.

Gracilariaceae

- B Ceratodictyon spongiosum Zanardini. Cribb 1983: 55, pl. 12, figures 3, 4.
- E B Gracilaria harveyana J. Agardh. May 1948: 56, pl. 15, figure 1
 B Gracilaria sp.

Grateloupiaceae

B Grateloupia filicina J. Agardh var. luxurians A. & E.S. Gepp 1906: 259.

Halymeniaceae

B Cryptonemia kallymenioides (Harvey) Kraft in Scott et al. 1982: 246, figures 2-25.

Hypneaceae

- E B Hypnea musciformis (Wulfen) Lamouroux. Lucas & Perrin 1947: 90, figure 57.
 - B H. pannosa J. Agardh. Cribb 1983: 59, pl. 15, figures 2, 3.
- E H. valentiae (Turner) Montagne. Dawson 1954: 436, figures 46L, 47.

Mychodeaceae

E Mychodea pusilla (Harvey) J. Agardh. Kraft 1978: 533, figures 7-9, 33, 34.

Plocamiaceae

B Plocamium sp.

Rhizophyllidaceae

B Portieria hornemannioides (Lyngbye) Silva. Cribb 1983: 35, pl. 8, figure 2 (as Chondrococcus hornemannii).

Solieriaceae

E B Eucheuma speciosum J. Agardh. Harvey 1859: pl. 64.
B Solieria robusta (Greville) Kylin. Min-Thein & Womersley 1976: 7, figures 1, 2, 49.

RHODYMENIALES Rhodymeniaceae

- B Coelarthrum sp.
- E B Rhodymenia australis (Sonder) Harvey. Fuhrer et al. 1981: 27, pl. 27.
 B Botryocladia leptopoda (J. Agardh) Kylin. Jaasund 1976: 103, figure 209.

Champiaceae

- E *Champia affinis* (Hooker & Harvey) J. Agardh. Reedman & Womersley 1976: 82, figures 3, 4, 11B, 12.
 - B Champia compressa Harvey.
 - B Champia sp.

CERAMIALES

Delesseriaceae

E B Hypoglossum heterocystideum (J. Agardh) J. Agardh. Womersley & Shepley 1982: 326, figures 1B, C, 4 (as H. hypoglossoides).

- B Martensia elegans Hering. Harvey 1847: 73, t. 43.
- E Platysiphonia intermedia (Grunow) Wynne.
- E P. miniata (C. Agardh) Borgesen. Ballantine & Wynne 1985:461, figures 7-8.
- E Platysiphonia sp.

Dasyaceae

- E B Dasya sp.
- E B Heterosiphonia callithamnion (Sonder) Falkenberg 1901: 647.
 - B H. crassipes (Harvey) Falkenberg. Kuetzing 1864: pl. 72.
 - B H. wurdemannii (Bailey ex Harvey) Falkenberg. Taylor 1960: 565, pl. 72, figure 9.

E Heterosiphonia sp.

Ceramiaceae

- E Acrothamnion preissii (Sonder) Wollaston 1967: 323, figure 24.
 B Aglaothamnion cordatum (Boergesen) Feldman-Mazoyer. Cribb 1983: 72, pl. 56, figure 4.
- E B Anotrichium tenue (C. Agardh) Naegeli. Cribb 1983:72, pl. 32, figures 1-5
- E Antithamnion armatum (J. Agardh) De Toni. Wollaston 1967: 290, figure 18A-J.
- E A. divergens (J. Agardh) J. Agardh. Wollaston 1967: 281, figure 15.
 B Antithamnionella sp.
- E B Centroceras clavulatum (C. Agardh) Montagne. Cribb 1983: 75, pl. 25, figures 2, 3.
- E B Ceramium australe Sonder. Womersley 1978: 230, figures 3B, C, 13A-D.
 - B C. codii (Richards) G. Mazoyer. Cribb 1983: 80, pl. 27, figures 1-4.
- E *C. flaccidum* (Kuetzing) Ardissone. Cribb 1983: 82, pl. 31, figure 2, pl. 59, figures 1-4.
- E C. puberulum Sonder. Womersley 1978: 216, figures 1E, F, 6.
- E C. shepherdii Womersley 1978: 212, figures 1A, B, 5A-C.
- E Crouania capricornica Saenger & Wollaston 1982: 79, pl. 6
- E Griffithsia ovalis Harvey. Baldock 1976: 527, figures 19-21, 78.
 B Griffithsia sp.
- E Haloplegma preissii Sonder. Fuhrer et al. 1981: 51, pl. 75.
- E Ptilocladia australis (Harvey) Wollaston 1967: 265, figures 5E-J, 12.
 B P. vestita (Harvey) Wollaston 1967: 263, figure 11.
- E B Spyridia filamentosa (Wulfen) Harvey. Womersley & Cartledge 1975: 222, figures 1, 3, A, B.

- E B Spyridia dasyoides Sonder. Womersley & Cartledge 1975: 231, figures. 3J, K, 5.
- E Spyridia velasquezii Trono 1971: 53, pl. 9, figures 1, 2, pl. 10, figure 3.
- E Tiffaniella cymodoceae (Boergesen) Gordon 1972: 121, figures 39D-F, 40.
- E Wrangelia plumosa Harvey. Gordon 1972: 21, figures 4, 5, 10G, H, J, 51.
 B W. argus (Montagne) Montagne. Cribb 1983: 94, pl. 66, figure 1.
- E Wrangelia sp.

Rhodomelaceae

- B Acanthophora dendroides Harvey. Kraft 1979: figure 7.
- B Acanthophora spicifera (Vahl). Boergesen. Cribb: 1983, 105, pl. 32, figure 2.
- E B *Chondria minutula* Weber-van Bosse. Cribb 1983: 108, pl. 34, figures 4-5.
- E Chondria sp. 1
 - B Chondria sp. 2
- E Coeloclonium umbellulum (Harvey) Falkenberg. Harvey 1860: pl. 47 (as Chondria umbellula).
 - B Dasyclonium flaccidum (Harvey) Kylin. Scagel 1962: 1024, figures 4, 32-34.
 - B Digenia simplex (Wulfen) C. Agardh. Cribb 1983: 109, pl. 32, figure 3.
- E Herposiphonia secunda (C. Agardh) Ambronn f. tenella (C. Agardh) Wynne. Cribb 1983: 111, pl. 67, figures 1-4 (as H. tenella).
- E Herposiphonia sp.
 B Laurencia brongniartii J. Agardh. Saito & Womersley 1974: 839, figures 4 C, D, 20, 21.
- E B *L. filiformis* (C. Agardh) Montagne. Saito and Womersley 1974: 832, figures 3 C, D.
- E B L. majuscula (Harvey) Lucas. Saito and Womersley 1974: 819, figures 1A, 6, 14-16.
 - B L. papillosa (Forsskål) Greville. Jaasund 1976: 139, figure 281.
- E B L. shepherdii Saito and Womersley 1974: 826, figures 2C, D, 10.
- E B Leveillea jungermannioides (Hering & Martens) Harvey. Cribb 1983: 127, pl. 32, figure 4.
 - B Lophocladia harveyi (Kuetzing) Schmitz. Kuetzing 1864: pl. 71E, F, (as Dasya harveyi).
 - B Neurymenia fraxinifolia (Mertens ex Turner) J. Agardh. Jaasund 1976: 133, figure 271.
- E Polysiphonia amphibolis Womersley 1979: 474, figure 3F, G, 4A-C.
- E B P. abscissoides Womersley 1979: 492, figure 9E-H.
- E P. decipiens Montagne. Womersley 1979: 499, figure 12.
 - B P. ferulacea Suhr ex J. Agardh. Cribb 1983: 129, pl. 71, figures 2-4.

E P. infestans Harvey. Womersley 1979: 481, figure 6A-E.

- E B P. scopulorum Harvey. Womersley 1979: 467, figure 2A-E.
- E P. sertularioides (Grateloup) J. Agardh. Womersley 1979: 478, figure 5A-D.
- E B Tolypiocladia glomerulata (Agardh) Schmitz. Cribb 1983: 135, pl. 68, figure 4.
- E B Vidalia spiralis Lamouroux. Harvey 1847: 25, t. 9, figures 1-6 (as Epineuron spirale).

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Seagrass in Shark Bay, Western Australia

D.I. Walker*

Abstract

There are 4000 km² of seagrass meadows in Shark Bay, mainly species of southern temperate affinities. This paper summarises the available information on their distribution, abundance and significance in Shark Bay. The dominant species is *Amphibolis antarctica* which can achieve biomass values of up to 2 kg dry weight m⁻² with maximum production rates of 17 g dry weight m⁻² d⁻¹. This high rate of production is supported by efficient recycling of nutrients. Seagrass has modified the physical, chemical and biological environment, as well as the geology of the area, and hence is the foundation of the marine ecosystem in Shark Bay.

Résumé

Il y a 4000 km² de prairies d'herbes marines dans la Baie des Chiens Marins, principalement des espèces à affinités tempérées méridionales. Cet article résume les informations disponibles sur leur répartition, leur abondance et leur importance dans la Baie des Chiens Marins. L'espèce dominante est *l'Amphibolis antarctica* qui peut réaliser des valeurs de biomasse allant jusqu à 2kg de poids sec m⁻² avec des taux de production maximum de 17g de poids sec m⁻²d⁻¹. Ce taux élevé de production est soutenu par le recyclage efficace des substances nutritives. L'herbe marine a modifié le milieu physique, chimique et biologigue, ainsi que la géologie de la région, et par là est le fondement de l'écosystème marin de la Baie des Chiens Marins.

Introduction

Seagrass may be regarded as the dominant organism in Shark Bay, as it has modified the physical, chemical, and biological environment, as well as the geology of the area. Shark Bay contains the largest reported seagrass meadows in the world, as well as some of the most species rich seagrass assemblages. Twelve species of seagrass (Table 1) have been found in Shark Bay (Walker *et al.* 1988). Several species are of essentially southern distribution at the northern limit of their range e.g. *Amphibolis antarctica* and *Posidonia australis*. Shark Bay also contains species of tropical affinity such as *Syringodium isoetifolium* and *Halodule uninervis* (Walker and Prince 1987). *Cymodocea angustata*, endemic to the northern section of the Western Australian coastline, is common in Shark Bay.

The most abundant species in the bay is *A. antarctica* which occupies some 3754 km^2 , 85% of the total seagrass area. It forms monospecific stands, with a maximum aboveground biomass of some 2 kg dry wt m⁻² and with erect stems up to 2 m long. The canopy may be very dense, 300-500 erect shoots m⁻² and 4500 leaf clusters m⁻² (Walker 1985), giving a leaf area index of approximately

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Table 1	. Sea	grass spc	cies foun	d in Sh	ark Bay.

Amphibolis antarctica (Labill.) Sonder et Aschers.	Halophila ovata Gaud.
Cymodocea angustata Ostenfeld	Halophila spinulosa (R.Br.) Aschers.
Cymodocea serrulata (R.Br.) Aschers. and Magnus	Posidonia angustifolia Cambridge and Kuo
Halodule uninervis (Forsk.) Aschers.	Posidonia australis Hook.f.
Halophila decipiens Ostenfeld	Posidonia coriacea Cambridge and Kuo
Halophila ovalis (R.Br.) Hook.f.	Syringodium isoetifolium (Aschers.) Dandy

15. Amphibolis antarctica is found under a wide range of current regimes and in varying sediment types. The large surface area of leaves also provides a substratum for attachment of epiphytes (66 species of algal epiphyte (Kendrick et al. 1988) and about 40 species of animal epiphytes (Lethbridge, pers. comm.)) as well as a refuge for juvenile fish (Robertson, pers. comm.) and notably in Shark Bay, a habitat for the abundant populations of seasnakes (Pers. Obs.). The upper depth limit of A. antarctica distribution is at ELWS, as the plants seem unable to tolerate emersion. The lower limit appears to be beyond the depth of substratum present in the bay, although dense meadows are rare below 13 m. P. australis also forms monospecific meadows but these are largely confined to channels, as described by Read (1974) and by Cambridge (1980) for the Wooramel delta. Small patches are often found adjacent to A. antarctica meadows, apparently on the "leading edge", projecting into the prevailing current, where sediment accretion is occurring. "Ridge and furrow" or rill structures occur on the Faure Sill which are oriented at right angles to the major tidal channels. Observations of water flow *in situ* show that during a flood tide, water flows along the channels then spreads across the banks, with the lines of seagrass (mainly A. antarctica) parallel to the prevailing currents.

Halodule uninervis is the only other species to occur in a large monospecific meadow, at the mouth of the Wooramel delta, in an area of fine anoxic mud. This area is the most important summer feeding ground for dugong (pers. obs. and Anderson 1986). The dugongs remove large amounts of rhizome mat, rich in starches (Masini 1983).

There is a decrease in seagrass cover with increasing salinity, with little seagrass present in Hamelin Pool. A. antarctica is rarely found at salinities greater than 60° , and P.australis rarely above 50° . Halodule uninervis is present at salinities of 62° , but in very low densities, as isolated plants. In areas where larger seagrasses were absent, various combinations of smaller seagrasses occur — Halophila ovalis, Halophila ovata, both narrow- and wide-leaved Halodule uninervis, Cymodocea angustata and Syringodium isoetifolium. These habitats include intertidal sand flats (up to 2 km wide), sand patches within meadows, the edges of channels and banks, and around islands. They occupy an area of approximately 500 km², about 4% of the bay. These have a low biomass (ca. 100 g dry wt m⁻²) but they are highly productive and form a preferred food
source for dugongs (Anderson 1986). Below about 8 m depth, Halophila spinulosa becomes abundant, with up to 800 shoots m⁻², commonly with large leaved Halophila ovalis, Cymodocea angustata, and S. isoetifolium.

Productivity and biomass and the influence of the salinity gradient

A. antarctica has above-ground biomass values of 1-2 kg dry wt m⁻² (Walker 1985). *P. australis* has leaf biomass values of less than 400 g dry wt m⁻², but has up to 1.5 kg dry wt m⁻² in below-ground material. At one site, *A. antarctica* had an annual average productivity of 1.6 kg m⁻², and *P. australis*, 1.0 kg m⁻² (Walker & McComb 1988). Maximum biomass and productivity in *A. antarctica* occurred at intermediate salinities, above those of normal seawater (Walker 1985). Specific growth rates also showed a similar trend, with maximum specific growth rate at 42.5%. The densest seagrass cover is also within the 40-50m^o/∞ salinity range and artificial seawater culture experiments with *Amphibolis* seedlings have confirmed that there is a primary response to salinity (Walker and McComb 1990).

Seasonality in productivity, biomass and nutrient content

A. antarctica displays marked seasonality, with maximum productivity and specific growth rate, coinciding with the period of highest light intensity (Walker & McComb 1988). This is accompanied by a decrease in the concentration of phosphorus in the leaf tissue but no overall change in the phosphorus pool contained in the plant material on an area basis, suggesting redeployment of phosphorus within the plants (Walker & McComb 1988). Phosphorus concentrations at all times of the year were relatively low, certainly well below the 1.3 mg g⁻¹ threshold concentration described by Gerloff and Krombholtz (1966) as being limiting for a number of aquatic macrophytes.

P. australis showed no clear seasonal pattern, with differences in production and specific growth rate occurring at different times. A low specific growth rate in winter was correlated with low light intensity and temperature. Biomass was found to be correlated with productivity. However, there was marked depletion of phosphorus in October, a period of low above-ground biomass, suggesting loss from above-ground material either to the rhizomes by retranslocation, or to the water column. Tissue concentrations were generally higher in *P. australis*, and leaf bases were particularly rich in phosphorus, as noted by Hocking *et al.* (1981).

A. antarctica has nearly twice the annual production of *P. australis*, (4.53 and 2.65 g dry wt m⁻² d⁻¹, respectively). A similar amount of nitrogen (11.0 and 9.7 mg g⁻¹ production) was incorporated into new leaf tissue in both species, but this is not so for phosphorus (0.79 and 1.62 mg g⁻¹ production). The mean N:P ratio for *A. antarctica* is 14, but is only 6 for *P. australis*, suggesting that for *P. australis* more phosphorus is required to support a lower productivity.

Seagrass

Nutrient cycling

By utilizing all the distribution, biomass, nutrient content and productivity data previously described, a total nutrient budget has been calculated for the seagrass meadows of Shark Bay, by grouping results on the basis of salinity. Table 2 summarises total area covered by seagrass (calculated from aerial photography and ground truthing). Using seasonal measurements of productivity from one site, an annual total was calculated, assuming the same pattern of seasonality throughout the bay. These results were then multiplied by the area, to give a total productivity for the whole bay of 7.7 x 10^6 tonnes dry weight year⁻¹, 3 x 10^6 tonnes Carbon year⁻¹.

Salinity %	Area km²	% cover	area km²	Production kg ⁻² yr ⁻¹	Production 10 ⁶ kg yr ⁻¹	TN required 10 ⁶ kg yr ⁻¹	TP required 10°kg yr ⁻¹
35-40 A	965.3	60	562.1	1.92	1.080	14.407	1.210
Р	84.9	40	34.0	0.81	.0.028	0.310	0.026
Total	1052.1		596.1		1.108	14.717	1.236
40-45 A	797.6	75	583.6	3.85	2.244	22.662	1.815
Р	49.3	40	19.7	0.81	0.016	0.180	0.015
Total	850.4		603.3		2.260	22.844	1.830
45-50 A	1207.6	75	879.9	4.21	3.705	41.149	2.586
Р	73.8	40	29.5	0.81	0.024	0.270	0.023
Total	1281.4		909.4		3.729	41.419	2.609
50-55	403.0	55	221.7	2.29	0.507	5.786	0.346
55-60	269.9	35	94.5	1.06	0.100	1.144	0.060
>60	33.0	5	1.6	0.93	0.001	0.013	0.001
TOTAL	3887.8		2426.5		7.706	85.926	6.082

Table 2. Table of total areas, productivity, and nutrient content

The results of nutrient analyses of whole leaf clusters were averaged for each salinity band and showed a trend of decreasing phosphorus and increasing nitrogen with increasing salinity. From these results an estimate of annual utilization of nitrogen and phosphorus was made for the whole bay. Smith and Atkinson (1983) estimated phosphorus input into the bay to be 5.8x10⁸ g phosphorus year⁻¹, approximately 10% of the calculated requirement to support seagrass productivity. Discussions by Mann (1982) suggest that for semi-enclosed systems, dominated by benthic macrophytes, net input should be about 10% of gross production, giving a factor of 10 for recycling of nutrients.

Two main types of recycling may account for most of the requirement for phosphorus: internal recycling within the seagrass plants themselves, by retranslocation, and recycling within meadows by decomposition and remineralisation. Nutrient concentrations within each leaf decrease with increasing age of leaves (Walker 1989). This suggests either retranslocation or an increasing "leakiness" with age. Uptake by epiphytes of such "leaked" material has been shown to be rapid (Penhale and Smith 1977; Penhale and Thayer 1980), but an estimate of 40% retranslocation from these data is conservative by terrestrial standards, where 70% retranslocation is not uncommon. Rates of decomposition by both *P. australis* and *A. antarctica* have been measured to be 0.5% day⁻¹ about one third of the specific growth rate for *A. antarctica* and about one half of that of *P. australis* (Walker and McComb 1985).

Thus the production of the seagrass meadows in Shark Bay is supported by the input of oceanic phosphorus to the bay, relying heavily on recycling. As net production cannot be supported by recycling, the amount of oceanic input of phosphorus may determine total net production.

Significance of seagrass in Shark Bay

The presence of extensive meadows of large seagrasses has influenced the current regimes of the bay, as the seagrasses slow the rate of water flow over the substratum. Rates of sediment accretion associated with the seagrass meadows in Shark Bay are greater than those associated with coral reefs (Logan, pers.comm.). This is largely a function of the rapid rates of leaf turnover (Walker 1985; Walker & McComb 1988). The leaves carry a heavy load of calcareous epiphytes (Harlin *et al.* 1985) which are also trapped under the seagrass. Over geological time, these processes have led to the development of large sedimentary banks, such as the Faure Sill (Logan *et al.* 1970, 1974; Walker and Woelkerling 1988). The build up of these barrier banks and sills has restricted the circulation of oceanic seawater, and in combination with low rainfall and high evaporation, has resulted in the increase in salinity observed in the inner reaches of the bay. This hypersaline environment has been unsuitable for the further growth of seagrass, but has provided suitable conditions for the development of stromatolites.

The restriction of exchange between the waters of the bay and the open ocean has resulted in depletion of phosphorus (Smith & Atkinson 1983). However, the seagrass meadows represent large accumulations of nutrients. The majority of the seagrass production is not consumed directly, but is broken down, providing a huge input to detrital food chains. Dugongs and turtles, as well as some fish and crustaceans, feed directly on the seagrass. Shark Bay is the only locality where dugongs feed on *A. antarctica*, as this is the only place where the distribution of the two species overlap.

Shark Bay provides an impressive example of the roles that seagrasses play in shallow benthic ecosystems, resulting in modification of the whole ecosystem.

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Preliminary observations on the zooplankton of Shark Bay, Western Australia, with emphasis on medusae and description of a new rhizostome jellyfish (Cnidaria, Scyphozoa)

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Abstract

The zooplankton of Shark Bay is of interest both because of the work by the French explorers at the beginning of the 19th century, especially Péron and Lesueur, and because of the unique hydrology of the Bay.

Samples revealed a high diversity of oceanic and neritic species in oceanic and metahaline waters in contrast to low species diversity in hyperhaline waters; high diversity and density of larval stages indicating importance of the area as a nursery; and concentrations of gelatinous species at the fronts of haloclines.

Phyllorhiza peronlesueuri sp. nov. is described from Hamelin Pool.

Résumé

L'étude de Shark Bay présente un double intérêt: historique d'abord par la récolte de spécimens observés par Péron et Lesueur lors de la première expédition française aux Terres Australes de 1800 à 1804, et océanographique par l'originalité de son hydrologie.

Les quelques pêches pratiquées font apparaître le contraste entre les eaux océaniques et métahalines riches en espèces et en stades larvaires, véritables nurseries, et les eaux hyperhalines désertiques. Les fronts halins sont matérialisés par des cordons de macroplancton gélatineux.

Phyllorhiza peronlesueuri sp. nov. est découverte à Hamelin Pool.

Introduction

The pelagic fauna of Shark Bay was the subject of work by the first French explorers in the beginning of the 19th century, especially François Péron and Charles-Alexandre Lesueur, who observed the bioluminescence of *Aequorea* as well as the morphology and swimming behaviour of *Beroe ovata* and *Physalia physalis* — a remarkable feat considering how very fragile these animals are. The same species were also encountered in the planktonic samples obtained during the present study.

Shark Bay is of interest not only historically, but also because of the effects of the unique hydrology (see Logan and Cebulski 1970) on the distribution and diversity of zooplankton.

Methods and Sampling

A specially designed small net was used (60 cm mouth opening; 2 m length; nylon netting 500 μ mesh) because the Bay's depth does not permit use of a standard net. Surface tows were made 20 m behind the ship at slow speed. Nineteen stations were sampled, chosen

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to cover the oceanic and metahaline water masses as defined by Logan and Cebulski (1970) (see Figure 1). In the hyperhaline areas specimens were collected by diving.

Temperature and salinity were measured with a portable thermo-salinograph.

Results

Oceanic water: 36% to 38% salinity: A wide diversity of planktonic organisms were represented: Medusae, Siphonophora, Chaetognatha (Sagitta robusta, Sagitta nagae), Hyperida, Appendicularia (Oikopleura rufescens), larval stages of crustaceans and ichthyoplankton.

Metahaline water: 38% to 42% salinity: Oceanic species were less abundant with some Chaetognatha, Appendicularia (Oikopleura dioica), eggs of fishes, larval stages of crustaceans, but the gelatinous zooplankton were very common, namely the medusa Aequorea and the ctenophore Beroe.

Medusae

During the first French Expedition of Baudin (1800-1804) the medusae were of considerable interest because they were treated for the first time as a separate zoological group (Bonnemains and Goy 1988).

Knowledge about them began during this cruise. Linné (1758) classified the 22 known species in the single genus *Medusa*. Péron and Lesueur described 29 genera and 122 species, from the coasts of the Land of Endracht or Witt (north-western Australia), explored by the French scientists. Many of the species are synonymous because Péron and Lesueur were not able to distinguish the morphological variations of growth or sexual dimorphism, and many were damaged.

Medusae found by Péron and Lesueur

Land of Arnhem: Berenix thalassina, Favonia octonema, Aequorea bunogaster, A. phosperiphora, A. cyanea, A. thalassina, A. pleuronata, A. undulosa, Pegasia cylindrella;

Land of Witt (Kimberley and Pilbara): Eudora undulosa, Phorcynia cudonoidea, Aequorea amphicurta, Melitea purpurea, Melicerta pleurostoma, Ephyra tuberculata, Ocyroe lineolata, Cassiopea dieuphila, Cephea fusca;

Land of Endracht (Shark Bay): Orythia viridis, Aequorea sphaeroidalis, A. purpurea, Evagore capillata;

North-west coast of Australia: Callirhoë micronema;

South-east coast and Bass Strait: Lymnorea triedra, Phorcynia petasella, P. istiophora, Aequorea eurodina, Pelagia australis, Euryale antarctica, Chrysaora pentastoma, C. hexastoma;

Austral Ocean: Eulimenes sphaeroidalis;

Ten species are now recognised: Berenix thalassina, Rhacostoma bunogaster, Aequorea aequorea, Zygocanna purpurea, Z. pleuronota, Z. diploconus, Pelagia noctiluca, Cassiopea andromeda, Cephea cephea, Chrysaora hysoscella (Goy 1980).







In Péron's manuscript of the collection at Musée d'Histoire naturelle du Havre (Collection Lesueur), the sea water temperatures were mentioned: 22° to 24°C in June at Land of Arnhem; 16° to 17°C in July at Land of Endracht; 10° to 12°C in April at Bass Strait; 14° to 15°C in January at Bass Strait. Péron wrote "in all the parts of the sea that we have seen, none is richer in pelagic zoophyta than those along the coast of the Land of Witt and Arnhem." Péron noted also that the winter was poorer in medusae than summer and suggested that the same rules regulate marine production in the two hemispheres.

Medusae of the present expedition

(Systematic after Kramp 1961 and Bouillon 1985).

In August 1988, the samples contained 18 species: 15 meroplanktonic (at the hydroid stage) and 3 holoplanktonic species (not at the hydroid stage) i.e. *Liriope tetraphylla*, a very cosmopolitan species in warm and temperate water of all oceans, *Aglaura hemistoma* and *Solmaris lenticula*.

The distribution was the same as for the other groups; i.e. maximum diversity in oceanic and metahaline waters with lower diversity in the other parts of the Bay. *Liriope* and *Aequorea*, which are associated with *Beroe ovata*, were always at the front of the haloclines.

Oceanic and metahaline waters: Dipurena halterata, Sarsia eximia, S. gracilis, Euphysa aurata, Ectopleura minerva, Podocoryne carnea, Bougainvillia britannica, B. fulva, B. prolifera, Nubiella mitra, Clytia sp., Obelia fimbriata, Cirrholovenia tetranema, Aequorea australis, Liriope tetraphylla, Aglaura hemistoma, Solmaris lenticula.

Front, salinocline water: Aequorea australis, Liriope tetraphylla and the ctenophore Beroe ovata.

Hyperhaline waters: A large scyphomedusa (described below as a new species) is always associated with stromatolites. This appears to be the preferred habitat for the species as different growth stages were observed (2 to 25 cm in diameter). It is a microphagous medusa and nanoplankton and phytoplankton were abundant.

Conclusions

The samples have not been fully studied, but the initial results reveal that a high diversity of oceanic and neritic zooplankton is represented and the variety and density of larval stages of crustaceans, fishes and medusae, indicate that Shark Bay is an important nursery ground for these species.

Gelatinous species such as Aequorea australis and Beroe ovata are useful indicators of halinoclines.

The most important feature observed was the high diversity and density of zooplankton in the oceanic and metahaline waters compared with the hyperhaline waters, in which only a bivalve mollusc *Fragum hamelini* and a large scyphomedusa predominate.

Shark Bay is an ideal locality for research on species with unknown meroplanktonic life-cycles, by diving. It is also a potentially ideal area to observe gelatinous zooplankton

J. Goy

Phyllorhiza peronlesueuri sp. nov. Figure 2

Diagnosis

Rhizostomeae with some double velar lappets typical of *Phyllorhiza*, with marginal arrangement between two rhopalar lappets: two single, two double, two single velar lappets, oral filament with triple heart-shaped distal knob with aperture of a branch of oral canal at the end.

Differs from *Phyllorhiza punctata* von Lendenfeld, 1884 in the arrangement of the velar lappets in each octant, the triple heart-shaped knob of oral filaments, the smaller diameter 25 cm, and the localization.

Holotype

Muséum National d'Histoire Naturelle 1720; Hamelin Pool, Shark Bay, August 1988, J. Goy.

Other material

Seven specimens, data as for holotype.

Description of holotype

Dome-shaped bell diameter and length 15 cm; without warts on apical part; without marginal tentacles; 8 rhopalia; 10 inter-rhopalar velar lappets with arrangement: rhopalar lappet, two single lappets, two double lappets, two single lappets and a rhopalar lappet; circular muscle; 8 rhopalar radial canals; 10 to 13 anastomosed canals by octant; 4 gonads with very large ostiums; 8 tripteral oral-arms with frilled mouths and stalked suckers. Two to three long filaments with a terminal triple heart-shaped appendage from the oral arm and many other smaller ones scattered between frilled mouths. The long oral tentacles contain a branch of the oral canal into the terminal club where there is an orifice.

Etymology

Named in recognition of the early studies on the medusae of Australia by Péron and Lesueur.

Discussion

Phyllorhiza peronlesueuri shares the following characters with *Rhizostoma* or *Anomalorhiza* (Kramp, 1961): the canal and orifice of the oral long tentacles; with *Phyllorhiza trifolium* of Haeckel (1880): the number of oral tentacles; with immature specimen of *Cotylorhizoides pacificus* of Light (1921): the number and arrangement of velar lappets and the oral club filament ends. In the systematic revision by Kramp (1961), the latter two species are actually synonyms of *Phyllorhiza punctata* von Lendenfeld, 1884.

In 1958, Southcott initiated a re-study of the South Australian medusae and he sent an interesting collection to the world renowned specialist P.L. Kramp. In this revision, Kramp (1965) examined the genus *Phyllorhiza* with its numerous species and concluded

that many are synonymous. Thus the only valid species in Australian waters (Port Jackson, northern Queensland and the Swan River) is *Phyllorhiza punctata*. Although *P. peronlesueuri* from Shark Bay has characters typical of the genus *Phyllorhiza*, marginal arrangement of the velar lappets and the terminal triple heart-shaped appendages of oral arms are sufficiently original to create a new species. The hyperhaline habitat also supports this. The rhythm of the bell's contractions, observed and filmed while diving, is so regular that I conclude that hyperhaline water is its preferred habitat as in general, when medusae are in bad conditions the pulses become spasmodic, irregular and asymetrical.

A revision of the jellyfishes of Australia, using fresh material, is needed in order to make comparisons with the descriptions of early authors.



Figure 2 Phyllorhiza peronlesueuri sp. nov.

J. Goy

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Hermatypic corals of Shark Bay, Western Australia

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Abstract

Shark Bay, lying between latitudes 24° and 26°S, has a depauperate coral fauna compared with the Ningaloo Reef to the north and the Houtman Abrolhos to the south. Intensive collecting has yielded only 80 species of 28 genera in scattered coral communities. No coral reefs occur in the bay nor around its margin. Strong, permanent salinity and seasonal temperature gradients either directly or indirectly restrict the occurrence of corals to areas of near normal salinity in the western half of the bay; a few species occur in the metahaline areas but none in the hypersaline waters. The exposed coasts of Dirk Hartog Island and Steep Point also have a very limited coral fauna.

Résumé

La Baie des Chiens Marins, se situant entre 24° et 26° de latitude sud, possède une faune corallienne imparfaitement développée en comparaison du récif de Ningaloo au nord et de Houtman Abrolhos au sud. Le ramassage intensif n'a produit que 80 espèces de 28 genres dans les communautés coralliennes éparses. Aucun récif corallien n'apparait dans la Baie ni autour de son bord. Une salinité élevée et permanente, et des gradients saisonniers de température restreignent soit directement ou indirectement l'apparition de coraux à des régions de salinité quasi normale dans la moitié occidentale de la Baie; quelques espèces apparaissent dans les régions métahalines mais aucune dans les régions hypersalines. Les côtes exposées de l'ile Dirk Hartog et de Steep Point ont également une faune corallienne très limitée.

Introduction

Some of the corals described by Lamarck from "Nouvelle Hollande" may have been collected in Shark Bay by the Baudin Expeditions (1801 and 1803) but without precise locality data it is not possible to be sure. The first reference to hermatypic corals in Shark Bay is by Saville-Kent (1897) who remarked on the predominance of *Turbinaria* species and noted that this genus was an important component of the coral fauna of extra-tropical areas in Australia. He also remarked on the large number of species and large size of coralla of *Turbinaria* in Shark Bay and figured specimens of *T. peltata* and *T. conspicua*. Shark Bay is the type locality of *T. conspicua* Bernard 1896 and of *T. magna* Bernard 1896, a junior synonym of *T. frondens* (Dana, 1846), both collected by Saville-Kent. No publications on corals resulted from the Hamburg Expedition (1905) which collected other taxa extensively in Shark Bay.

The Western Australian Museum collection of corals from Shark Bay began with a donation from the University of Western Australia of specimens collected by E.P. Hodgkin and B.R. Wilson at South Passage in 1957. Apart from a few trawled specimens, the next collection, again from the South Passage area, but

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including sampling stations outside the bar, off Steep Pt and off the S.W. end of Dirk Hartog Island, was made by the author in 1979. Cape Ransonnet, the south end of Dirk Hartog Island, Sunday Island and Egg Island were also sampled at this time (a total of 19 stations).

In 1980 S. Slack-Smith collected from Bernier and Dorre Islands (21 stations) and in 1981 Slack-Smith and Marsh collected corals from Turtle Bay and Louisa Bay (on the north and east sides of Dirk Hartog Island), Cape Peron North, Herald Bight, Eagle Bluff and Denham Channel (in Freycinet Reach). Other sites sampled, where no corals were found, include Useless Inlet, Faure Island, Freycinet Harbour and Hamelin Pool. Eleven stations were sampled by SCUBA and snorkelling while 63 were sampled by dredging and trawling. A comparison of the distribution of sampling sites at which corals were found with those where corals were absent (figure 1) indicates the pattern of coral distribution in the bay.

Physical features

Shark Bay stretches from the north end of Bernier Island (24°45'S, 113°10'E) to the south end of Freycinet Harbour (26°36'S, 113°41'E). It is a large shallow embayment approximately 13,000 km² in area with an average depth of 9 m and a greatest depth of c. 29 m. The bay is enclosed by Bernier, Dorre and Dirk Hartog islands and is subdivided internally by dune ridges and submerged banks or sills into numerous inlets, gulfs and basins. This resulted from marine transgression into a terrain composed mainly of Pleistocene dunes; the flooding created a series of broad gulfs and narrow inlets, which are partly cut off from the Indian Ocean. Influx of oceanic water is through the wide northern Geographe Channel, the Naturaliste Channel between Dorre and Dirk Hartog Islands and South Passage between Dirk Hartog Island and Steep Point.

Salinity

The embayment is adjacent to a hinterland of low relief in an arid to semiarid climate (evaporation exceeds precipitation). Two rivers drain into Shark Bay, but their flow is intermittent and runoff influx is small. Climatic factors combined with low runoff and restricted circulation result in an increase of salinity values from normal oceanic in the northern and western parts of the bay to hypersaline in the southern extremities (Logan and Cebulski 1970).

The inner parts of Shark Bay were first inundated by the rise of the postglacial sea about 8000 years BP. The bay had an oceanic - metahaline salinity regime from 8,000 to 4,500 yr BP and the hypersaline salinity regime of Hamelin Pool and Lharidon Bight has developed during the past 3000-4000 years (Logan 1974).

At present the salinity gradient (figure 1) ranges from oceanic (salinity 35-40‰) in the northern and western parts of the bay through metahaline (salinity 40-56‰) to hypersaline in Hamelin Pool and Lharidon Bight (salinity 56-70‰) (Logan and Cebulski 1970).





Figure 1. Map of Shark Bay with station locations indicating the presence (•) or absence (•) of corals. Salinity contours after Logan and Cebulski (1970).

Hermatypic corals are, with a few exceptions confined to the waters of near normal ocean salinity barely extending into the metabaline zone in Freycinet Reach.

Temperature

Sca surface temperature outside Shark Bay varies from 20.9°C (August-September) to 26°C (February-March) (Pearce 1986). Surface and bottom temperatures within the bay (1965 data, Logan and Cebulski 1970) have a greater range than the open sea temperature; the inner parts of the bay, including Freycinet Reach, fall to 17-18°C in August and to 19-22°C in the zone of oceanic salinity. In February a maximum of 27°C was recorded in Hamelin Pool, 24-26°C in Freycinet Reach and 22-24°C in the oceanic salinity zone. There is little difference between bottom and surface temperature either in summer or winter.

The Lecuwin Current (Cresswell and Golding 1980), an intrusion of warm low-salinity tropical water that flows southward near the Western Australian continental slope, occasionally meanders into Shark Bay but more often bypasses it. The current flows largely in autumn and winter but is very variable from month to month and year to year.

An infrared satellite image of 30 April 1980 shows a slight intrusion into the northern part of the bay (between Bernier Island and Carnarvon), between Dorre Island and the north end of Dirk Hartog Island and into South Passage (Legeckis and Cresswell 1981). An image of 22 October 1979 (Legeckis and Cresswell 1981) shows a complete absence of the Leeuwin Current while one of 18 October 1984 (Pearce 1985) shows a fairly well developed current penetrating well into Shark Bay.

Oxygen

Bottom waters within Shark Bay generally are saturated with oxygen although large diurnal fluctuations occur in proximity to seagrass stands (Logan and Cebulski 1970).

Tides

Tide is the major factor causing water movement in Shark Bay. The tides are mixed diurnal with a spring range of 1.70 m and a neap range of 0.61 m at Carnarvon (Logan and Cebulski 1970).

Wind

Shark Bay is in the belt of south-east trade winds which are locally reinforced by a strong sea-breeze system during summer and by winds associated with depressions in the Southern Ocean during winter. Winds are predominantly southerly with a mean velocity of 10-15 knots in summer (October to April) with a mean maximum velocity of 25 knots in January and February. Southerly winds also prevail during winter (May to September) but with a lower velocity in a range of 5-8 knots with periods of calm. Strong northerly winds can occur in association with depressions in the Southern Ocean and cyclonic disturbances from the north occasionally affect Shark Bay with severe winds.

The interaction of wind drift with tidal currents leads to a circulation in which net movement is from west to south-east, then east and finally north-west. This movement is probably along the density (salinity) trend lines (Logan and Cebulski 1970). The prevailing southerly winds generate substantial seas predominantly on shores with a south-easterly and south-westerly aspect. Sustained wave action mobilises fine sediments causing turbid conditions in the bay for much of the time.

Coral habitats in Shark Bay

The three elongate, narrow, north-south trending islands, (Bernier, Dorre and Dirk Hartog Islands) provide the principal coral habitats in Shark Bay. The islands are composed of Pleistocene coastal limestone (Tamala Eolianite) overlying Cretaceous limestone (Logan and Cebulski 1970). Bernier Island (24°45′S, 113°10′E to 24°59′S, 113°08′E) is 26.5 km long by 2.8 km wide, at its widest point; Dorre Island (24°59′S, 113°07′E to 25°16′S, 113°05′E) is 30.6 km long by 3.2 km wide at its widest point.

Bernier and Dorre islands are predominantly flat topped masses girt by cliffs which rise abruptly from the sea on their western side and reach an elevation of about 46 metres at Quoin Bluff North on Dorre Island (Ride 1962). Limited areas around Bernier and Dorre Islands have been sampled, to a depth of c. 5 metres, but they probably include those most favourable for coral growth. These are principally the southern end of Bernier Island (Cape Couture) where there is a coral covered platform, on the western side, at 1-2 m, with 'gardens' of staghorn and tabular Acroporas, and the northern end of Dorre Island (Cape Boullanger) where reefs extending northwards from the Cape support a diverse coral fauna.

The two islands are separated by a narrow channel 3-4 m deep through which there is considerable water movement.

Other areas with a fair diversity of corals are the eastern side of Cape Couture where there is 20-30% cover of living coral, principally *Montipora* spp, tabular Acroporas and faviids; Disaster Cove (N.E. side of Dorre Island) which has a coral community on rock substrate near the entrance to the bay, with 10-20% coral cover, principally *Turbinaria* spp, *Montipora* spp. and faviids. A few kilometres to the south near Smith Point is a fairly diverse coral community dominated by *Turbinaria* spp. Red Cliff Pt on the south-east side of Bernier Island has less than 5% coral cover, principally *Turbinaria* spp and faviids.

The western sides of Bernier and Dorre Islands are subjected to heavy wave action and have not been investigated. The principal coral areas appear to be those with some shelter from wave action but with close proximity to the open sea. Species richness drops, the diversity of *Acropora* species decreases and the

Hermatypic corals

diversity of *Turbinaria* species increases on the more sheltered eastern sides of the islands. Fifty-five species of 23 genera of hermatypic corals have been found at Bernier and Dorre Islands, very similar to the numbers for the South Passage area, however there are apparent differences in the species composition of the fauna (Table 1).

Table 1.Hermatypic corals of Shark Bay. Data from the Western Australian Museum collection;
registration numbers of specimens are given in Veron and Marsh (1988). Symbols:
+ = present, - = not found, V = visual record.

Hermatypic corals of Shark Bay	Bernier and Done Islands	Inside South Passage	Outside South Passage	Turtle Bay	Louisa Bay/Egg Island	Sunday Island	Cape Peron/Herald Bight	Freycinet Reach
Family Pocilloporidae								
Pocillopora damicornis (Linnaeus 1758)	+	+	V	V	-	-	V	2
P. verrucosa (Ellis & Solander, 1786)	-	÷	+			-		_
P. evdouxi Edwards & Haime, 1860	20	-	+	20	2	_	-	2
Stylophora pistillata (Esper, 1797)	+	+	-		-	-	+	-
Family Acroporidae								
Montipora monasteriata (Forskal 1775)	+	-	-	-	-	-	-	-
M. tuberculosa (Lamarck, 1816)	+	-	-	-		-	-	-
M. mollis Bernard, 1897	+	2	-	2	<u> </u>	1	-	1
M peltiformis Bernard, 1897	+	-	+	-	-	-	-	-
M. turgescens Bernard, 1897	+	+	+	-	-	-	-	-
M. capricornis Veron, 1985	+	-	-	-	-	-	-	4
M. spongodes Bernard, 1897	+	-	-	-	-	-	-	-
M. spumosa (Lamarck, 1816)	+		-	-	_	-	-	-
M. foveolata (Dana, 1846)	-	-	+	-	-	-	-	-
M. angulata (Lamarck, 1816)	+	\simeq	-	_	12	-	-	-
M. hispida (Dana, 1846)	+	+	+	-		-	-	-
M. aequituberculata Bernard, 1897	+	-	-		-		-	-
M. spp.	-	-	-	V	-	-	-	-
Acropora digitifera (Dana, 1846)	+	+	-	-		-	-	-
A. verweyi Veron & Wallace, 1984	<u></u>	+	+	2	<u></u>	322	20	<u></u>
A. robusta (Dana, 1846)	+	+	+	-	-		-	-
A. bushyensis Veron & Wallace, 1984	-	-	+	-	-	-	-	-
A. aspera (Dana, 1846)	+	-	+	-	÷	-	-	-
A. pulchra (Brook, 1891)	-	+	+	-	-	-	-	-
A. millepora (Ehrenberg, 1834)	÷	+	+	-	-	-	-	4
A. hyacinthus (Dana, 1846)	+	-	-	-	-	-	-	-
A. spicifera (Dana, 1846)	-	-	+	шī.	20	-	-	-

Hermatypic corals of Shark Bay	Bernier and Dorre Islands	Inside South Passage	Outside South Passage	Turtle Bay	Louisa Bay/Egg Island	Sunday Island	Cape Peron/Herald Bight	Freycinet Reach
A. latistella (Brook, 1892)	+	-		-	-	-	-	-
A. valida (Dana, 1846)	-	-	+	1725	-	4	12	-
A. solitaryensis Veron & Wallace, 1984	+	-	=	-	$\sim - 1$	-	-	-
A. florida (Dana, 1846)	+	+	+	-	-	-	-	-
A. spp.	-	-	-	V	+	-	-	-
Family Poritidae								
Porites lobata Dana, 1846	-	+	+	\sim	-	20	2	-
P. lutea Edwards & Haime, 1860		+	÷	577	-	-	1	-
P. sp.	+	\sim	\simeq	-	-	+	-	-
Goniopora lobata Edwards & Haime, 1860		+	± 1	-	(-)	-	-	+
G. tenudens Quelch, 1886	-	+	-	-	-	-	-	\overline{a}
G. stuchouryi wells, 1955	-	+	-	-	-	-	-	-
Alveopora allingi Hoffmeister 1995	+	ī	27 	1		20 A		
A. spongiosa Dana, 1846		+	_	-	_	_	-	-
A. tizardi Bassett-Smith, 1890	1	_	+	22	1	2	2	- 2
A. sp.	+	-	-	-	-	-		-
Family Siderastreidae								
Psammocora contigua (Esper 1797)	4	+	-	_	\mathbf{V}	÷		-
P. superficialis Gardiner, 1898		-	-		-		+	122
Coscinaraea columna (Dana, 1846)	-	-	+	$\overline{c} \overline{c} $	-		-	-
Family Agariciidae								
Pariona explanulata (Lamarch: 1816)	. <u>v</u>							
P minuta Wells 1954	+	+	v	- 31	2	-	- 24	
Leptoseris mycetoseroides Wells, 1954	4. H	+	+	-	-			12
Family Fungiidae								
Chalosenis andolites (Longards, 1901)					- 1			
Diaseris fragilis Alcock 1893	*	+	-		+	_	+	1
Dilisens Jugais Meock, 1855		-	-	50		-		1.30
Family Pectiniidae								
Echinophyllia aspera (Ellis & Solander, 1786)	+	+	-	-	-	-	-	100
E. orpheensis Veron & Pichon, 1980	+	-	-	-	-	177	-	-
Oxypora lacera (Verrill, 1804)	-	-	+	-	-	-	-	-
Family Mussidae								
Acanthastrea echinata (Dana, 1846)	+	-	-	-	-	-	123	-
A. hillae Wells, 1955	+	+	-	-	\sim	-	-	-
Symphyllia wilsoni Veron, 1985	+	+	+	<u></u>		+	-	-

Hermatypic corals of Shark Bay	Bernier and Done Islands	Inside South Passage	Outside South Passage	Tintle Bay	Louisa Bay/Fgg Island	Sunday Island	Cape Peron/Herald Bight	Frevcinet Reach
Family Merulinidae								
Hydnophora exesa (Pallas, 1766)	+	-	-	-	-	+	-	-
Emily Envidae								
Farria (arms (Fourland, 1775)	211							
Fania six		- 24				-	-	-
Faultes abdita (Fllis & Solander, 1786)	+	- 20	2	121	v	12	100	1
F. chinensis (Verrill, 1866)	+	-	_	-		_	_	_
F. pentagona (Esper. 1794)	+	+	+	-	23	+	-	+
F. russelli (Wells, 1954)	+	-	2	-	-	÷.	-	
Goniastrea edwardsi Chevalier, 1971	+	21	$\overline{\omega}$	-	4	-	-	-
G. favidus (Dana, 1846)	+	-	Ξ.	-	-	-	-	-
G. aspera Verrill, 1865	+	+	V	-	ŀ	+	÷	+
G. pectinata (Ehrenberg, 1834)	+	-	V	-	-	-	-	-
G. australensis (Edwards & Haime, 1857)	+	+	+	V	-	-		
Platygyra daedalea (Ellis & Solander, 1786)	-	-	+	-	<u> 1</u> 7	-	-	2
P. lamellina (Ehrenberg, 1834)		+	-	-	-	-	-	-
P. pini Chevalier, 1975	+	-	-	-	-	17	\overline{a}	-
Montastrea curta (Dana, 1846)	+	+	T.	-	V	+	-	-
M. magnistellata Chevalier, 1971	+	7	1	-	-	17	-	
M. valenciennesi (Edwards & Haime, 1848)	+	+	+	-	-		-	- 2
Plesiastrea versipora (Lamarck, 1816)	(†) 	+	+	-	-	+	-	+
Cyphastrea seranta (Porskal, 1775)	Ť	T	÷	-	-	+	V	+
<i>Movalava latistellata</i> Oveleb 1884	т 4	+	v	-	-	+ V	-	-
Moseleya lansienara Queen, 1864	1		x		70	v		æ
Family Dendrophylludae			-					
Turbinaria peltata (Esper, 1794)	+	+	V	-	+	+	V	+
T. frondens (Dana, 1846)	+	+	+	+	+	+		+
T. mesenterina (Lamarck, 1816)	-	+	-		+	+	V	+
T. Lefterman Definition (Bermand, 1890)	-	-	7	+	-	N.	-	+
T. ouron's Bruggemann, 1877 T. constring Permand, 1806	+		*	-	+	V	+	4
T conspicut definite, 1690 T co. 1	355 623	т. 4	-	20 5 5	1990	-	20 1 0 (2017	9 6 32
Duncanopsammia axifuga (Edwards & Haime, 1848)	-	+	+	-	-	1	-	3
Species	55	42	38	7	10	15	8	14
operes			132376	18	286	1880		2

Hermatypic corals

L.M. Marsh

Dirk Hartog Island (25°29'S, 112°58'E to 26°10'S, 113°13'E) is the largest of the three islands, 76 km long by 12 km wide at its widest point. The exposed western side is cliffed for its entire length, while the eastern side tends to be lower and is sheltered from the ocean swell.

Localities on the north, east, south and south-west sides of Dirk Hartog island were sampled for corals.

At Turtle Bay, 1 km east of Cape Inscription, a dissected limestone reef at 3-6 m was algal covered with scattered corals. Seven species of six genera were recorded (Table 1).

Several sites on the east coast of Dirk Hartog Island were searched for corals: A point at the south end of Louisa Bay; near Egg Island; c. 10 km south of Homestead Point and Sunday Island. At all these localities the coral fauna was depauperate and dominated by *Turbinaria* species. At Louisa Bay and Egg Island Bay nine species of six genera were found but around Sunday Island the coral fauna was richer with 15 species of 11 genera (Table 1). In Egg Island Bay and at Sunday Island *Turbinaria* spp. particularly yellow and green colonies of *T. mesenterina* formed dense stands reminiscent of Saville-Kent's (1897) description of stands of *T. conspicua* at Egg Island as resembling "subaqueous plantations of Brobdingnagian, crinkle-leaved, savoy cabbages". Curiously no specimens of *T. conspicua* were found in Egg Island Bay in 1979. It is possible that Saville-Kent confused the two species in the field.

One colony of *Acropora* sp was found in Louisa Bay but only fragments of dead staghorn *Acropora* at Egg Island Bay and in the bay north of Homestead Point.

The South Passage Area

At the south end of Dirk Hartog Island the coral diversity increases from Cape Ransonnet to Surf Point and changes from a *Turbinaria* dominated community to a more diverse one including *Acropora* spp. Between Cape Ransonnet and Surf Point an area of dead *Acropora* reef was found in 1979, some in situ but mostly staghorn *Acropora* rubble with no living *Acropora* species.

On the eastern side of Surf Point a moderately sheltered rock and rubble bottom at 2-3 m supports a fairly diverse coral fauna including six species of *Acropora*. *A. robusta* and *A. digitifera* formed very large colonies and *Pocillopora damicornis* was abundant in this area.

In contrast the southern shore, inside South Passage, is predominantly sandy with algal covered rock substrate offshore and very few corals. Dirk Hartog Island is linked to Steep Point by a limestone ridge, the outer bar, which rises to about six metres from the surface, and breaks heavily except in very calm weather. The reef top slopes seawards to 10-11 m then drops vertically to c. 18 m or is undercut by caves. The reef top is algal covered with scattered low-growing colonies of *Acropora*, *Montipora*, *Pocillopora* and faviids. The outer wall is covered mainly with alcyonaceans, sponges and ascidians with the ahermatypic

Hermatypic corals

corals *Tubastrea* spp under ledges. In places species of *Favia*, *Favites*, *Montipora* and *Oxypora* occur on the wall but more corals occur on boulders and as coral bommies on a gently sloping bottom at c. 20 m. In this area *Coscinaraea columna* forms large colonies and the coral fauna includes *Turbinaria*, *Goniastrea*, *Favia*, *Favites*, *Porites*, *Alveopora*, *Pavona*, *Moseleya*, *Duncanopsammia* and other genera.

On the south side of South Passage a reef connecting Monkey Rock to the mainland was examined. It slopes seaward and has scattered corals on the deeper part at c. 5 m. On the slope at c. 3 m there was 10-30% cover of living coral, predominantly *Montipora* spp with scattered colonies of *Acropora* spp, *Pocillopora damicornis, P. vertucosa* and *P. eydouxi*, a few species of Faviidae and no Turbinarias.

Two other seaward sites were examined: north of Surf Point (Dirk Hartog Island) at 10-12 m the bottom was gently sloping algal covered rock with sparse corals, mainly *Montipora* and *Acropora* spp; off the north east side of Steep Point a narrow intertidal platform drops vertically to c. 9 m then slopes to sand at 18 m. Rock towers c. 6 m diameter, rise from c. 15 m to 6-9 m from the surface. The sides are covered by sponges, ascidians, alcyonaceans and *Tubastrea* spp. No hermatypic corals were found on the towers but scattered colonies of *Turbinaria, Acropora, Montipora, Alveopora, Goniastrea, Favites* and *Moseleya* were found on the rock slope near their bases.

From these observations it seems unlikely that extensive coral areas occur on the seaward sides of Bernier, Dorre or Dirk Hartog Islands, all of which are subjected to heavy wave action on their western coasts.

A total of 53 species of 26 genera were found in the South Passage area, combining records from sheltered and exposed waters.

In Freycinet Reach islets off Eagle Bluff have a very depauperate coral fauna on rocks rising from silty sand. An isolated patch of corals yielded *Cyphastrea serailia*, *Goniastrea aspera*, *Favites pentagona*, *Favia* sp. *Goniopora lobata* and *Turbinaria* spp. No corals were found further south in Freycinet Reach.

Off Cape Heirisson on a silty sand and shell rubble bottom at 16.5 m, among sponges and gorgonians, colonies of *Turbinaria peltata* and *T. frondens* were common with a few colonies of *Favia* and *Moseleya*.

Cape Peron North

There is little suitable habitat for corals at the cape. The bottom is predominantly sand with some rock substrate at c. 2 m.

A few small Turbinaria spp and small faviids were the only corals found.

Herald Bight

This large bay on the east side of Cape Peron North has a silty sand bottom with scattered rocks and coral at 5-6 m. The water was turbid and many of the coralla were dead or partly dead. Three species of *Turbinaria* (Table 1) were

the most abundant corals, particularly *T. bifrons*. No corals were found further south off Faure Island or in Hamelin Pool.

Corals of soft substrates

The solitary fungiid *Cycloseris cyclolites* has been dredged from many parts of Shark Bay except in metahaline and hypersaline areas but no *Fungia* spp have been found. *Diaseris fragilis*, from Freycinet Reach, is the only other fungiid recorded.

Cyphastrea spp form free living coralliths, often with a hollow centre inhabited by a Xanthid crab. These are occasionally found on soft substrates both in coral areas and in deeper water away from other corals e.g. at a depth of 11 m, east of Castle Pt., Dorre I., where several examples were found. Lamberts and Garth (1977) reported Xanthid commensalism with corals of seven genera, this observation adds an eighth.

Turbinaria spp often attach to small fragments of rubble or shell on soft substrates and are tolerant of silty areas such as Freycinet Reach.

The coral fauna

Overall the known hermatypic coral fauna of Shark Bay numbers 80 species of 28 genera. This is an impoverished fauna compared with the Ningaloo Reefs to the north (21°47′S to 23°38′S) where 217 species of 54 genera are recorded or the Houtman Abrolhos to the south (28°16′S to 29°S) with 184 species of 42 genera (Veron and Marsh 1988).

From Table 1 the pattern of distribution of coral species in the bay is evident. *Turbinaria* is the most widespread genus in the areas sampled but the presence or absence data does not indicate the dominance of this genus at all the sheltered localities whereas at the seaward sites it becomes a small component of the fauna. *Montipora, Acropora* and *Pocillopora* species dominate the fauna of the seaward sites. *Goniastrea aspera* is one of the most common and widely distributed species in Shark Bay, found in almost all the habitats sampled. The temperate Western Australian endemic species, *Symphyllia wilsoni*, reaches the northern limit of its distribution in Shark Bay.

Figure 1 shows the presence or absence of corals at the localities sampled. The distribution of corals closely follows the zone of oceanic salinity, impinging on the metahaline zone in Freycinet Reach.

Discussion

While the list of corals from Shark Bay is probably not yet complete, sufficient is known to comment on the distribution patterns. The limits of coral distribution

Hermatypic corals

in Shark Bay, although coinciding fairly closely with the boundary between water of oceanic salinity and metahaline water and with the winter temperature minimum of 18-19°C (although data is lacking for some of the localities) may be affected indirectly as well as directly by these factors.

Kinsman (1964) found 11 species of 11 genera of corals living in waters with an extreme temperature range and high salinity in the southern Persian Gulf. Temperatures varied seasonally from 16° to >40°C at the surface and from 20° to 36°C below 4-5 metres depth. Salinities ranged from 42 to 45‰ with 48‰ in lagoons where large *Porites* colonies occur. Kinsman found that *Porites* could not survive salinity >48‰ while *Acropora*, *Platygyra*, *Cyphastrea*, *Stylophora*, *Favia* and *Turbinaria* could not tolerate salinities much in excess of 45‰. These salinities correspond with the metahaline waters of Shark Bay.

It is generally accepted that reef corals flourish best in the temperature range 25° to 29°C and that reefs are not usually formed where the scasonal minimum falls below 19°C although many species can withstand minimum temperatures of 16° to 17°C for short periods and a maximum of 36°C (Kinsman 1964).

The initiation of the Leeuwin Current coincides approximately with the mass spawning of hermatypic corals on the Western Australian coast and is believed to be a major factor in the distribution of corals and the maintenance of coral communities on the west coast (Simpson 1985). The slight impingement of the Leeuwin Current on Shark Bay, shown by Legeckis and Cresswell (1981, figure 1) coincides with the main areas occupied by coral communities in the bay.

The question of whether hermatypic corals need to feed heterotrophically or whether they can obtain sufficient nutrients from products translocated from zooxanthellae has been debated for some years. From experimental evidence Gladfelter (1985) concluded that where light is not limiting products translocated from zooxanthellae might be sufficient to fuel a reef coral's daily metabolic expenditure but where light limits productivity heterotrophic sources of energy are required even to fulfil maintenance respiratory needs. In all environments it appears that a source of nutrition other than translocated products from zooxanthellae is required to sustain growth (i.e. net synthesis of new tissue).

Kimmerer *et al.* (1985) have shown that there is a seven fold increase in zooplankton from the ocean to the central part of Shark Bay, then a decrease of four orders of magnitude into the hypersaline basins, possibly due to nutrient limitation in the hypersaline waters. Thus the lack of zooplankton as well as effects of salinity, temperature and turbidity may restrict the distribution of corals in the high salinity parts of Shark Bay. The lack of nutrients may also affect corals directly since they are capable of taking up phosphorus ions, ammonia and dissolved organic nitrogen from the environment (Muscatine 1973). Nutrient limitation may also affect the coral's zooxanthellae. Yellowlees and Miller (in press) suggest, from experimental data, that phosphorus rather than nitrogen limitation seems more likely as a regulatory factor in the symbiotic association between corals and zooxanthellae. Smith and Atkinson (1984) report that Shark

Bay is a P - limited ecosystem with a slow exchange of materials with the ocean and residence time of water exceeding 1 yr.

Hermatypic corals in Shark Bay are further limited by the lack of hard substrate in may parts of the bay and by the limited water movement in the enclosed basins.

Taking all these factors into account it is not surprising that the distribution of corals in Shark Bay is confined to the areas of oceanic salinity where there is adequate water movement to bring zooplankton and adequate light for photosynthesis. Further ecological research may define more precisely the physical factors controlling coral distribution in Shark Bay.

Acknowledgements

Without the help of many people the survey of the marine invertebrate fauna of Shark Bay, (of which the coral fauna was one segment) could never have taken place.

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The bivalves of Shark Bay, Western Australia

Shirley M. Slack-Smith*

Abstract

Two hundred and eighteen species of bivalves are recorded from Shark Bay and offshore waters. The patterns of their geographic distribution are discussed with reference to the biogeography of the Western Australian marine molluscan fauna as influenced by latitude and the longshore current systems. The spatial distributions of these bivalves within the Shark Bay area are given and are related primarily to the salinity regime of this negative estuary.

Résumé

Deux cent dix-huit espèces de bivalves vivant dans la Baie des Chiens Marins et près des côtes sont répertoriées. Les modèles de leur répartition géographique sont examinés en ce qui concerne la biogéographie de la faune de mollusques marins d'Australie-Occidentale tels qu'ils sont influencés par la latitude et les systèmes des courants littoraux. Les répartitions spatiales de ces bivalves dans la région de la Baie des Chiens Marins sont données et mises en relations essentiellement avec le régime de salinité de cet estuaire négatif.

Introduction

Shark Bay is a large marine embayment of almost 13,000 km² lying between the latitudes of 24°30'S and 26°45'S, and the longitudes of 113°E and 114°20'E on the semi-arid central western coast of Australia.

The physiography of the area and the bottom topography of the Bay have been well described by Logan (1959), Davies (1970), Hagan (1970), Logan and Cebulski (1970) and Hagan and Logan (1974a, b). These authors discussed the effects which various factors (e.g. high evaporation rate, low freshwater input, vigorous mixing through the water column and the restricted tidal flow with its anti-clockwise circulation pattern) have in producing the distinctive salinity regime described as a negative estuary.

Logan and Cebulski (1970) found that there is no general horizontal salinocline but that there is a series of vertical water layers of different salinities. These layers form a relatively stable salinocline over the shallow Faure Sill and a less stable salinocline running north from the Fork Flat Sill. The presence of these salinoclines enabled these authors to define areas of oceanic (35-40%), metahaline (40 to about 56%) and hypersaline water masses as in Figure 1. The exact positions of the boundaries between these water bodies shift with changes in the external physical environment.

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Figure 1: Map of Shark Bay, Western Australia, showing distribution of oceanic (salinity 35 to 40%), metahaline (salinity 40 to about 56%) and hypersaline water masses and the Cape Peron and Faure Sill salinoclines (after Logan and Cebulski 1970).

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Interest in the molluscan fauna of Shark Bay has been maintained since Dampier's visit in 1699. He commented on the abundance and diversity of the drift shells and on the "Muscles, Periwinkles, Limpits, Oysters, both of the Pearlkind and also Eating-Oysters, as well as the common Sort as long Oysters; beside Cockles, etc." (Dampier 1729). Some of the bivalve and other molluscan specimens collected in Shark Bay by Péron and fellow-members of the Baudin Expedition in 1801 and 1803, and by Quoy & Gaimard during the Freycinet Expedition some fifteen years later, served as the bases of descriptions of a number of new bivalve species (Péron 1807, Ouov & Gaimard 1824, Lamarck 1818, 1819 and Deshayes 1835, 1836). The German expedition of the "Gazelle" in 1875 yielded a bivalve collection reported upon by von Martens (1889). Hedley (1916) listed 217 species of bivalves from Western Australia which were represented in the collections of the Australian Museum and/or which had been recorded in the scientific literature to that time. He specified that 24 of these occurred in Shark Bay, which is the type locality for more than half of them. A report on collections made during the Hamburg Museum expedition of 1905 was published by Thiele (1930). It listed 37 bivalve species from Shark Bay, 33 of which had not been recorded from Shark Bay in Hedley's list. These included 6 new species.

Early visitors to the Bay were particularly interested in those groups of bivalves of value as food or for commerce. This interest was pursued by Saville-Kent (1897) who investigated the potential of the pearl-shell and natural pearl fishery and commented upon the oysters of Shark Bay. At present, the farming of pearlshell for the culture of pearls, the farming of rock oysters and the trawling of saucer scallops are important commercial bivalve fisheries there.

This account of the major components of the Shark Bay bivalve fauna is principally based upon the collections of the Western Australian Museum. Most records are derived from field work carried out in 1980 and 1981. This was accomplished with considerable assistance from the Western Australian Department of Fisheries (then the Department of Fisheries and Wildlife). These surveys included trawling and dredging as well as SCUBA-diving operations, and covered approximately 110 stations throughout the Bay. The results of those surveys are supplemented by records based upon other collections made by staff of the Western Australian Museum, the University of Western Australia and the Western Australian Department of Fisheries, and by private collectors. Where possible these records are correlated with those published by previous workers.

The species recorded in Table 1 are accompanied by data on their distributions within Shark Bay. The Bay has been divided into areas which correspond approximately to the distribution of water masses as described by Logan and Cebulski (1970). In each area intertidal, shallow and deep sublittoral rock and soft substrates, both bare and seagrass-covered, have been sampled. This record is, of necessity, a summation over time and does not reflect changes in distribution which might have occurred during the period of collecting (i.e. about 1950 to the present). Records from dead shells have been included and have been noted

Bivalves

as such only when they constitute the sole record in the most saline zone for that species' range. However some such records might represent collecting bias only, where dead shells have been collected in preference to living ones.

In addition Table 1 also indicates the geographic distributional ranges of the species included, if these are known. Such ranges are based upon the collections of the Western Australian Museum and of other Australian museums, as well as upon advice from private collectors and upon some literature records.

In general, minute species of bivalves have been omitted because of a lack of expertise in identifying them and because of their poor representation in collections.

Table 1.	Distribution of bivalves (a) within the Shark Bay salinity zones as defined by Logan and
	Cebulski (1970) and (b) along the coast of Western Australia. (See Appendix).
	An arrowhead indicates that a species' range extends beyond the borders of the State.

	Di	stribu Sh	ution ark I	with Say	iin		Ge Dis	ograj tribu	ohic tion	
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
NUCULIDAE Nucula pusilla Angas, 1877 N. superba Hedley, 1902	/ /*									->
NUCULANIDAE Nuculana verconis (Tate, 1891)	/*					<				
SOLEMYIDAE Solemya sp.		1	d							
ARCIDAE Anadara crebricostata (Reeve, 1844) A. kikaizimana (Nomura & Zinbo, 1934) A. vellicata (Reeve, 1844) Arca navicularis Bruguière, 1789 A. ventricosa Lamarck, 1819 Barbatia amygdalumtostum (Roeding,	 * 	 	/ d /				_			
1798) B. helblingii (Lamy, 1904) B. pistachia (Lamarck, 1819) Trisidos semitorta (Lamarck, 1819)		/	1			4	-			$\wedge \wedge \wedge \wedge$
NOETHDAE Arcopsis afra (Gmelin, 1791)	1	/	1				-		7	\rightarrow

	Di	istribu Sh	ution ark 1	with Bay	nin		Ge Dis	ograj tribu	ohic tion	
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
CUCULLAEIDAE Cucullaea labiata (Solander, 1786)	/*							510		\rightarrow
GLYCYMERIDIDAE Glycymeris ?broadfooti Iredale, 1929 G. dampierensis Matsukuma, 1984 G. persimilis Iredale, 1939 G. sordida (Tate, 1891) G. striatularis (Lamarck, 1819) G. sp.	d* d* / /	1					_			\rightarrow
MYTILIDAE Botula vagina (Lamarck, 1819) Brachidontes ustulatus (Lamarck, 1819) Lioberus sp. Modiolatus hanleyi Dunker, 1882 Modiolus auriculatus Krauss, 1848 M. philippinarum (Hanley, 1843) Musculista glaberrima (Dunker, 1857) Musculus nanulus Thiele, 1930 Ryenella cumingiana (Dunker, 1857) Septifer bilocularis (Linné, 1758) Stavelia horrida Dunker, 1857		/ ? / d //	/ / d / d /	/ / d	?	4				****
PINNIDAE Atrina pectinata (Linné, 1767) P. bicolor Gmelin, 1791 Streptopinna saccata (Linné, 1758)	1	1	d d			4 4				$\uparrow \uparrow \uparrow$
PTERIIDAE Pinctada albina (Lamarck, 1819) P. fucata (Gould, 1851) P. maculata (Gould, 1851) P. margaritifera (Linné, 1758) Pteria lata (Gray, 1845) P. penguin (Roeding, 1798)		111	1	7 7			1.1.1.1			<u> </u>
ISOGNOMONIDAE Crenatula modiolaris Lamarck, 1819 Isognomon legumen (Gmelin, 1791)	1					4	-			\rightarrow

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	Distribution within Shark Bay						Geographic Distribution				
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific	
MALLEIDAE Malleus albus Lamarck, 1819 M. meridianus Cotton, 1930 Vulsella vulsella (Linné, 1758)	1 1 1	1.1.1	/			44				\rightarrow \rightarrow	
PECTINIDAE Annachlamys leopardus (Reeve, 1853) Chlamys australis (Sowerby, 1842) C. scabricostata (Sowerby, 1915) C. squamosa (Gmclin, 1791) Decatopecten strangei (Reeve, 1852) Pecten modestus Reeve, 1852 Semipallium luculentum (Reeve, 1853)	アナノフィー	1?/	1 1 1/1	?		¢				$\uparrow \uparrow \uparrow \uparrow \uparrow$	
AMUSHDAE Amusium balloti (Bernardi, 1861)	1	2	Ł				_			\rightarrow	
PLICATULIDAE Plicatula australis (Lamarck, 1819)	1	1	1				_			\rightarrow	
SPONDYLIDAE Spondylus barbatus Reeve, 1856 S. squamosus Schreibers, 1793	1							_		$\uparrow \uparrow$	
DIMYIDAE Dimya sp.	/*						۰ <u></u>			?	
ANOMIIDAE. Monia sp.	1						-	_		\rightarrow	
LIMIDAE Lima lima (Linné, 1758) L. nimbifer Iredale, 1924 Stabilima tadena Iredale, 1939	111					<		7		$\uparrow \uparrow \uparrow$	
OSTREIDAE Dendostrea folium (Linné, 1758) Ostrea tuberculata Lamarck, 1804 O. ?virescens Angas, 1868 Saccotsea ?commercialis (Loudeda % Parachter	 	/ /	111			4				$\uparrow\uparrow$	
1933) S. cuccullata (Born, 1778)	1	1	1				_	-	\rightarrow	\rightarrow	

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	Di	istribu Sh	ution ark I	with Bay	iin		Ge Dis	ograj stribu	phic ition	
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
GRYPHAEIDAE Hyotissa hyotis (Linné, 1758)	/						_			\rightarrow
TRIGONIIDAE Neotrigonia uniophora (Gray, 1847)	1						_		\rightarrow	1
LUCINIDAE Anodontia pila (Reeve, 1850) A. sp. aff. A. omissa (Iredale, 1930) Bellucina pisiformis (Thiele, 1930) B. ?semperiana (Issel, 1869) Callucina lacteola (Tate, 1897) Codakia punctata (Linné, 1758) Ctena bella (Conrad, 1837) C. ?transversa Dall, Bartsch & Rehder,1938 Divalinga sp. Divaricella ornata (Reeve, 1850) Epicodakia sp. Wallucina sp. aff. W. jacksoniensis (Smith, 1885)		/ d / / d d / / /	/ d //////////////////////////////////	d / d //	d d	¢				ት ትት ትላት
Felaniella sp. Numella ?conspicua (Smith, 1885)	/	1	/ d	d				•		\rightarrow
CHAMIDAE Chama fibula Reeve, 1846 C. iostoma Conrad, 1837 C. lazarus Linné, 1758 C. pacifica Broderip, 1835 C. pulchella Reeve, 1846 C. ruderalis Lamarck, 1819 Pseudochama sp.	///////////////////////////////////////	1	1	///		¢	1 1 1 1			$\uparrow \uparrow \uparrow \uparrow$
ERYCINIDAE Lasaea sp. aff. L. australis (Lamarck, 1818)	1	1	1							
KELLIIDAE gen. and sp. undet.		1								
LEPTONIDAE Mysella sp.			1							

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	Di	stribu Sh	ition ark I	with Bay	nin		Geo	ograj tribu	ohic tion	
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
CARDITIDAE Cardita aviculina Lamarck, 1819 C. crassicosta Lamarck, 1819 Megacardita incrassata (Sowerby, 1825) "M." ?quoyi (Deshayes, 1852) M. turgida (Lamarck, 1819) Pleuromeris sp.	1/1/1	1	1	1		4				$\uparrow \uparrow \uparrow$
CRASSATELLIDAE Eucrassatella pulchra (Reeve, 1842)	1	1					3			
CARDHDAF Acrosterigma marielae Wilson & Stevenson, 1977 A. reeveanum (Dunker, 1852) A. rosemariensis Wilson & Stevenson, 1977 A. vlamingi Wilson & Stevenson, 1977 Ctenocardia perornata Iredale, 1929 Fragum erugatum (Tate, 1889) F. hemicardium (Linné, 1758) F. retusum (Linné, 1757) F. unedo (Linné, 1758) Fulvia aperta (Bruguière, 1789) Nemocardium bechei (Reeve, 1840) N. thetidis (Hedley, 1902)	/////////////	1 111111	/ d / d / d / d	1 1 1	1	¢				$\uparrow \uparrow $
TRIDACNIDAE Tridacna maxima (Roeding, 1798)	1	1					-			\rightarrow
MACTRIDAE Lutraria rhynchaena Jonas, 1844 Mactra cuvieri Deshayes, 1853 M. incarnata Reeve, 1854 M. ovalina Lamarck, 1818 M. ?pura Deshayes, 1853 M. sericea Deshayes, 1854		 	d / /	1						\rightarrow \rightarrow
MESODESMATIDAE Atactodea striata (Linné, 1767) Paphies (Amesodesma) elongatum (Reeve, 1854)	1	1	1	1					\rightarrow	\rightarrow

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	Di	istribu Sh	ution ark 1	with Bay	uin		Ge Dis	ograj stribu	phic tion	
	Occanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
CULTELLIDAE Phaxas cultellus (Linné, 1758)	1	1	d							\rightarrow
 TELLINIDAE Apolymetis spectabilis (Hanley, 1844) Arcopagia elegantissima (Smith, 1885) Exotica obliquilineata (Conrad, 1837) E. clathrata (Deshayes, 1835) E. triradiata (H. Adams, 1876) Macoma dispar (Conrad, 1837) M. hemicilla (Iredale, 1936) Phylloda foliacea (Linné, 1758) Quadrans parvitas Iredale, 1931) Tellina (Cadella) semitorta Sowerby, 1866 T (Merisca) ?ostracea Lamarck, 1818 T. (Pharaonella) perna Spengler, 1798 T. (Pharaonella) perna Spengler, 1798 T. (Pinguitellina) ? murrayi Smith, 1885 T. (P.) robusta Hanley, 1844 T. (Semelangulus) tenuilirata Sowerby, 1868 T. (Snithsonella) pulcherrima Sowerby, 1825 T. (S.) verrucosa Hanley, 1844 T. (Tellinangulus) sp. T. (Tellinella) staurella Lamarck, 1818 T. (T.) virgata Linné, 1758 T. (Tellinides) cockburnensis Brearley & Kendrick, 1984 			/ d d / d d d / / d d d / d d d / d	d d	,					ትትትትትት ት ትትትትትት ትት ትት
DONACIDAE Donax columbella Lamarck, 1818 D. faba Gmelin, 1791	1					<				\rightarrow
PSAMMOBIIDAE Asaphis violacens (Forskal, 1775) Gari amethystus (Wood,1815) G. anomala (Deshayes, 1855) G. maculosa (Lamarck, 1818) G. occidens (Gmelin, 1791) G. pulcherrima (Deshayes, 1854) G. rasilis Melvill & Standen, 1899	111111	////	///////////////////////////////////////	d				11111		$^{^{^{^{^{^}}}}}$

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	Di	stribu Sh	ution ark 1	with Bay	nin		Ge Dis	ograj tribu	phic tion	
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
Sanguinolaria sp. Soletellina sp.	1	1	1	d			2	•		→
SEMELIDAE Leptomya psittacus (Hanley, 1883) Semele exarata (Adams & Reeve, 1850) S. jukesii Adams, 1853	1	1	 	d			-	+		$\uparrow \uparrow \uparrow$
SOLECURTIDAE Azorinus sp. Solecurtus divaricatus (Lischke, 1869) S. sulcatus (Dunker, 1862)	111	 	d ∕ d						→	\rightarrow
TRAPEZIIDAE Trapezium bicarinatum (Schumacher, 1817)	1								_	\rightarrow
VENERIDAE Anomalocardia squamosa (Linné, 1758) Bassina disjecta (Perry, 1811) Callista impar (Lamarck, 1818) Chioneryx sp. Circe lenticularis Deshayes, 1853 C. scripta (Linné, 1758) C. sulcata Gray, 1838 Clementia papyracea (Gray, 1825) Costacallista planatella (Lamarck, 1818) Dosinia biscocta (Reeve, 1850) D. deshayesii A. Adams, 1856]]]]]]]]]]]	1 1 1 1 1 1 1	1 1111111	1 1 1 1 1 1	d	¢			 →	$ \begin{array}{c} \\ \\ \\ \\ \\ \\ \\ \end{array} \end{array} $
D. incisa (Reeve, 1850) D. lucinalis (Lamarck, 1818) D. sculpta (Hanley, 1845) Gafrarium intermedium (Reeve, 1863) Glycydonta ?costellifera (Adams & Reeve, 1850) G. ?recognita (Smith, 1885) Gomphina undulosa (Lamarck, 1818) Irus sp. aff. I. irus (Linné, 1758) Katelysia hiantina (Lamarck, 1818) Marcia induta (Hedley, 1906) Paphia crassisulca (Lamarck, 1818) Delicitette (Section 1012)	1 1/1/1/1		/ / / / /	d / / /	/ d /	4 4			· ↑ ↑ ↑	

Bivalves

	Distribution within Shark Bay					Geographic Distribution				
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Australia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
P. reticulata (Linné, 1758) Pitar affinis (Gmelin, 1791) P. citrina (Lamarck, 1818) P. ?pellucida (Lamarck, 1818) P. ?porrecta (Roemer, 1867) Placamen berrii (Gray, 1828) P. ?foliacea (Philippi, 1846) P. gravescens (Menke, 1843) Sunetta aliciae A. Adams & Angas, 1863 S. contempta Smith, 1891 Tapes literatus (Linné, 1758) T. deshayesii (Hanley, 1844) T. dorsatus (Lamarck, 1818) Tawera coelata (Menke, 1843) T. subnodulosa (Hanley, 1845) Ventricolaria embrithes (Melvill & Standen, 1889) V. toreuma (Gould, 1851) Venus chemnitzii (Hanley, 1845) V. lamellaris (Schumacher, 1817)		1 1 1 1 1 1 1 1 1 1 1 1		//////////////////////////////////////						$\mathbf{r} \mid \wedge $
PETRICOLIDAE Mysia sp.	1	1	1	u			1			~
CORBULIDAE Corbula monilis Hinds, 1843 C. stolata (Iredale, 1930) C. scaphoides Hinds, 1843	1 1 1	111	/ d d			¢		-		$\uparrow \uparrow \uparrow$
GASTROCHAENIDAE Gastrochaena cuneiformis (Spengler, 1783) G. pupina Deshayes, 1854	1	1	7					-		$\uparrow \uparrow$
HIATELLIDAE Hiatella sp.	1	/	d				<		?	
PANDORIDAE Pandora (Frenamya) sp.		/								
CLEIDOTHAERIDAE Cleidothaerus albidus (Lamarck, 1819)	1	1				<				

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	Distribution within Shark Bay				Geographic Distribution					
	Oceanic	Cape Peron Salinocline	Metahaline	Faure Salinocline	Hypersaline	Southern Ausualia	South-western Australia	Shark Bay	North-western Australia	Indo-West Pacific
LATERNULIDAE Laternula ?anatina Roeding, 1798	7	1	1	1						>
MYOCHAMIDAF. Myochama anomioides Stuchbury, 1830 Myadora ?complexa Iredale, 1924	1	Z	J.	1		<				\rightarrow
THRACHDAE Thracia alciope Angas, 1872	Ľ	7	F	7				-		
CLAVAGELLIDAE Brechites novaezelandiae (Bruguière, 1789)	ź						+			

Bivalves

Number of species in each zone

184* 134 129 53 9

Notes

 \dagger = excluding those found only in deep water off Shark Bay

/ = present (collected dead and/or alive)

d = present (collected dead only, in most hypersaline zone)

/* = present (collected dead and/or alive) only at stations west of Shark Bay

1 = geographic range to North-eastern Australian waters but not further north

2 = geographic range to northern Australia but not to Queensland or further north

Table 2. Geographic Ranges of Shark Bay Bivalves

		No of species*
Total	species recorded from Shark Bay area	218
Total (at	Shark Bay species with geographic range known least in part)	210
i,	Tropical range (a) Indo-West Pacific range (b) Northern Australian endemics	157 (74.8%) 147 (70.0%) 10 (4.8%)
ii	Southern Australian range	21 (10%)
iii	West coast endemics	32 (15.2%)

* figures in brackets () give total in each category expressed as a percentage of total of Shark Bay species with geographic range known (at least in part).

		No of species*
Tota	l	103 (49.0%)
i	Tropical species (Indo-West Pacific and northern Australian and endemic species)	72 (46.2%)
ii	Southern Australian species	12 (57.1%)
iii	West coast endemics	17 (53.1%)

Table 3. Bivalves with Distributional Range Limit at Shark Bay

* figures in brackets () give total in each category expressed as a percentage of the total of Shark Bay species with that geographic range (see Table 2).

Results

In Table 1, 218 species of bivalves are recorded from the Shark Bay area and their geographic ranges are indicated. Annotations on these species are given as an Appendix. A summary of their geographic ranges (where known) is given in Table 2. This illustrates the mixed nature of this fauna with tropical faunal elements (74.8%) dominating those of the west coast endemic (15.2%) and southern Australian (10%) faunas.

Table 3 summarises the significance of the Shark Bay area as a geographic limit for those bivalve species inhabiting the inshore waters of the central west coast of Australia. Of all species included in the survey for which geographic ranges are known, 49.0% reach their range limit in the Shark Bay area. Of the species belonging to the tropical Indo-West Pacific and/or northern Australian fauna 46.2% have been found no further south than Shark Bay, Of the few species representing the warm temperate Southern Australian fauna, 57.1% extend no further north. Of the species which appear to be endemic to the western coast of Australia, Shark Bay represents the geographic limit for 53.1% of them.

Table 1 also indicates the local distribution of bivalve species within the Shark Bay area. Of 218 species, 14 have been found there only in offshore waters (depth >30 m). Of the true Bay fauna of 204 species, 184 have been recorded from the area of the Oceanic Water Mass, 134 from the area of the Cape Peron Salinocline, 129 from the area of the Metahaline Water Mass, 53 from the area of the Faure Salinocline and 9 from the area of the Hypersaline Water Mass.

Discussion

The composition of the bivalve fauna of Shark Bay is, in part, related to the latitudinal location of the area. This was recognised by Péron (1816) who remarked upon the many tropical molluscan species found there. Wilson and Gillett (1971) and Wilson and Allen (1987) included the Bay within the Western Overlap Zone between the temperate and tropical marine faunas, rejecting the

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older concept of a north-west Dampierian Region. Wells (1980), in his analysis of the known distributional ranges of groups of better-known Western Australian gastropods, stated that 91% of those species recorded from Shark Bay are of tropical affinity. The bivalve fauna, as indicated in this study, differs in that only 74.6% of the Shark Bay species are tropical, though north-western Australian endemic species are not included in this figure.

The south-flowing Leeuwin Current (Cresswell and Golding 1980) is important in the temperature regulation of coastal waters of Western Australia. This current of low-salinity, tropical water flows close to the coast in the North West Cape-Shark Bay area from approximately 22°S (Legeckis and Cresswell 1981). Not only does this current modify the water temperature but it also serves to carry tropical marine organisms southwards, particularly during the winter months. In summer a cooler, more saline water mass moves northwards (Pearce 1985). The importance of the role of such a current system in the long-shore distribution of marine planktonic larvae can be reasonably inferred. In addition, scasonal and annual variation in the relative strengths of the system's components is presumably associated with temporal variation in the local abundance of those species with planktotrophic larvae. That significant longer term variation has occurred in the hydrological conditions of the Bay is indicated by Kendrick's study of the Pleistocene molluscan fauna of the Dampier Limestone of Shark Bay (Kendrick, this volume).

Though an examination of the bivalve fauna of the western Australian coastline is outside the scope of this paper, distributional patterns of the Shark Bay species indicate the significance of Shark Bay as an area of geographical limitation of both the tropical and the much smaller warm temperate elements of that fauna. Wells (1980) demonstrated that the Shark Bay area occupied only a subsidiary position as an area of major geographical limitation of the gastropod groups he examined.

As a habitat for bivalves, Shark Bay is of major significance on the western coast of Australia. Species diversity as well as the densities of many species are high. The abundance of bivalves in Shark Bay was remarked upon by Dampier (1729), by Péron (1816) and by later visitors. Recent work by Peterson and Black (1987, 1988) indicates the high densities of some species of venerids in their tidal-flat study areas. Pearl shells (*Pinctada albina*) and saucer scallops (*Amusium balloti*) in quantities sufficient to support commercial fisheries give further indications of the bivalve productivity of this area. That the dense though patchy aggregations of the cardiid *Fragum erugatum* in the southern areas of the Bay are of long standing is attested by the thick coquina beds which have been accumulating, particularly along its southeastern coast, since the Middle Holocene (van de Graaff, Hocking & Butcher 1983). The importance to this system of the extensive beds of sca grasses as a molluscan habitat has been demonstrated by Wells, Rose & Lange (1985). Smith & Atkinson (1983) showed that they are the most important source of primary production in Shark Bay.

The patterns of distribution of bivalves within Shark Bay show an apparent link with salinity gradients. Kimmerer, McKinnon, Atkinson & Kessell (1985) found that diversity of planktonic organisms in Shark Bay was related to salinity, as was the abundance of individual species. However the pattern of total abundance was apparently due to limitation of nutrients, particularly phosphorus, in the southern areas of the Bay (Smith & Atkinson 1984). Investigation of salinity tolerances and of other factors directly or indirectly related to nutrient supply is needed to elucidate their roles in governing the abundance and distribution of bivalves within Shark Bay.

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Appendix: Annotations on Shark Bay Bivalves

Nucula pusilla Infaunal in shallow sublittoral sand.

Nucula superba Off Shark Bay in depths to 80 m; sand.

Nuculana verconis Off Shark Bay in depths to 300 m; sand.

- Solemya sp. Similar to, but apparently distinct from, S. terraereginae Iredale, 1929 from North Queensland; infaunal in subtidal sea-grass beds; rare in collections.
- Anadara crebricostata Synonym Arca fultoni Sowerby, 1907 (S.E. Boyd pers. comm.); shallow sublittoral to about 30 m.
- Anadara kikaizimana Apparently conspecific with Japanese species; shallow subtidal to 30 m.
- Anadara vellicata Off Shark Bay in depths to 80 m.
- Arca navicularis First recorded from Shark Bay by Thiele (1930); sublittoral to 80 m on hard substrates.
- Arca ventricosa Synonym A. avellana Lamarck, 1819; W.A. coastal forms are relatively shorter than offshore forms; shallow, subtidal, hard substrates.
- Barbatia amygdalumtostum Synonym is Arca fusca Bruguière, 1798; intertidal to shallow sublittoral on hard substrates.
- Barbatia helblingii Common in intertidal and sublittoral reefs and flats, particularly in crevices. Synonym Arca decussata, Sowerby, 1833.
- Barbatia pistachia Shallow to deep sublittoral, hard substrates.
- Trisidos semitorta Apparently conspecific with specimens which Thiele (1930) recorded from Shark Bay as Arca (Trisidos) tortuosa (Linné, 1758), not otherwise recorded south of Exmouth Gulf; intertidal to subtidal sand and weed.
- Acropsis afra Collected on and under intertidal rocks in Shark Bay area.

Cucullaea labiata Off Shark Bay in sand to about 80 m.

- *Glycymeris ?broadfooti* The radial ribs of specimens from the Shark Bay area have sharper edges than those of specimens from further south; subtidal sand to 80 m.
- *Glycymeris dampierensis* Only small specimens taken rarely in deep water off Shark Bay, elsewhere larger specimens taken in shallow sublittoral sand.
- Glycymeris sordida Synonym is G. insignis Pilsbry, 1906; dredged in 10-150 m off W.A. coast.

Glycymeris persimilis In shallow sublittoral sand in Shark Bay.

- Glycymeris striatularis Abundant shallow sublittoral species, possibly conspecific with specimens recorded from Shark Bay by von Martens (1889) (*fide* Hedley, 1916) as *G. radians* (Lamarck, 1819), a similar but more southern species.
- *Glycymeris* sp. Apparently an undescribed west coast endemic which can be distinguished from generally sympatric *G. crebrelirata* (Sowerby, 1889), by its unpatterned exterior and stronger radial sculpture; 5-80 m.
- Botula vagina Possibly conspecific with Shark Bay specimens recorded as *Modiolus (Botula) fuscus* (Gmelen) *(sic)* by Thiele (1930); in weed and sand at 0-20 m.
- Brachidontes ustulatus Apparently the species recorded by Thiele (1930) as Brachyodontes (Hormomya) subramosus (Hanley) from Shark Bay and Rottnest I.; intertidal to shallow sublittoral rock.
- Lioberus sp. Intertidal to sublittoral seagrass beds; congeneric with American L. castaneus (Say, 1822) and similar to but not conspecific with Modiolus pulvillus Iredale, 1939. Possibly undescribed species (B.R. Wilson pers. comm.)
- Modiolatus hanleyi Congeneric with Mytilus plicatus Gmelin, 1791, the type species of Modiolatus (B.R. Wilson pers. comm.); shallow sublittoral.
- Modiolus auriculatus Common on more exposed shores, shallow subtidal rock and weed.
- Modiolus philippinarum Abundant in shallow sublittoral sea-grass and algal beds.
- Musculista glaberrima Infaunal in silty sand; shallow sublittoral to 40 m.
- Musculus nanulus Type locality is Shark Bay; common in byssal mat attached to other shells; sublittoral.
- Ryenella cumingiana Recorded by Thiele (1930) as Musculus cumingianus from Shark Bay; embedded in tests of simple ascidians, shallow subtidal.
- Septifer bilocularis Recorded by Thiele (1930) as Brachyodontes (Septifer) bilocularis from Shark Bay and Houtman Abrolhos; intertidal and subtidal rocks.
- Stavelia horrida Rarely found in Shark Bay; shallow sublittoral.
- Atrina pectinata Shallow sublittoral to 30 m; sand and sea-grass flats; possibly conspecific with *Pinna tasmanica* Tension Woods, 1876.
- Pinna bicolor Recorded as P. bicolor Chemnitz by Thiele (1930) from Shark Bay. Intertidal and sublittoral sea-grass beds and sand.

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- Streptopinna saccata In crevices and under rocks; intertidal reefs and shallow sublittoral.
- *Pinctada albina* Described, with Shark Bay type locality, by Jameson (1901) as *Margaritifera carchariarum* n.sp., and recorded from there and placed in the genus *Pteria* by Thiele (1930); abundant and attached to any hard substrate on intertidal and subtidal reefs and flats.
- Pinctada fucata Probably conspecific with Jameson's (1901) record of Margaritifera vulgaris (Schumacher) and Thiele's (1930) record of Pteria (Margaritifera) vulgaris, both from Shark Bay; subtidal, occasionally common in seagrass beds.
- Pinctada maculata Small; rarely found on shallow subtidal banks.
- *Pinctada margaritifera* Found very rarely in intertidal reef crevices, more common subtidally.
- Pteria lata Usually attached to subtidal seagrass (Amphibolus) stems.
- Pteria penguin Usually attached to gorgonians; subtidal.
- Crenatula modiolaris Possibly synonymous with C. nigrina Lamarck as recorded from Shark Bay by Thiele (1930); in sponges.
- Isognomon legumen Small specimens usually found in crevices and under rocks, intertidal and shallow subtidal; group needs revision.
- Malleus albus Recorded from Shark Bay by Thiele (1930); juveniles attached by fine byssus, adults usually free; rarely found.
- Malleus meridianus Common in Shark Bay byssally attached to intertidal and shallow sublittoral hard substrates.
- Vulsella vulsella Recorded from Shark Bay by Thiele (1930); synonym V. spongiarum Lamarck; embedded in sponges, subtidal.
- Annachlamys leopardus Recorded from Shark Bay by Thiele (1930) as Pecten leopardus; on subtidal sand.
- *Chlamys australis* Recorded from Shark Bay as *Pecten australis* by von Martens (1889) (*fide* Hedley 1916). Consistently larger than, and with different microsculpture from the more southern *C. asperrima* (Lamarck, 1819) recorded from Shark Bay by Thiele (1930); covered with sponge, attached or free in seagrass beds.
- Chlamys scabricostata Subtidal seagrass beds and hard substrate; smaller than C. australis but with relatively larger, spaced scales on dominant ribs.
- Chlamys squamosa Rarely taken in Shark Bay; intertidal to subtidal seagrass banks.

Decatopecten strangei Rarely taken in Shark Bay in subtidal seagrass beds.

- Pecten modestus Shark Bay specimens generally more strongly sculptured than those further south; subtidal sand and seagrass.
- Semipallium luculentum Conspecific with Pecten dringi Reeve, 1853 recorded from Shark Bay by Thiele (1930); subtidal seagrass beds.
- Amusium balloti Locally abundant and fished commercially; subtidal sand.
- Plicatula australis Australian forms of Plicatula need examination; intertidal and subtidal hard substrates.
- Spondylus barbatus Species interpreted as in Lamprell 1986: 48; shallow subtidal hard substrates.
- Spondylus squamosus Species interpreted as in Lamprell 1986: 46; shallow subtidal, hard substrates.
- Dimya sp. Inhabits offshore waters of 50 to 270 m. Possibly conspecific with Indonesian dimyids identified as D. lima Bartsch, 1913.
- Monia sp. Insufficient available material does not yet allow critical comparison with central Indo-West Pacific species of this genus; shallow subtidal, hard substrates.
- Lima lima Synonym L. persquamifer Iredale, 1939; shallow sublittoral, usually under rocks.
- Lima nimbifer Specimens identified by von Martens (1889) as L. multicostata Sowerby, 1843 and L. sowerbyi Deshayes, 1863 (fide Hedley 1916) may be conspecific with this species; shallow sublittoral.
- Stabilima tadena Possibly a synonym of Lima strangei Sowerby, 1872; sandy substrate to 80 m.
- Dendostrea folium Varies from acutely folded form attached to gorgonians, to less folded forms attached to flat rocks, dead coral etc.; subtidal.
- Ostrea tuberculata Usually attached to and often embedded in living corals; subtidal.
- Ostrea ?virescens Often confused with partly sympatric O. angassi, this small oyster shows distinctive anatomical, habitat and growth characteristics; subtidal hard substrates.
- Saccostrea ?commercialis Work in progress casts doubt on conspecificity of western and northern forms with this south-east Australian species; moderately sheltered intertidal and shallow subtidal hard substrates.

- Saccostrea cuccullata In Shark Bay is found only where wave action is constantly moderate to strong; on intertidal rocks.
- Hyotissa hyotis Often detached from hard substrate when large to lie free on bottom; subtidal.
- Neotrigonia uniophora Shallow sublittoral to 80 m depth.
- Anodontia pila Distinguished from A. edentula (Linné, 1758) by depressed lunule, this species has not yet been found alive in Shark Bay; subtidal silty sand and seagreass beds.
- Anodontia (Cavatidens) sp. aff. A. (C.) omissa The close similarity of the shells of species in this subgenus makes a tentative identification advisable pending anatomical and other studies; subtidal silty sand and seagrass beds.
- Bellucina pisiformis Described from Shark Bay holotype by Thiele (1930) as Phacoides (Parvilucina) pisiformis (see Ponder, 1978); subtidal sand.
- Bellucina ?semperiana WA forms are larger, more rounded and have more distant posterior lateral teeth than more typical forms; subtidal sand.
- Callucina lacteola Generally smaller than more southern specimens; subtidal sand.
- Codakia punctata Rarely found; subtidal and intertidal sand flats.
- *Ctena bella* Abundant as dead shells, rarely taken alive; intertidal and subtidal sand.
- Ctena ?transversa Closely resembles topotypic Hawaiian specimens; intertidal and subtidal sand.
- *Divalinga* sp. Superficially resembles *Divalucina cumingi* (Adams and Angas, 1863) but with dissymmetric lunule and short anterior adductor muscle scar as in *Divalinga*; subtidal sand and weed beds.
- *Divaricella ornata* Abundant as dead shells, rarely taken alive; subtidal sand and weed beds.
- *Epicodakia* sp. Smaller, slightly more oblique and more inflated than *E. tatei* (Angas, 1879) from southern Australia; intertidal and subtidal weed beds.
- *Wallucina* sp. aff. *W. jacksoniensis* WA forms have stronger, more distant growth ridges, more indented lunule, deeper hinge plate, stronger right anterior lateral and more slender left anterior cardinal teeth than south-east Australian forms; intertidal and subtidal weed beds.
- *Felaniella* (*Zemysia*) sp. Ligament more superficial and posterior cardinal teeth more vertical than in *F.* (*Z.*) globularis (Lamarck, 1819); subtidal sand and weed flats.

- *Numella ?conspicua* More globular than type species *N. adamsi* (Angas, 1867); possesses internal anterior denticles but is more equilateral than originial figure of type of *conspicua*; shallow sublittoral.
- Chama fibula Apparently conspecific with east Australian form; subtidal hard substrate.
- Chama iostoma Possibly same species as Thiele's (1930) record of Chama reflexa Reeve; subtidal hard substrates.

Chama lazarus Subtidal hard substrates.

Chama pacifica Intertidal and subtidal hard substrates.

Chama pulchella Apparently conspecific with Queensland forms; subtidal hard substrates particularly other shells.

Chama ruderalis Rarely taken in Shark Bay; intertidal to subtidal hard substrates.

- *Pseudochama* sp. Attached on exposed intertidal reef flats; rarely taken, possibly due to collecting bias.
- Lasaea ?australis Possibly conspecific with southern Australian forms (work in progress, O'Foighil pers. comm.); intertidal to subtidal nestler.
- Kelliid sp. Possibly is the species recorded by Thiele (1930) as Kellya ?rotunda (Deshayes); subtidal.
- Mysella sp. Not conspecific with ribbed Coriareus pusillus Thiele, 1930 (type locality Shark Bay); subtidal.
- Cardita aviculina Described with Shark Bay type locality; intertidal and subtidal.
- Cardita crassicosta Recorded by Thiele (1930) from Shark Bay (and elsewhere) as Cardita crassicostata Larmarck, which is an American species; subtidal reefs.
- Megacardita incrassata Shallow sublittoral specimens have stronger hinge elements than do specimens from depths of 80 m or more; subtidal weed beds, though intertidal further south.
- "Megacardita" ?quoyi Possibly conspecific with south-east Australian Cardita rosulenta Tate, 1886 (S.E. Boyd pers. comm.), may be better placed in Glans; subtidal sand.
- Megacardita turgida Perhaps conspecific with Cardita nodulosa Lamarck, 1819 described from Shark Bay types; intertidal to 40 m.
- *Pleuromeris* sp. Tan and white, less than 5 mm, similar to *Venericardia propelutea* Cotton, 1930 which might be a synonym of *Cardita bimaculata* Deshayes, 1852 according to Cotton (1961); shallow subtidal sand.

Eucrassatella pulchra Subtidal sand and weed beds.

- Acrosterigma marielae Shallow sublittoral banks in Shark Bay, though elesewhere usually found in deeper waters.
- Acrosterigma reeveanum Probably conspecific with Thiele's (1930) record of *Cardium flavum* Linné, which species is regarded as indeterminable by Iredale (1936) and Wilson & Stevenson (1977); intertidal and shallow subtidal banks.
- Acrosterigma rosemariensis Subtidal sand and weed banks.
- Acrosterigma vlamingi Subtidal sand and weed banks.
- Ctenocardia perornata Shallow subtidal to about 80 m.
- *Fragum (Afrocardium) erugatum* Shark Bay specimens usually small (< 1 cm long); synonym *F. hamelini* Iredale, 1949, type locality Shark Bay; subtidal sand.
- Fragum (Lunulicardia) hemicardium Recorded from Shark Bay by Thiele (1930) as Cardium (Hemicardium) hemicardium; Wilson & Stevenson (1977) followed Thiele (1930) in regarding C. tumoriferum Lamarck, 1819 (type locality Shark Bay) as a synonym; intertidal and subtidal flats.
- Fragum (Lunulicardia) retusum Subtidal sand banks.
- Fragum (Fragum) unedo Abundant on intertidal and shallow subtidal banks.

Fulvia aperta Intertidal and subtidal banks.

- Nemocardium (Nemocardium) bechei Off Shark Bay in sand at 80 m.
- Nemocardium (Pratulum) thetidis Off Shark Bay to 80 m.
- *Tridacna maxima* Recorded from Shark Bay and the Houtman Abrolhos by Thiele (1930) as *T. elongata* Lamarck; open coast intertidal reefs and wave-washed sublittoral rocks.
- Lutraria rhynchaena Subtidal banks.
- Mactra cuvieri Intertidal and subtidal banks.
- Mactra incarnata Subtidal to 80 m.
- Mactra ovalina The relationships between the Australian species of this and other species placed in the sugenus Mactrotoma need examination; intertidal and subtidal flats.
- *Mactra ?pura* The conspecificity of northern and southern Australian forms needs verification; intertidal and subtidal banks.
- Mactra sericea This species appears to be the west coast equivalent of the eastern coast *M. eximia* Deshayes 1853; shallow subtidal.

- Atactodea striata Shark Bay specimens show differences in size and shape of pallial sinus and hinge plate and teeth, but are here included in this variable species; intertidal and shallow subtidal sand.
- Paphies (Amesodesma) elongatum Differs from southern Australian P. (A.) angustum (Reeve, 1854) and West Irian P. (A.) altenai (Rooij-Schuiling, 1972) in hinge teeth details; intertidal and shallow subtidal sand.
- Phaxas cultellus Shallow subtidal flats.
- Apolymetis (Leporimetis) spectabilis Rarely taken on shallow sublittoral banks.
- Arcopagia (Clathrotellina) ?elegantissima Subtidal sand and rubble; differs from figured type specimen and description in having a narrower posterior area, less convex anterior slope and a stronger yellow colour.
- Exotica (Loxoglypta) obliquilineata Intertidal and subtidal sand.
- Exotica (Exotica) clathrata Shallow subtidal sand and weed banks.

Exotica (Exotica) triradiata Intertidal and subtidal sand.

Macoma (Scissulina) dispar Intertidal and shallow subtidal sand banks.

Macoma (Pinguimacoma) hemicilla Intertidal and subtidal sand.

Phylloda foliacea In subtidal sand.

Quadrans (Quadrans) parvitas Subtidal sand and weed flats.

- Tellina (Cadella) semitorta Shallow subtidal sand and weed flats.
- Tellina (Merisca) ?ostracea Differs somewhat from figure cited by Lamarck in original description in being more rostrate posteriorly, more convex anterodorsally and with sharper posterior ribs, but agrees with Hanley's (1846) description and figure; uncommon in subtidal sand.
- Tellina (?Moerella) sp. Differs from type species donacina Linné, 1758 in having larger right anterior lateral and shorter right posterior lateral teeth and in being less rostrate posteriorly; subtidal sand.

Tellina (Pharaonella) perna Intertidal and shallow subtidal sand.

- Tellina (Pinguitellina) ?murrayi Shark Bay specimens are relatively higher, shorter and less rostrate posteriorly than in Smith's description. However they possess the characteristic fine radial sculpture between concentric lirae which, at intervals, become stronger and almost lamellate; subtidal sand.
- Tellina (Pinguitellina) robusta Subtidal sand.
- Tellina (Semelangulus) tenuilirata Subtidal sand to 80 m.
- Tellina (Smithsonella) pulcherrima Shallow subtidal sand.

Tellina (Smithsonella) verrucosa Subtidal sand, 0-80 m.

Tellina (Tellinangulus) sp. Subgeneric placement is doubtlful as this small (< 1 cm) species has a posterior right lateral tooth, apparently unlike the type species *T. aethiopicus* (Thiele & Jaeckel, 1931).

Tellina (Tellinella) staurella Intertidal and shallow subtidal sand and reef.

Tellina (Tellinella) virgata Intertidal to subtidal sand flats.

Tellina (Tellinides) cockburnensis Subtidal sand and seagrass banks.

Donax columbella Intertidal and shallow subtidal sand.

Donax faba Intertidal and shallow subtidal sand.

Asaphis violacens Rarely taken in Shark Bay; occurs in deeper water than further north.

Gari amethystus Subtidal sand to 80 m.

Gari anomala Shallow subtidal sand.

Gari maculosa Subtidal sand.

Gari occidens Shallow subtidal sand.

Gari pulcherrima Subtidal sand to 60 m.

Gari rasilis Subtidal sand.

Sanguinolaria (Psammotellina) sp. More elongately ovate than S. (P.) ambigua (Reeve, 1857) with rayed colour pattern just anterior to posterior area; intertidal and shallow subtidal banks.

Soletellina sp. A new species to be described by R. Willan (pers. comm.).

Leptomya psittacus Rarely taken in Shark Bay, shallow subtidal sand.

Semele exarata Subtidal sand to 80 m.

Semele jukesii Subtidal sand, weed and reef.

Azorinus sp. Common in sheltered waters of north-west Australia but only tentatively identified. The shell is obliquely radially furrowed, is longer posteriorly with a deep, moderately rounded pallial sinus, and has two long flat cardinal teeth in each valve; shallow subtidal sand.

Solecurtus divaricatus Subtidal soft substrates.

Solecurtus sulcatus Subtidal soft substrate to 80 m.

Trapezium bicarinatum Synonymous with Cypricardia angulata Lamarck, 1819 described with Shark Bay as type locality; intertidal and subtidal reef.

- Anomalocardia squamosa Recorded from Shark Bay as Chione squamosa by Thiele (1930); intertidal sand and weed flats.
- Bassina disjecta Rarely taken in Shark Bay area and in greater depths (80 m) than further south.
- Callista impar Recorded from Shark Bay by Thiele (1930); intertidal and shallow subtidal sand and seagrass flats.
- *Chioneryx* sp. Resembles apparently variable *C. lionata* (Smith, 1885) but has a relatively larger and stronger hinge structure, a larger and more pointed pallial sinus and stronger and fewer crenulations only on the ventral part of the lunule lip; locally abundant on subtidal banks.

Circe lenticularis Intertidal and subtidal banks.

Circe scripta Intertidal and subtidal sand and weed.

Circe sulcata Intertidal and subtidal sand and seagrass.

Clementia papyracea Intertidal sand flats.

Costacallista planatella Intertidal and subtidal sand and seagrass banks.

Dosinia biscocta Sand and weed banks.

Dosinia deshayesii Subtidal sand and weed.

Dosinia incisa Subtidal sand to 80 m.

Dosinia lucinalis Intertidal and shallow subtidal sand flats.

Dosinia sculpta Intertidal and sublittoral sand.

Gafrarium intermedium Intertidal and shallow subtidal sand flats.

- Glycydonta ?costellifera Lynge (1909) considered that costellifera is a synonym of G. recognita (but see below). Shark Bay specimens closely resemble the original description and figures of costellifera in shape and in the sculpture of strong, simple, close-set, strongly scaled radial ribs; intertidal and shallow subtidal sand and weed banks.
- *Glycydonta ?recognita* WA shells resemble those figured by Smith, but are more closely radially ribbed with each rib bisected by a groove so that paired nodules are formed where ribs intersect concentric lirae; intertidal and shallow subtidal sand and weed.
- Gomphina undulosa Type locality Shark Bay (collected by Péron); intertidal and subtidal sand and weed.
- *Irus* sp. aff. *I. irus* Recorded from Shark Bay as *Venerupis irus* by Thiele (1930). Indo-West Pacific forms have not yet been convincingly distinguished from this European species; shallow nestler.

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- Katelysia hiantina Taken rarely in Shark Bay area and at greater depths than further north.
- Marcia (Granicorium) induta Off Shark Bay in sand at 80 m.
- Paphia crassisulca Type locality Shark Bay (collected by Péron); intertidal and subtidal sand and weed banks.
- Periglypta resticulata Intertidal and subtidal sand and reef.
- Periglypta reticulata Intertidal and sublittoral sand and reef.
- Pitar (Pitarina) affinis Subtidal sand.
- Pitar (Pitarina) citrina Intertidal sand flats.
- *Pitar (Pitarina) ?pellucida* Resemble Pacific Ocean forms in shape, texture and colour patterns of shell but have finer posterior and median cardinal teeth; intertidal and shallow subtidal sand.
- *Pitar (Costellipitar) ?porrecta* Shark Bay forms (with tan zig-zag shell patterns) have deeper shells with smaller beaks, less obvious growth striae and more posteriorly-placed internal colour ray than in Romer's description; shallow subtidal sand.
- Placamen berrii, which Thiele (1930) recorded as Clausinella berryi, occurs in intertidal sand, rubble and seagrasses.
- *Placamen ?foliacea* The sculpture and colour patterns of Australian specimens more closely resemble Philippi's description and illustrations than those of Dillwyn's (1817) *P. tiara*, which has been considered synonymous by some authors; shallow subtidal sand and weed.
- Placamen gravescens Intertidal sand and weed flats.
- Sunetta aliciae Shallow sublittoral, wave-washed sand.
- Sunetta contempta Shallow sublittoral, wave-washed sand.
- Tapes literatus Intertidal and shallow subtidal sand, reef and weed.
- Tapes deshayesii Shallow subtidal sand.
- Tapes dorsatus Intertidal and shallow subtidal sand and weed.
- *Tawera coelata* Intertidal and shallow subtidal sand and weed; the generic placement in this southern temperate genus seems to be appropriate here and below.
- Tawera ?subnodulosa Shell more oval than in figured types, with slightly exert lunule and with concentric ribs broken anteriorly to form nodules; intertidal and shallow subtidal sand and weed.

Ventricolaria embrithes Shallow subtidal to 80 m.

Ventricolaria toreuma Intertidal flats to 80 m.

- Venus (Antigona) chemnitzii Recorded from Shark Bay as Antigona (Periglypta) chemnitzii by Thiele (1930); synonym Venus laqueata Sowerby, 1853; shallow subtidal among rocks and sand.
- Venus (Antigona) lamellaris Shallow subtidal to 80 m.
- Mysia sp. Not yet taken alive. Similar to southern Australian M. pellucida (Tate, 1891) but lacking external sculpture.
- Corbula monilis Subtidal sand.
- Corbula stolata Subtidal sand.
- Corbula scaphoides Subtidal sand and weed.
- Gastrochaena cuneiformis Described, with Shark Bay as type locality, as G. tumidula Thiele, 1930; subtidal in silty sand.
- Gastrochaena pupina In shells of other bivalves e.g. Annachlamys leopardus.
- Hiatella sp. Recorded from Shark Bay by Thiele (1930) as Saxicava arctica Linné. The relationship of the northern Australian form with the southern H. australis (Lamarck, 1818) needs examination.
- Pandora (Frenamya) sp. Relatively more elongate than P. (F.) patula (Tate, 1889) from southern Australian waters; subtidal soft substrates.
- Cleidothaerus albidus Subtidal hard substrate.
- Laternula ?anatina Possibly the same species as that described from Shark Bay type locality as *L. imperfecta* Lamarck, 1818; shallow subtidal and intertidal sand flats.
- Myochama anomioides Shallow subtidal; attached to shells and other hard substrates.
- Myadora ?complexa Distributional range apparently discontinuous with that of south-east Australian population; subtidal soft substrate.
- Thracia alciope Described with Shark Bay as type locality; intertidal and shallow subtidal flats.
- Brechites (Foegia) novaezelandiae Shallow subtidal sand and rock.

Bivalves

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Genetic divergence of venerid clams in Shark Bay, Western Australia

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Abstract

Steep environmental gradients and low rates of water exchange in Shark Bay favour genetic divergence among populations of marine species. An earlier study of electrophoretic variation of enzymes in snapper revealed genetic differences between populations within Shark Bay and those outside, and between the eastern and western gulfs of the inner portion of the Bay, confirming the isolation of stocks in different areas. A study of five species of venerid clams provides additional examples of genetic divergence associated with Shark Bay. Although the amount of divergence is generally less than that found for snapper, each of the species of clams shows genetic differences among sites within Shark Bay. Larger differences were found between the populations in Shark Bay and those further north. These results confirm the importance of Shark Bay as a focal point for genetic divergence of marine species, and encourage further studies of microevolutionary processes.

Résumé

Les pentes écologiques raides et les taux bas d'échange d'eau dans la Baie des Chiens Marins favorisent la différence génétique parmi les populations d'espèces marines. Une étude antérieure sur les variations électrophorétiques des enzymes chez le mordeur a révélé des différences génétiques entre les populations à l'intérieur de la Baie et celles à l'extérieur, et entre les golfes orientaux et occidentaux de la partie intérieure de la Baie, confirmant l'isolement des espèces dans les différentes régions. Une étude sur cinq espèces de clams vénéridés fournit des exemples supplémentaires de différence génétique associée a la Baie des Chiens Marins. Bien que l'importance de la différences soit généralement moindre que celle trouvée chez le mordeur, chaque espèce de clams montre des différences génétiques entre les sites à l'intérieur de la Baie des Chiens Marins. Des différences plus grandes ont été trouvées entre les populations de la Baie des Chiens Marins et celles plus au nord. Ces résultats confirment l'importance de la Baie des Chiens Marins comme foyer de différence génétique des espèces marines, et encouragent les études ultérieures sur les processus micro-évolutionnaires.

Introduction

Two features make Shark Bay an outstanding laboratory for studies of population genetics. The most striking aspect of the Bay is its steep environmental gradients. Salinity is the most obvious of these, with an increase from $36 \text{ g} \text{ l}^{-1}$ in the outer bay to 60-70 g l⁻¹ in the eastern heads of the bay, but temperature gradients are also considerably steeper than along the outer coast (Davies 1970; Logan and Cebulski 1970). This environmental heterogeneity should favour genetic divergence among populations, through localised effects of natural selection.

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Genetic divergence is also favoured by the low rates of exchange of waters between the inner and outer portions of the Bay, as evidenced by the steep salinity gradients and estimates of salt and water budgets (Smith and Atkinson 1983). These low rates of exchange reduce the probability of passive dispersal of eggs or larvae, thereby increasing the opportunity for localised subdivision and genetic divergence of populations.

Genetic studies of marine species in Shark Bay are of interest in two contexts. The first is the opportunity to study genetic divergence in relation to this unique, partially isolated environment. Since pelagic dispersal greatly limits the potential for genetic divergence of many marine species, populations away from the main flow of currents, such as in Shark Bay, may be of special significance in the divergence and speciation of marine organisms. Shark Bay is of special evolutionary interest, because its origin is geologically recent. Flooding of the basin by the sea occurred 7000 to 8000 years ago, and its unique characteristics have developed only over the past 5000 years (Hagan and Logan 1974), providing the opportunity to study genetic change over a significant, but evolutionarily short period of time.

In addition to their theoretical context, genetic studies of marine species in Shark Bay are of interest in the management of the species and communities of the Bay. Genetic differences of populations from different areas can provide strong evidence for isolation of those populations. The special value of the genetic evidence is that it reflects isolation or connectedness over generations, without being confined to particular life stages. As a source of genetic markers, electrophoresis of enzymes has proved particularly useful in the detection of isolated breeding populations, setting the spatial scale over which effective management must be made (reviews in Shaklee 1983; Ryman and Utter 1987).

The first genetic study in Shark Bay was, in fact, initiated in the practical context of management of the fishery for snapper, *Chrysophrys auratus* (=*C. unicolor*). Snapper are caught commercially in the outer portions of the Bay, and by amateurs in the inner gulfs, and potential conflicts of management have been considerable. Electrophoretic studies of enzyme polymorphisms showed that there was genetic isolation between populations from the inner and outer portions of the Bay, and between the eastern and western gulfs of the inner bay (Johnson et al. 1986). These results complement tagging studies (Moran 1987), confirming that there are isolated stocks of snapper within Shark Bay, and that the commercial and amateur fisheries can be managed independently of each other.

Studies of snapper populations across southern Australia make clear the importance of Shark Bay as a focus of genetic divergence. Genetic evidence indicates that random mixing of coastal populations occurs over distances of about 1000 km (MacDonald 1980, discussed in Richardson *et al.* 1986), compared with the isolation of populations on a scale of less than 100 km in Shark Bay. Furthermore, populations in Shark Bay have some alleles which are not found throughout

the species' range across coastal southern Australia. This genetic uniqueness indicates that the Shark Bay populations are not simply a filtered subset of the genetic variants found outside the Bay. Instead, the accumulation of these alleles has apparently occurred in response to special conditions in the Bay, developing within the past 8000 years.

As a first extension of these genetic studies to other species, we have examined polymorphic enzymes in 5 species of venerid clams. Clams are abundant in Shark Bay, being the most obvious of the intertidal benthic consumers, and have been the subject of ecological studies (Peterson and Black, 1987, 1988). The initial questions of the genetic study were: 1) is there genetic subdivision of populations within Shark Bay and 2) are there genetic differences between Shark Bay and other areas?

Materials and methods

Between 2 and 8 samples were collected in Shark Bay (Figure 1) during 1987 for each of the following species: Anomalocardia squamosa (4 samples); Callista impar (5); Circe lenticularis (2); Placamen berryi (8); Placamen gravescens (2). All of these species have largely tropical distributions, and Shark Bay is the southern limit of any appreciable populations. In addition, the habitat between Shark Bay and Exmouth Gulf, a distance of about 400 km, is largely unsuitable for these species, and few specimens of any of the species are known from that area. Thus, the populations in Shark Bay are disjunct extremeties of the species' distributions. To compare the Shark Bay populations with those further north, samples of all of the species except C. lenticularis were collected from Bay of Rest, in Exmouth Gulf (22°19'S, 114°7'E), and samples of C. lenticularis, C. impar, and P. gravescens were collected from Withnell Bay, near Dampier (20°34'S, 116°48'E). With few exceptions, each sample consisted of 48 specimens.

Genetic markers were obtained through a survey of variation of several enzymes, using standard starch-gel electrophoresis of extracts from hepatopancreas. The eight polymorphic enzymes which were used to study geographic variation were isocitrate dehydrogenase (ldh), leucine aminopeptidase (Lap), leucylglycylglycine peptidase (Lggp), malate dehydrogenase (Mdh), mannosephosphate isomerase (Mpi), phosphoglucose isomerase (Pgi), phosphoglucomutase (Pgm), and phosphogluconate dehydrogenase (Pgd). Each species was polymorphic for 4 to 6 of these enzymes. Recipes for staining these enzymes can be found in Richardson *et al.* (1986). At each locus, for each species, alleles were labelled alphabetically, in order of decreasing electrophophoretic mobility of their corresponding allozymes.

Variation of allelic frequencies among populations was quantified using F_{ST} , the standardised variance of allelic frequencies. F_{ST} can vary between 0 and 1, and is the proportion of the total genetic variation in a set of samples which is due to differences among samples; thus, the larger the value, the greater the

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genetic divergence among the sampled populations. This was calculated for each allele, each locus, and across loci, using the methods of Weir and Cockerham (1984). To provide a less biased estimate of the mean F_{ST} across loci, the jackknife procedure (Reynolds *et al.* 1983) was used. A contingency X^2 was calculated from F_{ST} using the method of Workman and Niswander (1970). To ensure a valid X^2 , alleles for which the average expected value within populations was less than 4 were pooled in the determination of the degrees of freedom for that locus. To test the significance of the average F_{ST} across loci, we used the summed X^2 values and their degrees of freedom from the individual loci. Where available samples permitted, analysis of F_{ST} was conducted at several levels: within the eastern and western gulfs; between these two inner gulfs; among the inner gulfs and the outer bay; and between the pooled Shark Bay samples and the northern samples.

Under the island model of population structure, without selection, genetic divergence is related to gene flow by the formula

$$Nm = (1/F_{ST} - 1)/4$$

where Nm is the genetically effective number of migrants between populations per generation (Slatkin, 1985). We used the jackknife procedure to estimate Nm and its variance from the average F_{ST} across loci. Since this estimation ignores any effects of selection, it provides only a rough estimate, but it helps to put the values of F_{ST} into an ecological perspective.

Results

The five species of clams show a large range of divergence, as measured by average F_{ST} ; but generally less than the snapper populations (Table 1). Of the clams, *A. squamosa* shows the greatest variation among populations within Shark Bay; among the three major sections of the Bay, the average F_{ST} is 0.011, the same as found for the snapper populations. The spatial scale of that variation is relatively small, however, with 3 of 5 polymorphic loci showing significant differences between Monkey Mia and Herald Bight, the two sampling sites in the eastern gulf, and which are only 25 km apart. This variation within the eastern gulf is of the same magnitude as found between the eastern and western gulfs for the snapper, with an average F_{ST} of 0.016. The divergence between *A. squamosa* populations from the two gulfs is somewhat smaller, and is significant only for the Pgm locus. Including the outer bay in the comparisons does not increase F_{ST} confirming that the spatial scale of variation in this species is small relative to the major sections of the bay.

Considerable divergence within Shark Bay was also found for *C. impar*, which also shows a pattern of localised differention. Although the two samples from the eastern gulf did not differ significantly for any of the four polymorphic loci, two of the loci varied significantly among the three samples from the western

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	Within Shark Bay								
Species	Locus	Eastern gulf	Western gulf	Eastern vs.Western	East/West/ Outer Bay	Shark Bay vs.North			
C.auratus									
	Est	D.C.	n.c.	0.000	0.008***	11.C.			
	Idh	n.c.	1).C.	0.023***	0.014***	n.c			
	Mpi	n.c.	11.C.	0.008*	0.012***	nc			
	Pgi	1).C.	n.c.	0.035***	0.013***	n c			
	Average	n.c.	n.c.	0.016***	0.011***	n.c.			
A.squamo	sa								
	Idh	0.046*	11.C.	0.000	0.000	0.044***			
	Lap	0.016*	n.c.	0.006	0.007	0.016***			
	Legp	0.000	11.C.	0.005	0.006	0.012*			
	Pgm	0.008	n.c.	0.040***	0.031***	0.051***			
	Pei	0.025**	n.c.	0.005	0.010	0.011***			
	Average	0.016**	n.c.	0.010***	0.011***	0.020***			
C.impar									
	Lap	0.000	0.017*	0.015***	n.c.	0.057***			
	Pgm	0.009	0.008	0.009***	n.c.	0.012***			
	Pgd	0.011	0.054***	0.006*	n.c.	0.012***			
	Pei	0.003	0.000	0.003	nc	0.000			
	Average	0.005	0.012**	0.010***	n.c.	0.025***			
C.lenticule	uris								
	Idh	n.c.	n.c.	1).C.	n.c.	0.021*			
	Lap	n.c.	11.0.	0.001	n.c.	0.058***			
	Mdh	n.c.	11.C.	0.000	n.c.	0.014			
	Mpi	11.C.	n.c.	0.009	n.c.	0.023***			
	Pgm	n.c.	11.C.	0.000	n.c.	0.000			
	Pgi	n.c.	n.c.	0.014	n.c.	0.061***			
	Average	n.c.	n.c.	0.007	n.c.	0.045***			
P.berryi									
	Lap	0.008	0.003	0.007*	0.009**	0.48 * * *			
	Mdh-l	0.000	0.004	0.000	0.000	0.026***			
	Mdh-2	11.C.	n.c.	n.c.	n.c.	0.012**			
	Mpi	0.017*	0.012	0.004	0.006*	0.006**			
	Pgm	0.000	0.010	0.001	0.002	0.010***			
	Pgi	0.000	0.000	0.006*	0.002	0.061***			
	Average	0.003	0.006	0.004	0.004*	0.031***			
P.gravescer	<i>ns</i>								
1978	Idh	11.C.	1). <i>C</i> .	0.006	1).C.	0.000			
	Lap	11.C.	n.c.	0.000	n.c.	0.029***			
	Mdh	11.C.	11.C.	0.000	n.c.	0.006			
	Pgm	n.c.	11.C.	0.006	n.c.	0.013**			
	Pgi	11.C.	n.c.	0.015*	n.c.	0.042***			
	Average	n.c.	n.c.	0.008	nc	0.026***			

Table 1.	Values of	FST	for snapper	(C,	auralus) ;	und	live s	pecies	10	clams	from	Shark	Bay	y.
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n.c. = no comparison possible * = P < 0.05; ** = P < 0.01; *** = P < 0.001

gulf. The differences between the two gulfs were similar in magnitude to those within the western gulf.

Less differentiation among populations was found for *C. lenticularis* and *P. gravescens*, for which the average F_{ST} between the inner gulfs was only 0.007 and 0.008, respectively. For both of these species, analyses are limited because we obtained only a single sample from each of the inner gulfs. For *P. gravescens*, the two samples differ for only the Pgi locus, of the five polymorphic loci examined. For *C. lenticularis*, the samples do not differ significantly for any of the six polymorphic loci. Nevertheless, some differentiation in this species is evident for particular alleles. The Mpi^a allele was found at a frequency of 0.122 at Monkey Mia, in the eastern gulf, and was absent from Denham, in the western gulf (P<0.001). Similarly, in the Monkey Mia sample Lap^a and Lap^b have a combined frequency of 0.084 and Pgi^a and Pgi^b have a combined frequency of 0.071, but none of these alleles were found at Denham. Although not large, these differences are the only sign of uniqueness for any populations or regions for any of the five species of clams examined.

The species showing the least differentiation in Shark Bay is *P. berryi*, with an average F_{ST} of only 0.004 between the two inner gulfs or among the three major sections of the Bay. Nevertheless, there are significant differences in some comparisons: Mpi differs between the two samples in the eastern gulf; Lap and Pgi vary significantly between the eastern and western gulfs; and Lap and Mpi vary significantly among the three major areas of the bay. Overall, the magnitude of differentiation is as great within the gulfs as between them.

For each of the five species of clams, the magnitude of differentiation between Shark Bay populations and the northern populations was substantially greater than the differentiation within Shark Bay. The increase in average F_{ST} ranged from 25% for *A. squamosa*, to 675% for *P. berryi*. For the latter species, all six polymorphic loci showed highly significant differences between Shark Bay and the northern populations, and for the other species, the majority of loci examined showed detectable differences. Despite this pervasive differentiation between Shark Bay populations and those further north, no alleles in any of the species were found to be unique to either Shark Bay or the northern populations.

Discussion

All five species of clams show some genetic divergence of populations within Shark Bay, although only *A. squamosa* approaches the level of divergence found previously for snapper populations. For the three species in which it was examined, variation within the inner gulfs was as great as between them or among all three major areas of the Bay. Thus, the processes causing genetic divergence within the Bay are largely local, rather than regional.

The values of F_{ST} in Shark Bay are small, which is typical of species with pelagic larvae. They are, on average, slightly larger than the values found over

a distance of about 600 km in southern California and Baja California, for several species of fish with pelagic larvae (Waples, 1987). Geographically, the most useful comparative data available are for the intertidal limpet *Siphonaria jeanae*, which has an average F_{ST} of only 0.004 over 2500 km from Kalbarri, Western Australia, to Port Robe, South Australia (Johnson and Black, 1984), a value smaller than those found within Shark Bay for all of the species of clams except *P. berryi*. For the clams themselves, the divergence within Shark Bay is roughly half as great as that between the Bay and the northern populations, despite the considerably larger distances in the latter comparisons.

A useful perspective on the divergence is provided by the estimates of the number of migrants per generation between the castern and western gulfs of the Bay, which range from about 9 to 57 (Table 2). These are estimates of the genetically effective number of migrants, which will be less than the total number. On the other hand, the estimates of Nm reflect the effects of gene flow over long periods, not just recent generations. Since these clams can have occupied Shark Bay for no more than a few thousand generations, they have probably not reached genetic equilibrium, and the current rate of migration is presumably much less than the estimated values. From an ecological perspective, the implication is that recruitment between the gulfs is negligible in the short term, and even within the gulfs populations may be largely self-replenishing on a fairly local scale. This implication must be tempered by the possibility that some of the variation could be due to selection within a single generation, which is ignored in the estimation of Nm. This caveat is particularly important for P. berryi, as the small amount of genetic divergence among populations found in this species could result from selection, even in the face of substantial gene flow.

Species	Eastern/Western Shark Bay	Shark Bay/North		
C. unicolor	8.13 ± 2.12	n.c.		
A. squamosa	8.80 ± 3.01	10.45 ± 0.51		
C. impar	23.48 ± 1.27	0.10 ± 2.50		
C. lenticularis	23.06 ± 2.21	4.81 ± 0.14		
P. berryi	57.19 ± 1.52	4.77 ± 0.49		
P. gravescens	16.52 ± 2.93	6.17 ± 0.81		

Table 2. Estimates of the genetically effective number of migrants (\pm s.e.) between eastern and
western Shark Bay and between Shark Bay and northern populations.

n.c. = no comparison

The differences among the species in the amount of divergence is another striking feature of the results. Although an explanation for these differences is beyond this study, some obvious possibilities are worth considering. The first of these is the potential effect of variable recruitment, which has been shown

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to cause spatial genetic heterogeneity in other sedentary molluscs (Johnson and Black 1984). Studies at Monkey Mia indicate that yearly recruitment to populations of all five species is generally low, but all species except *P. berryi* had one or two years of fairly heavy recruitment in the period 1982 to 1987 (Black and Peterson, unpublished data). Interestingly, *A. squamosa* showed the greatest variance in recruitment, which could contribute to its relatively large spatial genetic variation if different cohorts are genetically different and if the temporal pattern of recruitment varies among sites. Unfortunately, we have no data on either of these points, and the sporadic nature of recruitment will make such data difficult to obtain. Furthermore, the 'arge variance in recruitment and the fact that, despite its abundance, *P. berryi* received almost no recruitment at Monkey Mia in the period studied, indicate that a very long term study is necessary even to confirm possible differences in the pattern of recruitment among the species.

Another factor which might be expected to affect the amount of divergence among populations is the vertical distribution of a species. Because intertidal sites are influenced by local atmospheric conditions, we might expect greater divergence among high-shore populations. Among the species examined, *A. squamosa* is one of the more intertidal species (Peterson and Black, 1988), and shows the greatest genetic variation among sites. However, the species which is most restricted to intertidal sites is *P. berryi*, which shows the least genetic heterogeneity among populations in Shark Bay, destroying any simple connection with depth.

A possible confounding factor could be the relatively continuous distribution of *P. berryi*, which was the only species found at all eight sites sampled in Shark Bay. Greater continuity is likely to increase gene flow through a stepping stone effect, possibly contributing to the low level of genetic differentiation of *P. berryi*.

Whether or not it affects the extent of divergence within Shark Bay, discontinuity presumably contributes to the relatively large divergence between the Bay and the northern populations. Such disjunctions are not uncommon for species found in Shark Bay. A good example is the gastropod *Littoraria cingulata*, which occurs as far south as Exmouth Gulf, and has a disjunct subspecies within Shark Bay (Reid, 1986). Disjunctions favour genetic divergence through the reduction of gene flow, but they also emphasize the special ecological characteristics of Shark Bay. Because of this, it is difficult to determine the relative balance between gene flow and selection in bringing about the genetic differentiation associated with the Bay. Our work on this and other questions about the nature of genetic divergence of populations in Shark Bay is continuing. The most informative studies are likely to be those on the relatively few species which have continuous distribution along the outer coast as well as into Shark Bay.

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Annotated checklist of marine decapod Crustacea from Shark Bay, Western Australia

Diana S. Jones *

Abstract

Two hundred and thirty two species of decapod crustaceans are recorded from the marine habitats of Shark Bay, Western Australia. For each species information is presented on distribution, habitat, previous records from the area and specimens housed in the Western Australian Museum, Perth. Shark Bay is the type locality for 14 species. Biogeographic affinities of the fauna are discussed. The bulk of species (115) occurring at Shark Bay show Indo-West Pacific faunal affinities. Only 16 species are endemic to Western Australia and 17 show affinities to southern Australian temperate species.

Résumé

Deux cent trente-deux espèces de crustacés décapodes vivant dans les habitats marins de la Baie des Chiens Marins sont répertoriées. Pour chaque espèce, des informations sont présentées concernant la répartition, l'habitat, les recensements antérieurs dans la région et les spécimens conservés au Museum d'Australie-Occidentale, à Perth. La Baie des Chiens Marins est la localité type de 14 espèces. Les affinités biogéographiques de la faune sont traités. La majorité des espèces (115) apparaissant dans la Baie des Chiens Marins montrent des affinités avec la faune indo-pacifique occidentale. Seulement 16 espèces sont endémiques à l'Australie-Occidentale et 17 montrent des affinités avec les espèces tempérées de l'Australie méridionale.

Introduction

The first historical reference to Crustacea occurring in Western Australia is in the 17th century in the region of Shark Bay. It is contained in the journals of Francis Pelsart, whose ship "Batavia" was wrecked at the Houtman Abrolhos Islands on June 4th, 1629. Pelsart, leaving crew and passengers on the islands, crossed to the mainland, and on 15th June, a little to the north of Shark Bay, "found remains of crabs..." around a native fire (Alexander 1914). No references to crustaceans were made by the Dutch explorer Vlamingh (1677) or the Englishman Dampier (1699) and it was not until nearly two hundred years later that reference was again made to the occurrence of crustaceans in Western Australia.

In the 19th century the French and English expeditions of discovery heralded the commencement of the scientific study of the Western Australian fauna. These expeditions were accompanied by professional naturalists who made collections which were returned to Europe to be described by various experts. The distinguished naturalist François Péron was on board the French ship "Géographe"

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which, accompanied by "Naturaliste" reached the south-western coast of Australia on 27th May, 1801. Travelling northwards, "Géographe" anchored off Bernier Island, Shark Bay on June 27th, where Péron observed many marine snakes. On opening the stomachs of these snakes Péron found them to be "...chiefly filled with small fish and with divers pelagic crustaceans...". Landing on Bernier Island on June 29th, Péron noted "...The Crustacean family does not embrace a large number of species on these coasts; there are but two of the genus *Portunus* of M. Latreille (*P. pleuracanthus* and *P. euchromus* n. sp.) which cover the rocks with their greedy multitudes. Some of these crabs are not much less than 10 or 13 cm in breadth, and their flesh was excellent. They might afford, in case of need, a diet inexhaustible as well as healthful" (Péron 1807).

Captain Freycinet commanded the French ship "Uranie" and "Physicienne" which visited Shark Bay in September 1818 during a world voyage. The naturalists Quoy and Gaimard reported on the zoological specimens, including crustaceans, which had been collected during the expedition, in Freycinet's account of the voyage (Quoy & Gaimard 1824). Quoy and Gaimard were also members of Dumont and d'Urville's expedition on "Astrolabe". They published an account of the zoology of this voyage, which collected specimens at King George Sound (Albany), but they also included descriptions of a few specimens which had been obtained by "Uranie" and "Physicienne" (Quoy & Gaimard 1834).

Nearly two hundred years later the knowledge of the crustacean fauna of Shark Bay, and of Western Australia in general, is still fairly scant. Miers (1884) described some crustacean specimens which had been collected at Shark Bay by Surgeon F.M. Rayner on H.M.S. "Herald" and Hale (1929) reported on specimens from Dirk Hartog Island. The works of Montgomery (1931) and Rathbun (1914, 1924), pertaining to crustaceans collected at the Houtman Abrolhos Island, the Monte Bello Islands and north-western Australia, are pertinent to defining the decapod crustacean fauna of Shark Bay. There has been no systematic review of the decapod fauna of Western Australia, most studies having been centred on the decapod species occurring in eastern, south-eastern and southern Australia (e.g. Haswell 1882; Whitelegge 1900; Baker 1905; Rathbun 1918, 1923; Hale 1917; Ward 1933; Griffin 1969, 1972; Griffin & Campbell 1969; Griffin & Yaldwyn 1971). In Western Australia, however, there have been a number of systematic revisions of various taxa (e.g. Alpheidae - Banner & Banner 1973, 1975, 1982; Thalassinidae - Poore & Griffin 1979; Hymenosomatidae - Lucas 1980).

This paper is an attempt to document the decapod crustacean species presently known from Shark Bay. The check-list has been generated from scientific literature and from the collections of the Crustacean Department, Western Australian Museum, Perth. Crustacean orders and families are based on the sequence of Bowman & Abele (1982) and genera and species are alphabetically arranged within families. Brief notes on the distribution and habitat of each species are provided, as are published records of occurrence in Shark Bay (or nearest localities) and Western Australian Museum (and in some cases Australian Museum) accession numbers. Western Australian Museum crustacean registration numbers prior to the year 1930 are discussed by Jones (1986).

The following abbreviations are used in the text: AM, the Australian Museum, Sydney; BMNH, The British Museum (Natural History); PM, Museum National d'Histoire Naturelle, Paris; WAM, Western Australian Museum, Perth. The symbols (H), (A) and (P) are used to indicate holotype, allotype and paratype material.

Checklist

Order Decapoda Latreille, 1803 Suborder Dendrobranchiata Bate, 1888

PENAEIDAE Rafinesque, 1815

Metapenaeopsis crassissima Racek & Dall, 1965 Type Locality N.T. (Darwin), W.A., S.Aust. To 30 m over muddy bottom. Racek & Dall 1965: 26; Grey et al. 1983: 74.

Metapenaeopsis lamellata (de Haan, 1850)

Qld. (northeastern) to W.A. (to Shark Bay); Japan, Malaysia. In 30-200 m, often associated with hard bottoms (reef, coral debris, etc.). In significant numbers but of minor economic importance.

Grey et al. 1983: 78.

WAM 171-73, 173-73, 175-73, 447-88 Shark Bay; 172-73 Bernier I.; 448-88 Carnarvon.

Metapenaeopsis novaeguineae (Haswell, 1879)

Qld. to W.A. (to Shark Bay); Papua New Guinea. In 5-30 m, over muddy to sandy bottom.

Dall 1957: 172; Grey *et al.* 1983: 70. WAM 358-87 2 km E of Koks I.

Metapenaeopsis palmensis (Haswell, 1879)

N.S.W. (Sydney), Qld., N.T., W.A. (to Shark Bay); Indonesia. In 5-30 m over muddy to sandy bottom. Abundant but not commercially significant. Miers 1878: 304; 1884: 296; Racek & Dall 1965: 23; Grey *et al.* 1983: 72.

Metapenaeus dalli Racek, 1957

N.T. (Darwin), W.A. (Broome to Mandurah); south-eastern Japan. Inshore (estuarine and rivers) out to marine waters (to 33 m). Generally over sandy mud or sand bottoms. Basis of extensive amateur fishery.

Racek & Dall 1965: 73; Grey el al 1983: 96.

Metapenaeus endeavouri (Schmitt, 1926)

N.S.W. (northern), Qld., N.T., W.A. (to Shark Bay). Juveniles in shallow estuaries (<10 m), adults deeper (to 50 m). Trawled over mud or sandy bottom. Commercial species.

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Dall 1957: 187, 189; Racek & Dall 1965: 77; Grey *et al.* 1983: 86. WAM 170-73 Hopeless Reach.

Metapenaeus ensis (de Haan, 1850)

N.S.W. (central), Qld., N.T., W.A. (to Shark Bay); Indo-West Pacific (Sri Lanka to Japan). Inshore waters (<3 m) to offshore (65 m), usually most abundant over mud or sandy bottoms. Juveniles estuarine. Commercial species. Dall 1957: 190; Racek & Dall 1965: 58; Grey *et al.* 1983: 90.

Penaeus esculentus Haswell, 1879

N.S.W. (mid), Qld., Gulf of Carpentaria, N.T., W.A. (to Shark Bay); S. Borneo. Juveniles occupy shallow waters of estuaries' etc., adults to 200 m but generally trawled in 10-20 m, over mud, sandy mud bottom. Commercial species. Dall 1957: 159; Racek & Dall 1965: 11; Grey *et al.* 1983: 66. WAM 160-73 Denham; 177-73 Hopeless Reach; 570-73 Carnarvon.

Penaeus latisulcatus Kishinouye, 1896

N.S.W. (northern), Qld., N.T., W.A., S. Aust.; Indo-West Pacific (Red Sea and south-eastern Africa to Indonesia, New Guinea, Japan). Trawled over hard bottoms of sand, sandy mud, or gravel to 90 m. Juveniles occupy nursery areas in shallow waters of high salinity. Major commercial species. Dall 1957:151; Penn & Hall 1974: 1; Penn 1975: 93; Grey *et al.* 1983: 56. WAM 156-73 Bernier I.; 571-73 Carnaryon.

Penaeus longistylus Kubo, 1943

Qld., Gulf of Carpentaria, N.T., W.A. (to Shark Bay), Lord Howe I.; South China Sea, Malaysia. In 35-55 m, associated with hard bottoms near reefs. Penn 1980: 547; Grey *et al.* 1983: 50. WAM 143-73 Bernier I; 157-72 6 km NE Koks I.; 144-73 off Koks I.

Penaeus marginatus Randall, 1840

Northeastern and northwestern Australia (to Shark Bay); Indo-West Pacific (East Africa, Madagascar to Hawaii). In 40 to 300 m over sand and muddy sand, uncommon.

Grey et al 1983: 48.

Penaeus merguiensis de Man, 1888

N.S.W. (northern), Qld., Gulf of Carpentaria, N.T., W.A. (to Shark Bay); Indo-West Pacific (Persian Gulf to New Guinea, New Caledonia). Trawled over muddy bottom, in 10-45 m. Commercial species.

Racek & Dall 1965: 17; Grey et al. 1983: 58.

Trachypenaeus anchoralis (Bate, 1888)

Qld. (Keppel Bay), N.T., W.A. (to Shark Bay). To 60 m over varying bottom type (mud to coral debris).

Racek & Dall 1965: 93; Grey et al. 1983: 122.

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Trachypenaeus curvirostris (Stimpson, 1860)

N.S.W. (Sydney), Qld., N.T., W.A. (to Shark Bay); Indo-West Pacific (Red Sea to Japan) through Suez Canal to Mediterranean. In 13-150 m, over muddy sand. Racek & Dall 1965: 89; Grey *et al.* 1983: 124.

Trachypenaeus fulvus Dall, 1957

Qld. (Moreton Bay), N.T., W.A. (to Shark Bay); Philippines, Malaysia, Indonesia. From 60 m, over muddy bottom. Grey *et al.* 1983: 120.

Suborder Pleocyemata Burkenroad, 1963 Infraorder Stenopodidea Claus. 1872

STENOPODIDAE Claus, 1872

Stenopus hispidus (Olivier, 1791)

N.S.W., Qld., N.T., W.A. (to Rottnest I.); Indo-West Pacific (E Africa to Hawaii), also W Indies and Caribbean Sea. In rock crevices, coral or underwater caves; known to clean fish. Holthuis 1946: 20.

WAM 486-73 W of Carnarvon; 2334-86, 2337-86 Carnarvon Blow Holes.

Infraorder Caridea Dana, 1852

PALAEMONIDAE Rafinesque, 1815

Anchistus custos (Forskål, 1775)

Qld., S. Aust., W.A. (Shark Bay and Monte Bello Is), S. Aust. (St. Vincent Gulf); common and widespread throughout the Indo-West Pacific region (to Fiji). Mainly in association with bivalves of the genus *Pinna*.

Miers 1884: 291 (as *Harpilius inermis*); Rathbun 1914: 656 (as *Anchistus inermis*); Bruce 1983: 199.

WAM 1193-85 Denham.

Coralliocaris graminea (Dana, 1852)

Qld. (Palm Is, Great Barrier Reef); W.A. (Rottnest I., Pt. Quobba); Indo-West Pacific (except Hawaiian Is). Obligate symbiont of *Pocillopora* and *Acropora* corals.

Black & Prince 1983: 139 (as Coralliocaris ?viridis/?graminea); Bruce 1983: 201.

Harpiliopsis beaupressii (Audouin, 1825)

Qld. (Heron I.), W.A. (Rottnest I., Pt. Quobba). Throughout Indo-West Pacific, also Easter I. Abundant on corals of the genera *Pocillopora* and *Stylophora*, in 4-6 m.

Black & Prince 1983: 139; Bruce 1983: 202. WAM 25-82, 39-82 Pt. Quobba.

Marine decapod Crustacea

Palaemonella rotumana (Borradaile, 1898)

Qld. (Low Isles, One Tree I., Heron I., Moreton Bay), W.A. (Rottnest I., Shark Bay); Indo-West Pacific. One of the commonest and most widely distributed pontonine species, from Red Sea to Hawaii and into E Mediterranean. Freeliving, in shallow water to 125 m (common in 4-6 m), associated with but not necessarily symbiotic with coral.

Black & Prince 1983: 139; Bruce 1983: 204. WAM 477-63 Outer Beacon I.

Palaemonetes atrinubes Bray, 1976

W.A. - Swan R. to Cockatoo I. Usually close to shore in shallow water, over mud or detritus.Bray 1976: 76, Figs 23-42.WAM 456-73 (P) Gladstone.

Periclimenes amymone de Man, 1902

Qld. (Heron I., One Tree I.), W.A. (Pt. Quobba); Nicobars to Samoan Is. Associated with corals of the genera *Pocillopora*, *Stylophora* and *Acropora*. Black & Prince 1983: 139. WAM 41-82 Pt. Quobba.

ALPHEIDAE Rafinesque, 1815

Alpheopsis trispinosa (Stimpson, 1861)

N.S.W. (Port Jackson), Tas., S. Aust., W.A. (to Shark Bay). Trawled from 11-137m.

Banner & Banner 1982: 308. WAM 250-79 between C. Inscription and C. St Cricq.

Alpheus alcyone de Man, 1902

Qld. (Lizard I.), N.T., W.A. (to Shark Bay); Indo-West Pacific (Red Sea, Persian Gulf, E Africa to Fiji, Tonga and Samoa). To 130 m, associated with dead coral heads and living sponges. Banner & Banner 1982: 113.

WAM 202-79 NW of Carnarvon.

Alpheus bicostotus de Man, 1908

Qld. (to One Tree I.), N.T., W.A. (to Shark Bay); Indonesia, Philippines. Intertidal to 12 m.

Banner & Banner 1982: 127; Black & Prince 1983: 139.

WAM 116-65 near bar of South Passage; 28-82 Pt. Quobba.

Alpheus chiragricus H. Milne Edwards, 1837

Qld. (to Port Curtis), N.T., W.A. (Cape Jaubert to Cockburn Sound); Indonesia, Mergui Arch. Under intertidal rocks, also dredged to 20 m; in dead coral heads, in fouling communities on buoys, etc., in sponges. Banner & Banner 1982: 270.

Alpheus collumianus Stimpson, 1861

Qld. (northern), N.T., W.A. (to Houtman Abrolhos Is); Indo-West Pacific (Red Sea, Madagascar to Hawaii and Society Is). Common on reef flats and dredged to 75 m; associated with dead coral heads.

Banner & Banner 1982: 49; Black & Prince 1983: 139.

WAM 29-82 Pt. Quobba.

Alpheus distinguendus de Man, 1909

N.S.W. (Botany Bay), Qld., N.T., W.A. (to Perth); Mergui Arch., Singapore, China, Japan. Trawled in <37 m.

Banner & Banner 1982: 160.

WAM 134-65 N of Peron Flats; 241-65 Shark Bay; 264-65 Shark Bay.

Alpheus edwardsii (Audouin, 1827)

All coasts of Australia; Indo-West Pacific (Red Sea, Philippines, Thailand). Largely intertidal, under rocks in sandy, muddy conditions; dredged to 26 m; also from buoys, beacons and dead coral.

Rathbun 1914: 654 (as *Crangon edwardsii*); Hale 1927: 308; 1929: 68; (both as *C. edwardsi*); Banner & Banner 1982: 273.

WAM 167-65, 179-65, 243-65 Shark Bay; 123-65 Denham; 168-65, 169-65 Monkey Mia; 106-65 Dirk Hartog I.; 161-65 'tween C. Inscription and C. St Cricq; 286-65 Pt. Gregory, NW side of Peron Pen.

Alpheus facetus de Man, 1908

N.S.W. (Sydney), Qld., N.T., W.A. (to Perth); Vietnam, Thailand, Indonesia, Philippines. Intertidal to 30 m, mostly collected in 6 m or less, from dead coral heads.

Banner & Banner 1982: 65.

Alpheus gracilis Heller, 1861

W.A. (Rottnest I., Pt. Quobba); Indo-West Pacific (Red Sea. ?S. Africa to Society Is, Hawaii).

Black & Prince 1983: 139.

Alpheus inopinatus Holthuis & Gottlieb, 1958

N.S.W. (Grafton), Qld., N.T., W.A. (to Perth); Mediterranean coast of Israel, W Pakistan. Intertidal under rocks.

Banner & Banner 1982: 242.

WAM 256-79 Pt. Gregory, NW side of Peron Pen.

Alpheus lobidens lobidens de Haan, 1850

N.S.W. (Sydney), Qld., N.T., W.A. (Houtman Abrolhos Is), Lord Howe I.; Indo-West Pacific (Red Sea to Hawaii). Intertidal to 26 m. In mud, occasionally in dead coral heads.

Banner & Banner 1982: 252.

WAM 142-65 SW of Herald Cay.

Marine decapod Crustacea

Alpheus lottini Guérin, 1829

N.S.W. (Sydney), Qld., N.T., W.A. (Dampier Arch. to Perth), Lord Howe I.; widespread Indo-West Pacific (Red Sea to Gulf of California). Obligate symbiont on *Pocillopora* coral; subtidal, associated with crabs of the genus *Trapezia*. Banner & Banner 1982: 68; Black & Prince 1983: 139. WAM 32-82 Pt. Quobba.

Alpheus novaezealandiae Miers, 1876

All coasts of Australia; New Zealand. Intertidal under rocks, or associated with seagrasses and tunicates; dredged to 26 m. Banner & Banner 1982: 148. WAM 23-65 Carnarvon area; 237-65 Shark Bay or Exmouth Gulf.

Alpheus pachychirus Stimpson, 1861

Qld. (to Port Douglas), N.T., W.A. (to Pt. Quobba); Indo-West Pacific (Red Sea to Tahiti). Mainly an obligate dweller in algal tubes, lower intertidal to 36 m. Banner & Banner 1982: 105; Black & Prince 1983: 139. WAM 33-82 Pt. Quobba.

Alpheus pacificus Dana, 1852

N.S.W. (to Sydney), Qld., N.T., W.A. (to Perth); Indo-West Pacific (Red Sea and E. Africa to Clipperton I.). Intertidal under rocks on reef flats, occasionally burrowing in clean sand, and from dead coral heads, to 20 m. Banner & Banner 1982: 220. WAM 43-65 Pt. Quobba.

Alpheus palyxo de Man, 1909

Qld. (to Stradbroke I.), N.T., W.A. (to Shark Bay); Indonesia. In dead coral to 4 m, extending to 130 m. Banner & Banner 1982: 276. WAM 201-79 NW of Carnarvon; 222-79 Shark Bay.

Alpheus papillosus Banner & Banner, 1982

N.S.W. (Careel Bay), Qld., N.T., W.A. (to Cockburn Sound), also S. Aust. (Kangaroo I.). Intertidal, under stones and dredged to 18 m. Banner & Banner 1982: 263; Jones 1986: 27. WAM 34-65 (P) Exmouth Gulf or Shark Bay.

Alpheus paracyone Coutière, 1905

Qld. (Heron I. to Lizard I.), N.T., W.A. (off Carnarvon); Indo-West Pacific (Maldives, Seychelles, Ceylon, Indonesia, to Hawaii). From dead coral heads, subtidal to 165 m.

Banner & Banner 1982: 116.

WAM 290-65, 219-79 W of Carnarvon.
Alpheus parasocialis Banner & Banner, 1982

Old. (to Moreton Bay), N.S.W., Vic., Tas., S. Aust., W.A. (to Shark Bay), Tas. Intertidal and subtidal to 135 m.

Banner & Banner 1982: 72; Jones 1986: 28.

WAM 23-65 (P) Carnarvon; 95-65 (P), 108-65 (P), 203-65 (P), 228-65 (P) near bar of South Passage; 173 to 175 Bernier I.

Alpheus parvirostris Dana, 1852

Old. (to Capricorn Gp.), N.T., W.A. (to Houtman Abrolhos Is); Indo-West Pacific (Red Sea, South Africa to Japan, Society Is). Dredged to 32 m, also abundant on reef flats; in dead coral and living sponges. Banner & Banner 1982: 188.

Alpheus rapacida de Man. 1908

Qld. (One Tree I.), N.T., W.A. (to Shark Bay); Indo-West Pacific (Red Sea, South Africa to Hawaii). Intertidal to 56 m, burrows in sandy to muddy bottoms. Banner & Banner 1982: 163. WAM 244-65 Shark Bay.

Alpheus spongiarum Coutière, 1897

Qld. (Heron I.), N.T., W.A. (to Cockburn Sound); Indo-West Pacific (Djibouti, Gulf of Aden to Japan). Intertidal to 42 m, in sponges. Banner & Banner 1982: 116. WAM 203-79 NW of Carnaryon.

Apheus sulcatus Kingsley, 1878

Vic., N.S.W. (Sydney), Old., W.A. (C. Leveque to Rottnest I.); Indo-West Pacific (Red Sea to Society Is); E. Pacific (Galapagos to Panama and Peru); E. Atlantic. Intertidal, under rocks, and in corals from shallow water. Dredged to 24 m. Banner & Banner 1982: 83.

WAM 41-65, 173-65 Shark Bay, 80 km SW of Carnarvon.

Athanus areteformis Coutière, 1903

Qld., Torres Str., W.A. (Pt. Quobba); Indo-West Pacific (Red Sea, South Africa to Tonga, Samoa and Society Is). In dead coral heads. Banner & Banner 1973: 306; Black & Prince 1983: 10.

Athanas dimorphus Ortmann, 1894

N.S.W. (to Port Jackson), Qld., N.T. (Darwin), W.A. (to Perth); Indo-West Pacific (to Philippines, New Caledonia). Under rocks and associated with coral heads and rubble.

Banner & Banner 1973: 316: Black & Prince 1983: 139.

Athanas ornithorhynchus Banner & Banner, 1973 N.T., W.A. (to Cockburn Sound). From growth on pearl shell. Banner & Banner 1973: 321. AM P18001 (P) Shark Bay.

Athanas sibogae de Man, 1910

Qld. (Whitsunday and Capricorn Gp), Torres Str., N.T., W.A. (Dampier to Rockingham); Indo-West Pacific (Red Sea, Singapore, Indonesia, Japan, Philippines, Tonga, Samoa). Intertidal under rocks on sandy beaches, also dredged to 70 m; in live and dead coral and living sponges.

Banner & Banner 1973: 324; Black & Prince 1983: 139.

Metalpheus paragracilis (Coutière, 1897)

Qld. (C. Moreton to Coral Sea), N.T., W.A. (Houtman Abrolhos Is and Dirk Hartog I.); ?circumtropical (Red Sea to Hawaii and Society Is); St. Helena (Atlantic Ocean). Largely on dead coral, calcareous algae and under inter-and sub-tidal rocks, also dredged to 20 m.

O'Loughlin 1969: 37; Banner & Banner 1983: 282.

Synalpheus comatularum (Haswell, 1882)

Qld. (C. Grenville), Torres Str., W.A. (Broome to Busselton); Ceylon, Singapore. Often associated with crinoids.

Banner & Banner 1975: 290.

WAM 115-65, 128-65 near bar of South Passage; 190-65 Shark Bay; 37-65 Dirk Hartog I.; 220-65 ? Shark Bay.

Synalpheus carinatus (de Man, 1888)

Qld. (Moreton Bay to Capricorn Gp.), W.A. (Bluff Pt. and Shark Bay); Indonesia, Malaysian Arch., Caroline, Marshall and Gilbert Is. Often associated with crinoids, to 98 m.

Banner & Banner 1975: 284. WAM 171-65 near bar of South Passage.

Synalpheus demani Borradaile, 1900

W.A. (between Shark Bay and C. Farquar); Indo-West Pacific (Red Sea, Indonesia, Philippines, Japan, Loyalty and Marshall Is). Often associated with crinoids. Banner 1975: 326.

AM 177 dredged 'tween Shark Bay and C. Farquar.

Synalpheus fossor (Paulson, 1975)

Qld. (Southport), N.T., W.A. (Shark Bay to south-western areas), also S. Aust. (Spencer Gulf and Kangaroo I.); Indo-West Pacific (Red Sea, Maldive Arch., Indonesia, Thailand, Philippines). Associated with dead coral and living sponges. Banner & Banner 1975: 340.

WAM 108-65 near bar of South Passage.

Synalpheus heroni Coutière, 1909

Qld. (Great Barrier Reef), W.A. (Dirk Hartog I.); Indo-West Pacific (Red Sea to Fiji, Phoenix and Line Is, Society Arch.). Associated with dead coral heads, to 5 m.

Banner & Banner 1975: 334. WAM 192-65 W of Dirk Hartog I.

Synalpheus iocosta de Man, 1909

Gulf of Carpentaria, N.T., W.A. (to C. Naturaliste); Aru Is. Dredged from many types of bottom to 132 m. Associated with sponges and bryozoans. Banner & Banner 1975: 368. WAM 290-65 W of Carnarvon.

Synalpheus lophodactylus Coutière, 1908

Qld. (off Port Douglas to Whitsunday Gp.), W.A. (Dirk Hartog I.). Mostly from sponges, or dredged from 4 m, or from dead coral (1-2 m). Banner & Banner 1975: 352.

Synalpheus neomeris (de Man, 1888)

Qld. (Bundaberg), Gulf of Carpentaria, W.A. (Carnarvon to Esperance); Indo-West Pacific (Suez Canal, Red Sea, Persian Gulf to Japan). Commonly associated with alcyonarians, also sponges and dead coral heads; shallow water to 130 m. Banner & Banner 1975: 361.

WAM 91-65 NW of Carnarvon.

Synalpheus neptunus neptunus Banner & Banner, 1975

N.S.W. (Port Jackson), Qld., N.T., W.A. (to Perth); Indo-West Pacific (Red Sea to Japan, Sulu Sea). Associated with coral heads or sponges in shallow water, or dredged to 20 m.

Banner & Banner 1975: 317.

WAM 189-65, 243-65 Shark Bay; 289-65 W of Carnarvon.

Synalpheus nilandensis Coutière, 1905

W.A. (Exmouth Gulf, Dirk Hartog I., Houtman Abrolhos Is); Indo-West Pacific (Red Sea to Hong Kong, Tuamotus). Dredged 32-134 m. Banner & Banner 1975: 327.

Synalpheus stimpsoni (de Man, 1888)

N.S.W. (Sydney), Qld., N.T., W.A. (to 27°S); Indonesia, Singapore, Thailand, Celebes, Philippines, Japan, Marshall and Gilbert Is. Commonly associated with crinoids.

Banner & Banner 1975: 292.

WAM 115-65 near bar of South Passage.

Synalpheus streptodactylus Coutière, 1905

All coasts of Australia; Indo-West Pacific (Red Sea to Hawaii, Samoa). Intertidal to 68 m, in dead coral and living sponges.

Banner & Banner 1975: 364.

WAM 107-65 Denham; 290-65 W of Carnarvon; 34-65 Exmouth Gulf or Shark Bay.

Synalpheus tumidomanus (Paulson, 1875)

All coasts of Australia, Norfolk I., Lord Howe I.; Indo-West Pacific (S. Africa, Red Sea to Phoenix Arch.). Intertidal to 148 m, from heads of dead corals and living sponges.

Banner & Banner 1975: 382; Black & Prince 1983: 139. WAM 76-65 Pt. Peron; 125-65 Pt. Gregory, NW of Peron Pen.

HIPPOLYTIDAE Dana, 1852

Alope australis Baker, 1904 S. Aust., W.A. (Dirk Hartog I.). Hale 1929: 67.

Hippolysmata vittata Stimpson, 1860 W.A. (Dirk Hartog I.). Hale 1929: 67.

Saron marmoratus (Olivier, 1811)

W.A. (Pt. Quobba); Indo-West Pacific (Red Sea and Mozambique to Hawaii). In 2-4 m, from dead coral heads. Black & Prince 1983: 139 (as S. ?marmoratus).

Thor amboinensis (Heller, 1861)

W.A. (Pt. Quobba); Indo-West Pacific (Red Sea and Madagascar to Mariana Is). From 2 m, associated with living and dead coral, and *Cymodocea* and *Sargassum* beds.

Black and Prince 1983: 139. WAM 38-82 Pt. Quobba.

Infraorder Thalassinidae Latreille, 1831

AXIIDAE Huxley, 1879

Axiopsis brocki (de Man, 1887)

N.T. (Darwin), W.A. (to Augusta); Indonesia. Intertidal and shallow subtidal, usually on reefs.

Poore & Griffin 1979: 228.

Scytoleptus serripes Gerstaecker, 1856

Northern and north-western Australia (W.A. - Cockatoo I. to Exmouth Gulf); Indo-West Pacific (Mauritius, Madagascar, Aldabra, S. Africa to Indonesia). On intertidal reefs.

Poore & Griffin 1979: 243.

UPOGEBIIDAE Borradaile, 1903

Upogebia (Calliadne) hexaceras (Ortmann, 1894) Qld. (northern), N.T., W.A. (Dampier Arch. to Bunbury); Persian Gulf, Salawati

Is, Indonesia. Intertidal to 20 m; associated with sponges. Poore & Griffin 1979: 299.

Infraorder Palinura Latreille, 1803.

PALINURIDAE Latreille, 1803

Panulirus cygnus George, 1962

W.A. (North West Cape to C. Leeuwin). Shallow subtidal to 120 m, on rocky reefs. Basis of major fishery.

George 1962: 100, pls I-II, Figs 1-4; Jones 1986: 31, 32.

WAM 54-58 (P) W of Herald Heights, Dirk Hartog I.; 106-62 (P), 110-62 (P) Dirk Hartog I.; 111-62 (P) South Passage; 79-62 puerulus, W of Dirk Hartog I. and W of Steep Pt.; 81-62 puerulus, Dirk Hartog I.; 86-62 puerulus, W of Dirk Hartog I.

SCYLLARIDAE Latreille, 1825

Ibacus alticrenatus Bate, 1888 N.S.W. (Newcastle), Vic., Tas., S. Aust., W.A. (to Shark Bay); New Zealand. In 20-500 m, soft mud and sand. Holthuis 1985: Morgan & Jones 1987: 14. WAM 256-82 NW of Shark Bay.

Ibacus peronii Leach, 1815

N.S.W. (to Newcastle), Vic., Tas., S. Aust., W.A. (to Shark Bay). In 40-250 m, fine to coarse bottoms. Minor economic significance in W.A. George & Griffin 1972: 228; Holthuis 1985: 63. Holotype dry (PM) "Nouvelle Hollande" 1801-1803 F. Péron. WAM 156-81 NW of C. Cuvier; 157-81 off Carnarvon.

Scyllarides squammosus (H. Milne Edwards, 1837)

Eastern Australia and W.A. (Shark Bay); Indo-West Pacific (Zanzibar to Hawaii and N of Clipperton I.). Rocky areas of coral reefs. Holthuis 1946: 99. WAM 350-33 Shark Bay.

Scyllarus demani Holthuis, 1946

W.A. (Shark Bay); E of Sumatra. Trawled in prawn trawls, over sand. Holthuis 1946: 91.

WAM 166-57, 65-58, 319-64, 320-64, 325-64 to 327-64, 330-64, 19-65, 93-66 to 96-66, 1-71 Shark Bay; 332-64 nr Homestead, Shark Bay; 328-64 80 km SW of Carnarvon; 333-64 Denham Sound; 239-70 Hopeless Reach; 572-73 Carnarvon; 329-64 Exmouth Gulf or Shark Bay; 236-70 'tween Shark Bay and Onslow.

Thenus orientalis (Lund, 1793)

Qld. (to Moreton Bay), N.T., W.A. (to Shark Bay); Red Sea, Mauritius to E. India, Kermadec Is, China. Taken in prawn trawls, over muddy, sandy bottom. George & Griffin 1972: 228.

WAM 20-65, 573-73 Carnarvon.

Infraorder Anomura H. Milne Edwards, 1832

DIOGENIDAE Ortman, 1892

Calcinus dapsiles Morgan, in press. W.A. (E of Albany to Shark Bay). Subtidal (rarely intertidal) to 20 m, sand, rock, seagrass.

Morgan, in press. WAM 191-88 (P), 193-88 (P) Shark Bay.

Calcinus latens Randall, 1839

Eastern, northern and western Australia; Indo-West Pacific (E. Africa and Persian Gulf to Tuamotu and Hawaiian Is). Littoral and shallow sublittoral, often associated with coral.

Morgan, in press; Hale 1929: 68. WAM 911-88 Sunday I.

Clibanarius taeniatus (H. Milne Edwards, 1848) Type Locality N.S.W. (Port Hacking), Qld., Gulf of Carpentaria, N.T., W.A. (to Shark Bay). Quoy & Gaimard 1824: 529 (as *Pagurus clibanarius*); Miers 1884: 265; McCulloch 1913: 349; Morgan 1987: 173. WAM 906-88, 908-88 Shark Bay.

Clibanarius virescens (Krauss, 1843)

Qld., N.S.W., W.A. (Shark Bay), Lord Howe I.; New Caledonia, Funafuti - Ellice Gp.

McCulloch 1913: 346; Hale 1929: 68; Morgan 1987: 171; Morgan, in press. WAM 921-88 Shark Bay.

Dardanus imbricatus (H. Milne Edwards, 1848) Qld., N.T., W.A. (Shark Bay); ? New Zealand; Ceylon, Vietnam. Miers 1884: 264; Morgan 1987: 184.

Dardanus setifer (H. Milne Edwards, 1836) N.T., W.A. (Shark Bay); Indo-West Pacific (E. Africa to Hong Kong). Morgan 1987: 181. WAM 846-86.

Diogenes granulatus Miers, 1880 W.A. (Shark Bay). Miers 1880: 373; Haswell 1882: 158.

PAGURIDAE Latreille, 1803

Pagurus sinuatus (Stimpson, 1858) N.S.W. (to Sydney), Vic., S. Aust., W.A. (to Shark Bay). Subtidal to 20 m, usually associated with high energy shores. Morgan, in press.

LOMIDIDAE Bouvier, 1895

Lomis hirta Lamarck, 1810

Tas., Vic., S. Aust., W.A. (to Shark Bay). Intertidal under rocks on medium to high-energy coasts.

Hale 1929: 68; Phillips et al. 1984: 111.

GALATHEIDAE Samouelle, 1819

Allogalathea elegans (White, 1848)

Qld. (southern), Torres Str., W.A. (C. Jaubert, Shark Bay); Indo-West Pacific (Red Sea to Fiji Is). Littoral to 146 m, frequently associated with comatulid Crinoidea. Haig 1973: 276.

WAM 91-68 'tween Shark Bay and Nickol Bay.

Galathea australiensis Stimpson, 1858

N.S.W. (to Port Jackson), Vic., S. Aust., W.A. (to Shark Bay). Usually occurring under rocks in the shallow subtidal. Miers 1884: 278; Glauert 1924: 62; Haig 1973: 277. WAM 47-72 NE corner of Dirk Hartog I.

Phylladiorhynchus pussilus (Henderson, 1885)

Qld. (Capricorn Gp), N.S.W., Vic., Tas., S. Aust., W.A. (to Shark Bay); Indian Ocean (Providence I.), Japan, New Zealand. Littoral to 310 m, common in deeper water.

Haig 1973: 277, 282.

WAM 276-64 Outer Beacon, Shark Bay.

PORCELLANIDAE Haworth, 1825

Pachycheles johnsonii Haig, 1965Type LocalityN.T. (Darwin), W.A. (Broome to C. Leeuwin); Palau, Caroline and MarshallIs. Intertidal, under stones, on rocky reefs; also trawled in 29 m.Haig 1965: 102; Jones 1986: 32.WAM 197a-60 (H), 197b-60 (P) Pt. Gregory, NW side of Peron Pen.

Pachycheles sculptus (H. Milne Edwards, 1837)

Qld., N.T., W.A. (SW of Troughton I. to Cottesloe); Mergui Arch., China, Philippines, E. Indies, Ryukyu Is, Loyalty Is. Intertidal, under stones, also trawled to 180 m.

Haig 1965: 102; 1973: 283.

WAM 356-60, 321-62, 332-62, 334-62, 337-62, 77-68 Shark Bay; 196-60 Pt Gregory, NW side Peron Pen.; 338-62 near bar of South Passage; 354-62, 355-62 NE side of Peron Flats; 45-72 NE corner Dirk Hartog I.; 76-62 Exmouth Gulf or Shark Bay.

Petrolisthes boscii (Audouin, 1826)

2Qld., 2N.T., W.A. (Pender Bay to Port Gregory); Indo-West Pacific (Red Sea to Japan). Intertidal, under stones and coral, on reef flats, beaches. WAM 204-57 SE end Dirk Hartog I.; 194-60 Pt. Gregory, NW side Peron Pen;

42-68 Quoin Bluff, Dorré I.

McCulloch 1913: 353; Hale 1929: 68; Haig 1965: 99.

Petrolisthes haswelli Miers, 1884

Qld., N.T., W.A. (Yampi Sound to Shark Bay). Intertidal, under stones on reef flats, beaches. Haig 1965: 100.

WAM 194-60 Pt. Gregory, NW side of Peron Pen.; 57-68 Monkey Mia.

Petrolisthes militaris (Heller, 1862)

Qld., N.T., W.A. (Broome to Shark Bay); Indian Ocean (Seychelles to Nicobars), Japan to Philippines, E. Indian Arch. In 9-12 m. Haig 1965: 98. WAM 356-60 off Shark Bay; 76-68 Shark Bay; 113-68 W of Koks I.; 115-68 off

Carnarvon.

Petrolisthes ohshimai (Miyake, 1937)

Qld., W.A. (Roebuck Bay to Shark Bay); Indo-West Pacific (Zanzibar to Marshall and Fiji Is). Low tidal levels. Haig 1965: 101. WAM 39-68 Shark Bay.

Petrolisthes scabriculus (Dana, 1852)

W.A. (Peak I., Onslow, Shark Bay); Philippines, E Indian Arch. In 11-18 m. Haig 1965: 98. WAM 46-72 NE corner Dirk Hartog I.

Petrolisthes teres Mclin, 1939

Qld., W.A. (Broome to Shark Bay); Gulf of Siam. Intertidal, under stones, on rocky reefs, beaches.
Miers 1884: 268 (as *P. japonicus* var. *inermis*); Hale 1929: 68 (as *P. japonicus*); Haig 1965: 100.
WAM 179-60 Monkey Mia; 195-60 Denham; 40-62 Pt. Gregory; 75-62 Dirk Hartog I.; 58-68 Red Bluff, Shark Bay.

Pisidia spinuligera (Dana, 1852)

W.A. (Pender Bay to Abrolhos Is); Ryukyu Is, Palau Is, Hong Kong, East Indian Arch. Intertidal, among coral, also to 27 m. Haig 1965: 106. WAM 206-57, 207-57 SE of Dirk Hartog I.

Pisidia dispar (Stimpson, 1858)

Qld., N.S.W., S. Aust., W.A. (Warnbro Sound to Broome); Japan. Intertidal, on reefs, boom piles, also to 54 m. Haig 1965: 107; 1973: 284. WAM 339-62 near bar of South Passage, Shark Bay.

Polyonyx biunguiculatus (Dana, 1852)

Qld., W.A. (King Sound to Shark Bay); Indo-West Pacific (Eritrea, Seychelles to East Indian Arch., Taiwan). In 24-37 m. Haig 1965: 113. WAM 76-62 Exmouth Gulf or Shark Bay; 78-68 Shark Bay; 112-68 off Carnarvon.

Polyonyx maccullochi Haig, 1965

Qld. (Port Curtis), W.A. (Broome to Shark Bay). Low tidal level to 17 m. Haig 1965: 114, Fig. 3; Jones 1986: 33. WAM 334c-62 (P) Shark Bay.

Polyonyx obesulus Miers, 1884

Qld., N.T., W.A. (SW Troughton I. to SW of Geraldton); Indo-West Pacific (Gulf of Iran to E Indian Arch., Philippines). Littoral to 54 m. Haig 1965: 113; 1973: 285.

Polyonyx triunguiculatus Zehntner, 1894

W.A. (Broome to Shark Bay); Indo-West Pacific (Red Sea to Singapore, Amboina, Sumatra). In 18-42 m.Haig 1965: 113.WAM 76-62 Exmouth Gulf or Shark Bay; 334-62 Shark Bay.

Porcellana gravelei Sankolli, 1963

N.S.W., Qld., N.T., W.A. (Broome to Esperance); India. Intertidal to at least 17 m, usually under rocks on sand or reefs. Haig 1965: 108. WAM 196-60 Pt. Gregory, NW side of Peron Pen.

Porcellana triloba White, 1852

Qld. (Bowen and off C. Capricorn), W.A. (SW of Adele I. to Shark Bay). In 6-73 m. Haig 1965: 111. WAM 34-68 W of Koks I.

ALBUNEIDAE Stimpson, 1858

Austrolepidopa trigonops Efford & Haig, 1968 W.A. (Beagle I. to Rottnest I.). To 35 m, from soft substrates. Efford & Haig 1968: 904; Jones 1986: 33. WAM 72-62 (P) near bar of South Passage.

HIPPIDAE

Hippa pacifica (Dana, 1852)
N.S.W. (Coffs Harbour), Qld., N.T., W.A. (to Rottnest I.); Indo-West Pacific (E. Africa to Panama). Intertidal, sandy substrates.
Haig 1974: 181.
WAM 117-68 Pt. Quobba.

Infraorder Brachyura Latreille, 1803 Section Dromiacea de Haan, 1833

DROMIIDAE de Haan, 1833

Dromidiopsis michaelsensi Balss, 1935 Type Locality W.A. (Cockburn Sound, Warnbro Sound, Shark Bay). In 7-11 m. Balss 1935: 113.

Petalomera lateralis (Gray, 1831)

Qld. (Low Isles), N.S.W., Vic., S. Aust., W.A. (to Nickol Bay); ?Japan, Philippines. Intertidal, to 220 m. Usually carries sponges or ascidians on carapace. Miers 1884: 259; Griffin & Yaldwyn 1971: 44; Griffin 1972: 55. WAM 58-83 Hopeless Reach.

Platydromia thomsoni Fulton & Grant, 1902 Vic. (to Westernport Bay), S. Aust., W.A. (to Shark Bay). In 46-137 m. Griffin 1972: 52. WAM 1248-85 14 km W of South Passage.

Section Archaeobrachyura Guinot, 1977

RANINIDAE de Haan, 1839

Lyreidus tridentatus de Haan, 1841

Qld. (from N of C. Moreton), Vic. (to Bass Str.), W.A. (from Rottnest I. to Carnarvon); Indo-West Pacific (Japan, Hong Kong, New Caledonia, New Zealand, Hawaii). In 50-400 m, over muddy sand or sand. Griffin 1972: 56. WAM 58-64 NW of Carnarvon.

Notopus ovalis Henderson, 1888

W.A. (Houtman Abrolhos, Shark Bay); Japan, Little Ki I. Dredged in 70 m, over sand.

Tyndale-Biscoe & George 1962: 90. WAM 348-60 3 km W of C. Couture, Bernier I.

Section Oxystomata H. Milne Edwards, 1834

DORIPPIDAE Macleay, 1838

Dorippe (Dorippe) frascone (Herbst, 1785)

Qld., W.A. (Shark Bay to Dampier Arch.); E. Africa to China, Japan, Banda and Amboina. To 20 m, over sand, weed and rock.

Miers 1884: 257 (as D. dorsipes); Tyndale-Biscoe & George 1962: 66.

WAM 62-64 NW Bluff Pt.; 63-64 NW of Carnarvon; 64-64, 68-64, 72-64, 73-64, 12-70 Shark Bay; 65-64 W of Dirk Hartog I.; 67-64 NE side of Peron Flats; 4-70 SE Corner of Dirk Hartog I.; 5-70 Hopeless Reach; 7-70 W of Koks I.; 11-70 'tween Shark Bay and Onslow; 334-60 Exmouth Gulf or Shark Bay.

CALAPPIDAE de Haan, 1833

Calappa calappa (Linnaeus, 1758)

W.A. (Shark Bay); Indo-West Pacific (E. Africa, Mauritius to Hawaii). To 10-50 m, bottoms of rock or broken shells.

Tyndale Biscoe & George 1962: 69.

WAM 296-60 Koks I.; 14-70 to 16-70 Shark Bay; 17-70 South Passage, mainland side.

Calappa hepatica (Linnaeus, 1758)

Eastern Australia, W.A. (Abrolhos to Yampi Sound); widespread in Indo-West Pacific. In 10-50 m, on hard substrates, coral reefs.

Tyndale-Biscoe & George 1962: 69.

WAM 616-85 Carnarvon.

Calappa philargius (Linnaeus, 1758)

Eastern Australia, W.A. (Swan R. to Dampier); Indo-West Pacific (Red Sea to Japan, Samoa). In 30-100 m, substrate sand or broken shells.

Tyndale-Biscoe & George 1962: 69.

WAM 9623 Maud Landing; 401-38 Dirk Hartog I.; 301-60 9 km W of Cape St Cricq, Dorré I.; 302-60 Carnarvon; 195-64 to 197-64 Shark Bay.

Matuta granulosa Miers, 1877

Qld., W.A. (Yampi Sound to Shark Bay); Indian Ocean. Intertidal to 55 m, substrate sand.

Tyndale-Biscoe & George 1962: 71.

WAM 318-60 9 km SW C. Ronsard, Bernier I.; 151-64, 106-70, 107-70 Shark Bay; 163-73 NE Koks I.

Matuta planipes Fabricius, 1798

Northern and north-western Australia (W.A. - Broome to Shark Bay); Indian Ocean, East Asia and Japan. In shallow waters, substrate sand.

Tyndale-Biscoe & George 1962: 71. WAM 137-64 'tween Shark Bay and Pt. Sampson.

Matuta inermis Miers, 1884 Qld. (Thursday I.), Torres Str., N.T., W.A. (Broome to Shark Bay). In 11 m, substrate sand. Tyndale-Biscoe & George 1962: 72. WAM 102-70 W of Koks I.

Matuta lunaris (Forskål, 1775)

Eastern Australia, W.A. (Yampi Sound to Shark Bay); Indian Ocean, East Indies, Asia. Intertidal and to 15 m, substrate sand. Miers 1884: 256 (as *M. victrix*); Tyndale-Biscoe & George 1962: 71.

WAM 217-47 40 km N of Carnarvon; 316-60 Pt. Gregory, NW end of Peron Pen.

LEUCOSIIDAE Samouelle, 1819

Actaeomorpha erosa Miers, 1878

Qld., W.A. (Shark Bay); Mauritius, Kermadec Is, Hawaii. Intertidal to 20 m, substrate sand, coral reefs.

Balss 1935: 117; Tyndale-Biscoe & George 1962: 76.

Arcania novemspinosa (Adams & White, 1849)

North-eastern and north-western Australia (Shark Bay); Philippines, Indian and Malaysian Archs. Dredged in 70 m over loose coral and rock. Tyndale-Biscoe & George 1962: 76. WAM 283-60 'tween C. Inscription and C. St Cricq.

Arcania quinquespinosa Alcock & Anderson, 1894

W.A. (Shark Bay); Indo-West Pacific (Red Sea to Japan). In 60-150 m, on sandy mud. Sakai 1976: 95.

Sakal 1970: 95.

WAM 168-64 NW of Carnarvon; 169-64 NW of Dirk Hartog I.

Arcania undecimspinosa de Haan, 1841

Qld., W.A. (Shark Bay, Rottnest I.); India, Seychelles, China, Japan. In 30-100m over sand, sandy mud, sponge and Bryozoa. Sakai 1976: 91. WAM 180-64 Shark Bay.

Ixa acuta Tyndale-Biscoe & George, 1962 Qld., W.A. (Shark Bay to Onslow); India, Seychelles, China, Japan. Trawled 30-100 m, over sand and sandy mud. Tyndale-Biscoe & George 1962: 72. WAM 33-71 'tween Shark Bay and Onslow.

Ixoides comutus MacGilchrist, 1905

W.A. (Shark Bay); Persian Gulf, Hong Kong, Japan. In 50-100 m, on bottoms of sand or rock. Sakai 1976: 103.

WAM 245-64 NW of Dirk Hartog I.; 247-64 NW of Carnarvon.

Leucosia haematosticta Adams & White, 1848

Qld., N.S.W., W.A. (Shark Bay and Malus I., Dampier Arch.); Indo-Pacific (including Palk Str., Singapore, Japan and Timor). In 18-100 m on shelly or soft sandy bottoms.

Tyndale-Biscoe & George 1962: 80; Griffin 1972: 64; Sakai 1976: 121. WAM 223-60 16 km W of C. Couture, Bernier I.

Leucosia haswelli Miers, 1886

Qld. (Thursday I.), W.A. (Shark Bay and Dampier Arch.); Bay of Bengal, Andamans, Gulf of Siam, Singapore, Celebes. In 18 m on sandy bottom. Tyndale-Biscoe & George 1962: 84. WAM 237-60 E side of Dirk Hartog I.; 240-60 near Homestead, Shark Bay; 242-

60 C. Inscription; 116-64 Shark Bay.

Leucosia perlata de Haan, 1841

Qld. (Thursday I.), W.A. (Yampi Sound to Cockburn Sound); Persian Gulf, Indian Arch. to New Guinea, Hong Kong. On sandy bottoms in shallow water. Tyndale-Biscoe & George 1962: 86. WAM 118-64 'tween Shark Bay & Pt. Sampson.

Leucosia pubescens Miers, 1877 Type Locality W.A. (Shark Bay, Rottnest I.); Indian Ocean from Red Sea to India, East Indies, Japan. From inshore waters and estuaries. Miers 1877: 238; Haswell 1879: 46; 1882: 119; Glauert 1924: 61; Tyndale-Biscoe & George 1962: 84.

Leucosia reticulata Miers, 1877 Type Locality Northern and western Australia (W.A. - Yampi Sound to Shark Bay). Intertidal on reefs and beaches. Miers 1877: 237; Haswell 1882: 119; Tyndale-Biscoe & George 1962: 80.

WAM 1525-30, 1526-30 Shark Bay; 15-50 Carnarvon (donated to BMNH); 208-60 Denham; 214-60 Monkey Mia.

Leucosia unidentata de Haan, 1841

Torres Str., W.A. (Shark Bay, Rottnest I.); Japan, Hong Kong, Malabar, Moluccas. In 30-150 m, over sand or sandy mud. Sakai 1976: 119. WAM 122-64 NW of Dirk Hartog I.

Leucosia whitei Bell, 1855

North-eastern Australia, W.A. (Dampier Arch., Onslow, Shark Bay); Indo-West Pacific (E. Africa to E. Indies). In 26-51 m, over sand and mud, sponge. Miers 1884: 249; Tyndale-Biscoe & George 1962: 77.

Myra affinis Bell, 1855

North-eastern and north-western Australia (W.A. - Shark Bay to Dampier Arch.); Persian Gulf, Indian Arch., E. Indies. In 5-84 m, over sand, mud, gravel, shell. Rathbun 1924: 26; Tyndale-Biscoe & George 1962: 88. WAM 1540-86 Shark Bay.

Myra australis Haswell, 1880

Qld., Torres Str., W.A. (Dampier Arch., Shark Bay); Singapore, Gulf of Martaban. In 5-57 m, over sand, mud.

Miers, 1884: 251; Tyndale-Biscoe & George 1962: 88.

Myra mammillaris Bell, 1855

Qld. (Port Dennison), S. Aust., W.A. (Leighton Beach to Yampi Sound). Estuarine to marine, in 18 m over sand, weed and rock.

Tyndale-Biscoe & George 1962: 89.

WAM 5785, 1-61, 219-64, 220-64 Shark Bay; 281-60 2 km E of Koks I., Bernier I.

Pseudophilyra perryi (Miers, 1877)

W.A. (Shark Bay). Miers 1877: 237 (as *Leucosia Perryi*); Haswell 1879: 46 (as *L. Perryi*); Haswell 1882: 119 (as *L. Perryi*).

Randallia eburnea Alcock, 1896

W.A. (Shark Bay); India, Laccadives, E. Indies, Japan. In 30-150 m, over sand or shell.

Tyndale-Biscoe & George 1962: 87.

WAM 207-60 25 km NW of C. St Cricq. Dorré I.; 98-64 NW of Bluff Pt.; 99-64 NW of Dirk Hartog I; 102-64 W of Carnarvon; 105-64 NW of Carnarvon.

Section Oxyrhyncha Latreille, 1803

MAJIDAE Samouelle, 1819

Achaeus brevirostris Haswell, 1879

N.S.W. (Port Jackson), Qld., N.T., W.A. (to Fremantle); Indo-West Pacific (Zanzibar to Indonesia). To 50 m, over sand, gravel and clay.

Miers 1884: 189 (as A. affinis); Griffin & Yaldwyn 1965: 47; Griffin 1970: 98.

Achaeus curvirostris (A. Milne Edwards, 1873)

Eastern Australia (S Coral Sea to Bass Str.), W.A. (C. Naturaliste to North West Cape); widespread Indo-West Pacific (E Africa to Philippines, Japan, New

Zealand). In 36-160 m over coral, sand, shells. Griffin 1970: 102; 1972: 69 (as *A. fissifrons*). WAM 276-67 NW of Carnarvon.

Achaeus lacertosus Stimpson, 1857

N.S.W. (Port Jackson), Qld., N.T., W.A. (to Shark Bay); widespread Indo-West Pacific (S. Africa, Iranian Gulf to Japan). Low tidal levels to 90 m, over sand, shells, coral, mud.

Griffin 1972: 69.

Achaeus podocheloides Griffin, 1970

W.A. (C. Naturaliste to Pt. Cloates). In 128-137 m. Griffin 1970: 112. WAM 276-67 (part.) NW of Carnarvon (now AM P1677).

Achaeus pugnax (de Man, 1928)

W.A. (Pt. Cloates to Shark Bay); southeastern Japan. In 78-216 m, over sand, coral sand.

Griffin 1970: 116.

WAM 67-67 NW of Dirk Hartog I.; 167-67 NW of Carnarvon (now AM P16772).

Camposcia retusa Latreille, 1829

Northeastern, northern and north-western Australia (Shark Bay); Philippines, Guimaras and Bureas, Fiji, Ngau, Mauritus. Shore and coral reefs, to 38 m over stones, corals.

Miers 1884: 189; Balss 1935: 118.

Cyclax suborbicularis (Stimpson, 1858)

W.A. (Houtman Abrolhos and Shark Bay); Indo-West Pacific (Red Sea and Zanzibar to Rotuma). In 0.5 to 3.5 m; coral reefs. Hale 1929: 68; Montgomery 1931: 420; Balss 1935: 125.

Cyrtomaia murrayi Miers, 1886

W.A. (Pt. Cloates to Rottnest I.); E Africa, Kai Is., Japan, South China Sea. Dredged to 200 m, over sponges, Bryozoa, shells. Griffin & Tranter 1986: 29. WAM 13-67 W of Dirk Hartog I.

Ephippias endeavouri Rathbun, 1918

N.S.W. (northern), S. Aust., W.A. (Rottnest I., Houtman Abrolhos Is, Shark Bay). Subtidal to 50 m. Montgomery 1931: 416; Griffin & Tranter 1986: 31.

WAM 3-85 NW of Shark Bay; 489-86 Denham.

Hyastenus diacanthus (de Haan, 1839)

Qld., W.A. (Shark Bay); India to Japan, China Sea. In 12-108 m, over sand, stones. Miers 1884: 195; Rathbun 1924: 3; Griffin 1966b: 290. WAM 223-86 WSW of Carnarvon; 225-86, 226-86, 299-86, 301 to 303-86, 305-86, 309-86, 310-86 Denham; 248-86, 252-86, 254-86 Carnarvon; 307-86 W of Carnarvon; 312-86 SW of Carnarvon; 164-67, 158-72 Shark Bay; 235-67 2 km W of C. St Cricq, Dorré I.

Hyastenus elatus Griffin & Tranter, 1986

N.S.W. (to Botany Bay), Qld., W.A. (to just N of Perth); Irian Jaya, Arafura Sea. Intertidal and dredged to 21 m, over sand, sponges, sandy mud beds of *Cymodosia* and *Posidonia*.

Griffin & Tranter 1986: 141.

AM P18844 48 km S of Carnarvon; AM P17404 Shark Bay.

Hyastenus sebae White, 1847

Qld. (Thursday I.), Torres Str., W.A. (Monte Bello Is to Rottnest I.); common in tropical Indo-West Pacific (Ceylon to China, Philippines, Palau). Littoral to 120 m (to ? 400 m), associated with coral, shell, sand, rarely mud.

Miers 1884: 195 (as *H. oryx*); Rathbun 1914: 661 (as *H. oryx*); Balss 1935: 123 (as *H. oryx*); Griffin & Tranter 1986: 155.

WAM 236-67, 248-67 near bar of South Passage; 84-71 SE corner of Dirk Hartog L; 86-71, 204-86, 215-86 South Passage; 203-86 South Passage, near mainland side.

Lahaina agassizii (Rathbun, 1902)

W.A. (Shark Bay, Abrolhos Is, Geraldton); Indian Ocean to Philippines, New Caledonia. Shore and reef to 150 m, over mud, sand, coral, sponge and Bryozoa. Griffin & Tranter 1986: 159.

WAM 295-67 6 km W of C. St Cricq, Dorré I.; 85-71 off Carnarvon.

Leptomithrax sternocostulatus (H. Milne Edwards, 1851)

Qld., N.S.W., S. Aust., W.A. (Shark Bay); New Zealand. In 5.5 m. Balss 1935: 125; Griffin 1966b: 290.

WAM 8-67 NW of Carnarvon; 69-67 NW of Dirk Hartog I., 237-67 NW of C. Inscription.

Menaethius monoceros (Latreille, 1825)

N.S.W. (to Port Jackson), Qld., Torres Str., W.A. (Cossack, Shark Bay, Rottnest I.), Lord Howe I.; common and widespread in Indo-West Pacific (Red Sea and E Africa to Japan and Hawaii). Between high and low tide levels on rocky, weedy beaches.

Miers 1884: 190; Hale 1929: 68; Montgomery 1931: 417; Balss 1935: 122; Griffin 1972: 71; Black & Prince 1983: 40; Griffin & Tranter 1986: 90.

WAM 5788, 253-67 Shark Bay; 87-67 South Passage; 208-67 Denham; 216-67 near bar of South Passage; 218-67, 89-71 1 km N of Denham; 242-67 Pt. Gregory, NW of Péron Pen.; 255-67 Dirk Hartog I.; 78-71 0.5 km W of C. Péron.

Micippa curtispina Haswell, 1880

Old., W.A. (Shark Bay, Rottnest I.); Singapore. In 9 m.

Griffin & Tranter 1986: 275.

WAM 70-67 NW of Dirk Hartog I.

Micippa philyra (Herbst, 1803)

Eastern and northern Australia (W.A. - Houtman Abrolhos to Broome); Indo-West Pacific (Red Sea to Japan). On beaches, reefs, and trawled to 45 m over mud, coral sand, coral, Lithothamnion.

Miers 1884: 198; Montgomery 1931: 405; Griffin 1976: 202; Griffin & Tranter 1986: 277.

Naxioides carnarvon Griffin & Tranter, 1986 W.A. (NW of Carnarvon, Pt. Cloates). Trawled in 128-131 m. Griffin & Tranter 1986: 169. WAM 147-67 (H) NW of Carnarvon.

Paranaxia serpulifera (Guérin, 1829)

Qld. (Torres Str., Thursday I.), N.T., W.A. (to Abrolhos Is). In 7-26 m. Haswell 1882: 21; Miers 1884: 196; Rathbun 1914: 661; 1924: 7 (as Naxioides

serpulifera); Montgomery 1931: 419; Balss 1935: 127; Griffin 1966b: 290; Griffin & Tranter 1986: 280.

WAM 12192 Carnarvon; 152-72 Shark Bay; 575-86, 576-86 Sunday I.

Paratymolus sexspinosus Miers, 1884

North-eastern and north-western Australia (Broome, S of Carnarvon); southern India, Aru Is, Japan. In 7 m, over sand and rubble, algae. Griffin & Tranter 1986: 42. AM P25101 3 km S of Carnarvon.

Phalangipus hystrix (Miers, 1886)

Qld. (Coral Sea); W.A. (Shark Bay, Rottnest I.); widespread Indo-West Pacific. In 50-150 m (? to 353 m), from bottoms of sand, sandy mud or broken shells. Miers 1886: 60; Griffin 1973a: 178.

WAM 44-67, 100-71 NW of Dirk Hartog I.; 80-67 W of Dirk Hartog I.; 96-67, 146-67, 73-71, 99-71 NW of Carnarvon; 87-71 'tween Shark Bay and Onslow.

Pseudomicippe varians Miers, 1879 Qld. (Thursday I.), Torres Str., W.A. (Shark Bay). Intertidal amongst stones and dead coral, on reefs below low tide level, amongst thick *Sargassum*. Miers 1879: 12; 1884: 197; 1886: 68 (all as *Zewa varians*); McCulloch 1913: 334

(as Z. varians); Bass 1935: 121 (as Z. varians); Griffin 1966b: 277 (as Z. varians); Griffin & Tranter 1986: 237.

Schizophrys dama (Herbst, 1804)

Torres Str., N.T., W.A. (C. Jaubert, Monte Bello Is, Shark Bay, King George Sound); Straits of Malacca, Indonesia, Malaysia. Intertidal to 9 m, rocky bottoms.

Miers 1884: 197; 1886: 67; Rathbun 1914: 662; 1924: 6; Montgomery 1931: 420; Balss 1935: 124; Griffin 1966b: 286; Griffin & Tranter 1986: 249.

Simocarcinus pyramidatus (Heller, 1861)

W.A. (Barrow I. to Lancelin I.); Indian Ocean (Aldabra, Mauritius to Cocos Keeling Is). In 1.5-18 m, over sand.

Griffin & Tranter 1986: 99.

WAM 348-73 (part.) near bar of South Passage.

Simocarcinus simplex (Dana, 1852)

W.A. (Shark Bay, Abrolhos Is); Indo-West Pacific (Red Sea to Hawaii). On shore platforms, reefs, to 5 m; under weed and stones.

Griffin & Tranter 1986: 100.

WAM 348-73 (part.) near bar of South Passage.

Sunipea indicus (Alcock, 1895)

Central eastern and north-western Australia (NW of Pt. Cloates to NW of Bluff Pt.); Red Sea, Amirante and Seychelles, Andamans, Ceylon, Philippines. In 69-130 m, over coral, shells, sand, gravel and lithothamnion. Griffin 1972: 68 (as *Aepinus indicus*).

WAM 276-67 (part.) NW of Carnarvon (now AM P16779).

Thacanophrys albanyensis (Ward, 1933)

North-eastern Australia, Arafura Sea, W.A. (to Shark Bay). In 25-57 m, over sand and shells, stones, coral, sponge, mud.

Griffin 1966a: 4, 10, 13 (as Chlorinoides albanyensis); Griffin & Tranter 1986: 254.

WAM 349-67 'tween C. Inscription and C. St Cricq.

HYMENOSOMATIDAE MacLeay, 1838

Halicarcinus bedfordi Montgomery, 1931

Qld. (to Moreton Bay), N.T., W.A. (to Swan R.). Estuarine, littoral, on muddy substrate, associated with seagrasses (*Posidonia australis*). Montgomery 1931: 425; Lucas 1980: 181. WAM 267-64 Monkey Mia.

Trigonoplax spathulifera Lucas, 1980

Qld. (to Gladstone), N.T., W.A. (to Lancelin I.). Under stones at low tidal levels, from coral reefs, to 137 m over sponge and Bryozoa. Lucas 1980: 189.

PARTHENOPIDAE MacLeay, 1838

Cryptopodia spatulifrons Miers, 1879 Type Locality N.S.W. (Port Jackson); northern Australia (Thursday I., Prince of Wales Channel); W.A. (Shark Bay). In 5-13 m. Miers 1879: 26; Haswell 1882: 38; Miers 1884: 203.

Oreophorus morum (Alcock, 1896)

W.A. (Shark Bay); India, Japan. In 55-150 m on bottom of sandy mud or sand. Sakai 1976: 81.

WAM 163-64 NW of Dirk Hartog I.

Parthenope (Parthenope) nodosus (Jacquinot, 1853)

North-eastern, northern and western Australia (W.A. - Shark Bay), Japan. Habitat unknown. Miers 1884: 200. WAM 384-73, 385-73 Shark Bay.

Rhinolambrus pelagicus (Ruppell, 1830)

Northern and western Australia - W.A. (Montebello Is, Shark Bay); tropical Indo-Pacific (from E Africa to Samoa). In 50-100 m, on sandy mud bottoms. Rathbun 1914: 663 (as *Parthenope (Rhinolambrus) pelagicus*); Balss 1935: 128.

Section Cancridea Latreille, 1803

ATELECYCLIDAE Ortmann, 1893

Kraussia nitida Stimpson, 1859

Qld. (Thursday I.), W.A. (Houtman Abrolhos Is, Shark Bay); Japan. In 30-55 m, on bottoms of sand or broken shells. Balss 1922: 98; Montgomery 1931: 433; Balss 1935: 132; Serène 1972: 51.

Kraussia pelsartensis Serène, 1972

W.A. (Pt. Cloates, Houtman Abrolhos Is, Rottnest I.). In 37-46 m. Serène 1972: 49; Jones 1986: 35.

Section Brachyrhyncha Borradaile, 1907

PORTUNIDAE Rafinesque, 1815

Charybdis feriata (Linnaeus, 1758)

Qld. (to Moreton Bay), N.S.W., W.A. (Swan R. to Exmouth Gulf); Madagascar, S. Africa, India to Japan. In 10-18 m, over sandy mud, also from live coral. Stephenson *et al.* 1957: 497; Stephenson 1972: 31. WAM 63-58, 64-58 between Koks I. and Quobba Pt. (as *C. cruciata*).

Charybdis helleri (A. Milne Edwards, 1867)

Qld., N.S.W., W.A. (Shark Bay to C. Bossut); Mediterranean, E African coast to Hawaii. Intertidal, under rocks and stones, amongst live coral, dredged in 6-38 m.

Stephenson et al. 1957: 497.

WAM 14-66 flats S of Dirk Hartog I.

Charybdis jaubertensis Rathbun, 1924

Qld. (to Mackay), N.T., W.A. (to Shark Bay). In 4-37 m, over mud and sandy mud.

Stephenson *et al.* 1957: 498; Stephenson 1961: 116; 1972: 32. WAM 36-60 near bar of South Passage; 4-65, 6-65, 5-66, 7-66 Shark Bay; 10-65 N of Peron Flats.

Charybdis lucifera (Fabricius, 1798)

Qld. (Mooloolabah to Cairns), W.A. (North West Cape, Bernier I., Shark Bay); India to Japan. Dredged, also possibly intertidal. Stephenson *et al.* 1957: 500; Stephenson 1972: 33. WAM 4153 Bernier I.

Nectocarcinus spinifrons Stephenson, 1961 W.A. (Shark Bay). Trawled in 73 m. Dredged 74-80 m. Stephenson 1961: 92; 1972: 22; Jones 1986: 35. WAM 47-60 (H), 476-60 (A), 47c-60 (A) 2 km W of C. St Cricq, Dorré I.

Ovalipes australiensis Stephenson & Rees, 1968

Qld. (to Wide Bay), N.S.W., Vic., S. Aust., W.A. (to Shark Bay), Lord Howe I. Subtidal to 60 m; in sandy areas on low energy coasts.

Haswell 1882: 84 (as *Platyonychus bipustulatus*); Miers 1886: 202 (as *P. bipustulatus*); Stephenson & Rees 1968: 231; *Griffin & Yaldwyn 1971: 49; Griffin 1972: 76; Stephenson 1972: 227.

Portunus argentus (A. Milne Edwards, 1861)

W.A. (Onslow & Dampier Arch.); Natal to Honolulu. Dredged, in 10-150 m, over sand and mud.

Stephenson 1961: 105; 1972: 38.

WAM 107-71 NW of Carnarvon.

Portunus granulatus H. Milne Edwards, 1834

N.S.W., Qld., W.A. (Shark Bay, Dampier Arch.); Madagascar and Red Sea to Hawaii, Samoa. Dredged in 9-12 m, or on reefs in shallow water.

Stephenson & Campbell 1959: 108; Stephenson & Rees 1967: 25; Stephenson 1972: 39.

Portunus hastoides Fabricius, 1798

Qld. (to Moreton Bay), Torres Str., Arafura Sea, N.T. (Darwin), W.A. (Roebuck Bay to Shark Bay); Madagascar and E Africa to Japan, Philippines and Australia. LWM to 82 m, over soft mud, mud and shell.

Stephenson & Campbell 1959: 101.

WAM 51-60 E side of Dirk Hartog I.

Portunus orbitosinus Rathbun, 1911

Qld. (to Capricorn Gp.), N.T., W.A. (to Shark Bay); Indo-West Pacific (Seychelles to Japan). Shore to 75 m, over sand and mud.

^{*} These authors suggest 'Shark Bay' locality in Stephenson & Rees 1968 is a *lapsus* for Geographe Bay.

Stephenson & Campbell 1959: 114; Stephenson 1961: 108; Stephenson 1972: 41. WAM 47a-60 2 km W of C. St Cricq, Dorré I.; 49-60 2 km SW C. Ronsard, Bernier I.

Portunus pelagicus (Linnaeus, 1766)

S. Aust. (Spencer Gulf), Vic., N.S.W., Qld., N.T., W.A. (to Fremantle), Lord Howe I.; widely distributed in Indo-West Pacific (E Africa to Tahiti). Intertidal, in mud and *Zostera*, shallow pools and under stones; estuarine, also trawled to 65 m. Basis of commercial fishery.

Miers 1884: 229 (as *Neptunus pelagicus*); Rathbun 1924: 22; Montgomery 1931: 427; Balss 1935: 130 (as *N. pelagicus*); Stephenson & Campbell 1959: 97; Stephenson 1972: 41.

WAM 12193 Carnarvon; 13-60 Shark Bay.

Portunus pseudoargentatus Stephenson, 1961

W.A. (Houtman Abrolhos Is, Shark Bay). Surf to 65 m, dredged in coral rubble, sponge, seaweed.

Stephenson 1961: 209; 1972: 42. WAM 258-62, 259-62 Shark Bay.

Portunus rubromarginatus (Lanchester, 1900)

N.S.W. (to Port Jackson), Qld., W.A. (Cygnet Bay to Shark Bay); Malay Arch., Hong Kong, South China Sea. Depths to 38 m, over sandy mud. Stephenson & Campbell 1959: 112; Stephenson 1972: 42. WAM 44-60 0.5 km E of Koks I., Bernier I.; 105-71, 108-71, 109-71 Shark Bay.

Portunus rugosus (A. Milne Edwards, 1861)

Torres Str., W.A. (Shark Bay to Cottesloe). In 7-120 m, substrate sand. Stephenson 1972: 42. WAM 47-60 NE side of Dirk Hartog I.; 51-60 E side of Dirk Hartog I.

Portunus sanguinolentus (Herbst, 1783)

Qld., N.S.W., S. Aust., W.A. (to Exmouth Gulf); E Africa to Hawaii, including Japan; alsos Adriatic. Trawled, subtidal to 30 m. Stephenson & Campbell 1959: 98; Stephenson 1972: 43. WAM 53-86 Dirk Hartog I.

Thalamita gatavakensis Nobili, 1906

Australia - W.A. (Shark Bay, Maud Landing); Madagascar and Tuamotus. Dredged 10-20 m over coral. Stephenson 1972: 47.

Thalamita macropus Montgomery, 1931

Qld. (southern), N.S.W. (Port Stephens to Eden); W.A. (Houtman Abrolhos Is, Shark Bay). In 7-100 m, dredged or trawled.

Montgomery 1931: 431; Stephenson & Hudson 1957: 343; Stephenson & Rees 1961: 122; 1968: 295; Griffin 1972: 77; Stephenson 1972: 49. WAM 47b-60 2 km W of C. St Cricq, Dorré I.

Thalamita prymna (Herbst, 1803)

Qld. (Torres Str.); N.T., W.A. (to Houtman Abrolhos Is); Indo-West Pacific (Delagoa and Red Sea to Marshall Is). Intertidal coral reefs to 30 m. Montgomery 1931: 427; Stephenson 1972: 50.

GONEPLACIDAE MacLeay, 1838

Eucrate crenata de Haan, 1835

W.A. (Shark Bay); India, Andamans, Seychelles, Hong Kong, China, Korea, Japan. In 35-100 m, substrate sand or sandy mud.
Sakai 1976: 535.
WAM 1808-85, 1809-85, 1824-85, 1827-85 Shark Bay.

XANTHIDAE MacLeay, 1838

Actaea jacquelinae Guinot, 1976

Torres Str., N.S.W., S. Aust., W.A. (Rottnest I., Houtman Abrolhos Is, Shark Bay, Holothuria Bank); Indo-West Pacific (Red Sea to Tahiti). Subtidal, from coral reefs in shallow waters.

Odhner 1925: 53 (as *A. calculosa*); Montgomery 1931: 437 (as *A. calculosa*); Balss 1935: 136 (as *A. calculosa*); Serène 1984: 113.

Actaea michaelseni Odhner, 1925

Type Locality

Type Locality

W.A. (Shark Bay). In 0.5-3.5 m. Odhner 1925: 43; Hale 1929: 69; Balss 1935: 136.

Actaea savignyi (H. Milne Edwards, 1834)

W.A. (Shark Bay); Indo-West Pacific (Suez Canal, Sinai, Gulf of Aden, Mozambique to Japan). In 7-146 m.

Odhner 1925: 52; Montgomery 1931: 438; Balss 1935: 136.

Atergatopsis globosa Balss, 1935 W.A. (Shark Bay). 10-13 m. Balss 1935: 137.

Calvactaea tumida Ward, 1933

N.S.W. (Port Jackson and Port Hacking), W.A. (Shark Bay); southeastern Japan. On rocky beaches and in 10-30 m; occasionally associated with Alcyonarians. Sakai 1976: 520; Griffin 1972: 79.

Chlorodiella nigra (Forskal, 1775)

Northern Australia, W.A. (Shark Bay); Indo-West Pacific (Red Sea, E Africa to Hawaii). Intertidal, on rocky beaches and coral reefs, in shallow waters.

Hale 1929: 69 (as C. niger); Montgomery 1931: 441 (as C. niger); Serène 1984: 258.

Cymo andreossyi (Audouin, 1826)

Qld., W.A. (Beagle Bay, Shark Bay), Norfolk I.; throughout Indo-West Pacific (Red Sea to Tahiti). Associated with coral reefs in shallow waters; probably an obligate symbiont of *Pocillopora* corals.

Balss 1935: 139; Black & Prince 1983: 140; Serène 1984: 34.

WAM 19-82 Pt. Quobba.

Demania splendida Laurie, 1906

W.A. (Shark Bay); Madagascar, Ceylon, Indian Ocean. In 15-35 m, on rocky or sandy bottoms.

Serène 1984: 190.

WAM 448-87 NW of C. Inscription.

Etisus anaglyptus (H. Milne Edwards, 1834)

W.A. (Pt. Quobba); Indo-West Pacific (Red Sea to Japan). Intertidal, on rocky or stony beaches, under stones or in rock crevices, shallow waters. Black & Prince 1983: 11; Serène 1984: 228.

Leptodius exaratus (H. Milne Edwards, 1834)

Northern Australia, W.A. (Shark Bay); common in tropical Indo-West Pacific (Red Sea to Hawaii). Intertidal on rocky beaches under stones or in rock crevices. Miers 1884: 214; Serène 1984: 184.

Liomera cinctimana (White, 1847)

Northern Australia, W.A. (Shark Bay); Indo-West Pacific (Madagascar to Japan); also lower California to Galapagos. Intertidal, on coral reefs and rocky beaches, to 35 m.

Odhner 1925: 14 (as *Carpilodes cinctimanus*); Hale 1929: 69 (as *C. cinctimanus*); Serène 1984: 57.

Liomera hartmeyeri Odhner, 1925

W.A. (Shark Bay). In 7-16 m. Odhner 1925: 23 (as Carpilodes hartmeyeri); Balss 1935: 145 (as C. hartmeyeri).

Liomera rubra (A. Milne Edwards, 1865)

Northern Australia, W.A. (Shark Bay); Indo-West Pacific (Madagascar to Hawaii). Coral reefs, in shallow waters.

Odhner 1925: 23 (as *Carpilodes ruber*); Hale 1929: 69 (as *C. ruber*); Serène 1984: 65.

Liomera rugata (H. Milne Edwards, 1834)

Northern Australia, W.A. (Shark Bay); Indo-West Pacific (Red Sea to Hawaii, Tahiti). Intertidal, on coral reefs, in shallow waters.

Odhner 1925: 20 (as Carpilodes rugatus); Hale 1929: 69 (as C. rugatus); Serène 1984: 62.

Type Locality

Paractaea rufopunctata rufopunctata (H. Milne Edwards, 1834) W.A. (Pt. Quobba); Indo-West Pacific (Red Sea to Tahiti, Samoan Is). Low tidal level to 50 m, on rocky bottoms.

Black & Prince 1983: 11 Pt. Quobba (as Actaea rufopunctata); Serène 1984: 122.

Pilodius areolatus (H. Milne Edwards, 1834)

N.S.W., N.T., W.A. (Swan River to Shark Bay); warmer Indo-West Pacific (E Africa to Polynesia and Japan). Intertidal to 3.5 m, on coral reefs. Hale 1929: 70; Montgomery 1931: 443; Balss 1935: 139; Serène 1984: 241. WAM 549-86 Pt. Quobba.

Psaumis cavipes (Dana, 1852)

W.A. (Pt. Quobba); Indo-West Pacific (Red Sea to Tahiti and Samoan Is). Coral reefs, shallow waters.

Rathbun 1914: 658 (as *Glyptoxanthus cymbifer*); Hale 1929: 69 (as *Actaea cavipes*); Black & Prince 1983: 11 (as *A. cavipes*).

Xanthias elegans Stimpson, 1858

Eastern Australia (Capricorn Gp. to Port Jackson), W.A. (Rottnest I. to Monte Bello Is), Norfolk I.; south-eastern Japan, Taiwan. Littoral to 35 m, on bottoms of rock or broken shells; facultative symbiont of living and dead coral, and occurring in a variety of reef habitats.

Hale 1929: 69; Montgomery 1931: 441; Balss 1935: 135; Griffin 1972: 79; Black & Prince 1983: 140 (as *Paraxanthias elegans*).

Xanthias lamarcki (H. Milne Edwards, 1834)

Qld., W.A. (Shark Bay); warmer areas of the Indo-West Pacific (Mozambique to Polynesia). In 0.5 to 3.5 m.

Hale 1929: 69; Balss 1935: 134; Serène 1984: 196.

Xantho danae Odhner, 1925

Australia - W.A. (Shark Bay); Indo-West Pacific (Madagascar to Hawaii, Caroline Is).

Odhner 1925: 80; Balss 1935: 133.

Zozymodes cavipes (Dana, 1852)

Australia - W.A. (Shark Bay); Indo-West Pacific (Red Sea, Zanzibar to Penang, Christmas I., Bonin Is, Palau Berhala). In 0.3 to 5.0 m. Balss 1935: 132 (as Xantho (Leptodius) cavipes); Serène 1984: 153.

PILUMNIDAE Samouelle, 1819

Actumnus setifer (de Haan, 1835)

Torres Str., W.A. (Broome, Shark Bay); Indo-West Pacific (Red Sea and E Africa to Japan and Tahiti). Intertidal to 50 m, rocks and coral. Miers 1884: 226; Rathbun 1914: 660.

Pilumnus semilanatus Miers, 1884

Northern Australia, W.A. (Houtman Abrolhos Is, Shark Bay, Port Hedland), S. Aust. Dredged in deeper waters. Miers 1884: 222; Montgomery 1931: 446; Balss 1935: 145.

WAM 49-72 NE corner of Dirk Hartog I.

TRAPEZIIDAE Miers, 1886

Trapezia cymodoce (Herbst, 1799)

Qld., W.A. (Shark Bay to Fremantle area); Indo-West Pacific (Red Sea to Tahiti, Society Is). Associated with coral reefs in shallow waters. Obligate symbiont of living pocilloporid corals.

Balss 1935: 139; Black & Prince 1983: 140.

WAM 11-82, 14-82, 510-86, 517-86 Pt. Quobba; 502-86 Monkey Mia; 518-86 Carnarvon.

GRAPSIDAE MacLeay, 1838

Cyclograpsus audouinii H. Milne Edwards, 1837

Qld. (to Hervey Bay); N.S.W., Vic., S. Aust., W.A. (to Shark Bay); New Guinea. Supralittoral and intertidal to 6-10 m, amongst heaped stones and boulders, or associated with seaweed or logs; on rocky platforms, beaches; on reefs and estuarine flats; from high tide level into shallow waters.

Balss 1935: 143 (as *C. punctatus audouinii*); Campbell & Griffin 1966: 152; Griffin & Yaldwyn 1971: 59.

Grapsus albolineatus (Lamarck, 1818)

W.A. (Pt. Quobba); Indo-West Pacific (Red Sea, E Africa to Japan, Hawaii). Above high tidal levels, on rocky beaches or coral reefs.

Sakai 1976: 630.

WAM 1842-85 Pt. Quobba.

*Leptograpsus variegatus (Fabricius, 1793)

Qld. (to Rockhampton)), N.S.W., Vic., Tas., S. Aust., W.A. (to North West Cape); southern warm temperate Indo-West Pacific (W.A. to Peru, Chile). Intertidal (high tide to lower mid-tidal) on exposed rocky shores.

Montgomery 1931: 452; Balss 1935: 142; Griffin & Yaldwyn 1971: 58; Griffin 1973b: 418.

WAM 154-63 Pt. Gregory, NE end of Peron Pen.

Metopograpsus messor (Forskål, 1775)

Qld., W.A. (Shark Bay to King Sound); warmer Indo-West Pacific (Red Sea, E Africa to Japan, Hawaii)). Occurring near high tidal levels, amongst stones, pebbles.

Miers 1884: 245; Balss 1935: 141.

^{*} Synonym Grapsus personatus Lamarck. Type, dry, "New Holland"; type not extant.

Percnon planissimum (Herbst, 1804)

Torres Str., W.A. (Rottnest I., Abrolhos Is, Shark Bay), Norfolk I.; warmer Indo-West Pacific (Madagascar to Hawaii) and Atlantic. In 0.5 to 3.5 m on rocky beaches and platforms.

Hale 1929: 70; Montgomery 1931: 457; Balss 1935: 144.

Plagusia depressa tuberculata Lamarck, 1818

N.S.W., W.A. (Shark Bay); warmer Indo-West Pacific (E Africa to Hawaii, Chile) and Atlantic. Near high tidal levels on rocky beaches, also occasionally attached to floating timber.

Montgomery 1931: 457; Balss 1935: 143.

Varuna litterata (Fabricius, 1798)

W.A. (Shark Bay); Indo-West Pacific (E Africa, Madagascar to Japan). Usually estuarine, sometimes found clinging to floating timber.Sakai 1976: 644.WAM 1876-85 Carnaryon.

MICTYRIDAE Dana, 1851

Mictyris longicarpus Latreille, 1806

N.S.W. (southern), Qld., N.T., W.A. (to Shark Bay); Indo-West Pacific (Malay Arch., Nicobar, Andamans, New Caledonia, Japan, Hong Kong, Philippines). Sandy or muddy flats, on protected shores. Rathbun 1914: 661; Griffin 1972: 87. WAM 578-39 Carnaryon; 151-62 Monkey Mia.

PINNOTHERIDAE de Haan, 1833

Pinnotheres edwardsi (de Man, 1888) W.A. (Houtman Abrolhos Is, Shark Bay); Mergui Arch., Kei Is. Montgomery 1931: 451. WAM 1883-86 Shark Bay.

Pinnotheres hickmani (Guiler, 1950)

Vic. (eastern), Tas., W.A. (to Shark Bay). Commensal of bivalves, especially *Mytilus edulis*.
Griffin & Yaldwyn 1971: 57 (as *P. pisum*); Pregenzer 1979: 23; Phillips *et al.* 1984: 116.
WAM 1891-86 Useless Loop.

Pinnotheres spinidactylus Gordon, 1936

Qld. (Moreton Bay), W.A. (Shark Bay); Singapore, ?Philippines. Commensal of bivalves; in 3-10 m. Griffin & Campbell 1969: 156.

WAM 1873-86 SE corner of Dirk Hartog I.; 1884-86 Peron Pen.

OCYPODIDAE Rafinesque, 1815

Macrophthalmus verreauxi H. Milne Edwards, 1848

W.A. (Shark Bay); Indo-West Pacific (Red Sea, Madagascar to Japan, Hawaii). Mud flats or to 10-20 m, on soft substrates.

Sakai 1976: 611.

WAM 1413-86, 1415-86, 1423-86, 1424-86 Shark Bay.

Ocypode ceratophthalma (Pallas, 1772)

N.S.W. (to Port Macquarie), Qld., N.T., W.A. (to Shark Bay); Indo-West Pacific (E and S. Africa, Red Sea to southern Japan, Hawaii). On sandy beaches at high tidal levels; mostly nocturnal.

Miers 1884: 237 (as O. kuhlii (part.)); George & Knott 1965: 17; Allender 1969: 63.

WAM 83-63 Ocean Beach Reef, NW end of Dorré I.; 143-63, 19-64, 20-64 Hospital Beach, Bernier I.; 202-73 Monkey Mia.

Ocypode convexa Quoy & Gaimard, 1824 Type Locality W.A. (North West Cape and Barrow I. to Yallingup). Burrows high on sandy beaches, above strand line; mostly nocturnal.

Quoy & Gaimard 1824: 525; Miers 1882: 237; (as *O. kuhlii* (part.)); Montgomery 1931: 451 (as *O. pygoides*); Ride 1962: 17 (as *O. pygoides*); George & Knott 1965: 20; Allender 1969: 61.

WAM 95-60, 97-60, 53-63, 70-63 Quoin Bluff, Dorré I.; 98-60, 50-63, 51-63 Bernier I.; 52-63 Pt. Quobba; 58-63 Pt. Gregory, NW end of Peron Pen.; 60-63, 445-88 Shark Bay; 64-63, 444-88 Dirk Hartog I.; 77-63 Dorré I.; 206-73 Monkey Mia.

Ocypode fabricii H. Milne Edwards, 1837

North and west coasts of Australia (west of Darwin to Shark Bay).

Balss 1935: 140 (as *O. aegyptiaca*); George & Knott 1965: 18; Allender 1969: 63. WAM 101-63 Shark Bay; 144-63 Denham Hummock; 145-63 Denham (donated to PM); 4-64 3 kms N of Denham; 18-64 1 km N of Denham; 357-74 Monkey Mia.

Uca elegans George & Jones, 1982

N.T. (to Gove), W.A. (to Shark Bay). Landward of mangroves on salt flats. George & Jones 1982: 22; Jones 1986: 36.

WAM 654-65 (P) Teggs Channel; 656-65 (P) Denham Hummock; 181-62, 118-68 (P) Fauré I.; 124-68 (P) Quobba; 22-77 (P), 23-77 (P) Vendoo Ck., S of Carnarvon; 181-78 (P) Shark Bay or Exmouth Gulf; 73-82 Kaiboolia Ck., nr Carnarvon; 75-82 Monkey Mia.

Uca mjoebergi Rathbun, 1914

N.T. (to Gove), W.A. (to Carnarvon). On edges of mangroves (usually landward), on coarse, sandy substrates.

George & Jones 1982: 83. (as U. mjobergi).

WAM 71-82, 72-82 Kaiboolia Ck., nr Carnarvon.

Discussion

Although historically Shark Bay was one of the first areas of Western Australia to be visited by early naturalists, and crustaceans were recorded and collected here by these scientific pioneers, there has been no formal documentation of the crustacean fauna of the area. The present checklist is an attempt to solve this dilemma. Due to a dearth of information (and collections) of non-decapod crustacean groups in Western Australia these taxa have been omitted from the checklist. Even within decapod groups, certain taxa remain virtually undescribed, or are absent or poorly represented in the WAM crustacean collection. Other groups, however, which have undergone major revisions, are well represented (e.g. Alpheidae, Portunidae, Majidae). For these reasons the checklist must be regarded as preliminary, incomplete and biased towards certain taxa. It will definitely be expanded as further collections in Shark Bay, as well as taxonomic revisions of taxa at present undescribed, are undertaken. At present 232 species are listed from the Shark Bay area. Shark Bay is the type locality for 14 holotypes, 1 allotype and 10 paratypes.

The marine fauna of Western Australia is clearly partitioned into tropical and temperate components. The tropical component occurs on the northern coastline and has clear faunistic affinities with the much wider Indo-West Pacific region, with the Indo-Malayan Archipelago and with northern Australia. Only a small proportion of these tropical species extends southwards and few species are endemic to northern Australian waters. On the southern coast a temperate fauna occurs which is part of the wider southern Australian faunistic area. Some of these temperate species are of widespread occurrence and there is a relatively large proportion of species endemic to southern Australian waters. The west coast of Western Australia represents an overlap area between the tropical and the temperate fauna, and species endemic to the west coast also occur here.

The bulk of species (115) occurring at Shark Bay show Indo-West Pacific faunal affinities (50%). Fifty-seven species (25%) show affinities to the Indo-Malayan Archipelago, and 26 species (11%) to northern Australia. Only 7% (17 species) show faunistic affinities to temperate southern Australian species and 16 species (7%) are endemic to Western Australia.

The hydrological effects of the Leeuwin Current on the west coast of Australia are well documented (Hodgkin & Phillips 1969; Cresswell & Golding 1980). The increased water temperatures of the southerly flowing current significantly influence the distribution of tropical marine larvae from northern waters down the west coast of Western Australia and this influence extends well into the Great Australian Bight (Maxwell & Creswell 1981). Considering the latitudes of Shark Bay it is not surprising that the bulk of species (50%) occurring there exhibit tropical rather than temperate affinities. However, considering the preliminary nature of the above checklist, further comment on the faunistic affinities of the decapod crustaceans of Shark Bay and their biogeographical implications would be unwise.

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A guide to the shallow-water barnacles (Cirripedia: Lepadomorpha, Balanomorpha) of the Shark Bay area, Western Australia.

Diana S. Jones*

Abstract

Sixteen species of shore and shallow-water barnacles have been collected from the Shark Bay region. A key and general notes are provided for identification of these species. From literature records 27 species could possibly occur in the region. Shark Bay barnacles exhibit distinct faunal affinities to the Indian Ocean/Malay Archipelago area and the wider Indo-West Pacific region.

Résumé

Seize espèces de bernaches littoraux et d'eau superficielle ont été ramassées dans la région de la Baie des Chiens Marins. Une clef et des notes générales sont fournis pour l'identification de ces espèces. D'après les recensements disponibles, 27 espèces pourraient probablement apparaitre dans la région. Les bernaches de la Baie des Chiens Marins présentent des affinités fauniques distinctes avec la région de l'Océan Indien et de l'Archipel Malais ainsi qu'avec la plus large région indo-pacifique occidentale.

Introduction

The early French expeditions of discovery made the first collections of barnacles in Australia. Barnacles were collected by the scientists Péron and Lesueur in New Holland (southern Australia) between 1800 and 1804, during the voyage of the French corvette "Géographe", under the command of Nicholas Baudin. In Western Australia the expedition explored and collected specimens at King George Sound (Albany), Georgaphe Bay and Shark Bay between February and March, 1803. Lamarck (1818) described seven species of barnacles from the material collected by Péron and Lesueur. In Western Australia only "baie des chiens marins" (Shark Bay) was nominated as type locality for two barnacle species — *Balanus subimbricatus* and *Acasta sulcata*.

Reporting on barnacles housed in the Berlin Museum, Weltner (1897) made mention of specimens of Acasta cyathus Darwin and Oxynaspis celata Darwin (now synonymized with O. indica Annandale) which had been collected in Shark Bay. Krüger (1914) reported on the barnacles collected by the Hamburg Expedition of 1905 in south-west Australia, between Shark Bay and Princess Royal Harbour, Albany. No new species were described but 11 species were recorded, including six from Shark Bay — viz. Smilium peronii Gray, Chthamalus stellatus Poli var. communis Darwin, Balanus tintinnabulum Linnaeus var. validus Darwin, B. concavus Bronn, Acasta nitida Hoek and Tetraclita porosa Gmelin var. viridis Darwin. The record of Chthamalus stellatus

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Shallow water barnacles

var. communis probably represents C. malayensis Pilsbry since the latter is now known to occur in this locality, whilst C. stellatus is a northern hemisphere species. Balanus tintinnabulum var. validus is now recognized as Megabalanus validus, B. amphitrite var. stutsburi as B. variegatus Darwin, A. nitida as A. pectinipes Pilsbry and T. porosa var. viridis as Tetraclitella purpurascens (Wood). The record of B. concavus from Shark Bay is puzzling since this species is not known from Australian waters. Darwin's record of B. concavus from Australia (Darwin 1854) must also be considered anomalous since the known distribution of this species is China, India and the Persian Gulf (Newman & Ross 1976). However, B. amphitrite Darwin, a species superficially similar to B. concavus is now known to occur in Shark Bay and the two species may have been confused.

Since these early expeditions there have been few studies on Western Australian cirripedes. Several studies have mentioned fouling species occurring in Cockburn Sound (Russ & Wake 1975; Dunstan 1978; Lewis 1981, 1982; Chalmer 1982) or the Swan River (Jones 1987a, 1987b), or species which occur on the limestone reefs and rocky shores of Western Australia (Marsh 1955; Hodgkin 1959, 1960; Hodgkin *et al.* 1959; Marsh & Hodgkin 1962). Eighty-one cirripede species were recorded from Western Australian waters by Jones (1987c) and, more recently, Jones *et al.* (in press) have listed 23 species which could be expected to occur on the central west coast of Western Australia — an area which includes Shark Bay.

The France-Australe Expedition to Shark Bay in July, 1988, provided an excellent opportunity for a study of the local cirripede fauna. This report describes the 16 species which have been collected from the Shark Bay region of Western Australia. These barnacles belong to two suborders of the subclass Cirripedia — namely the Lepadomorpha and the Balanomorpha. The former are more commonly known as goose or stalked barnacles, the latter as acorn or sessile barnacles. Using the following key these four lepadomorph and 12 balanomorph species may be readily identified.

The terminology used in the key and notes for species identification is that of Jones (1987b, 1987c). Complete synonymies, descriptions and literature records to the barnacles listed in the present contribution may be found in Jones (1987c). Measurements refer to those of the largest specimen examined.

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1.	Peduncle and capitulum present, latter with or without calcified plates
	Peduncle absent, calcified plates attached directly to substrate
2.(1)	Peduncle with small, peg-like scales embedded in rows in integument (Figurel)

3.(2)	Capitulum with 13 calcified capitular plates (Figure 2) Smilium peronii
	Capitulum with less than 13 calcified capitular plates
4.(3)	Capitulum with five calcified capitular plates; tubular ear-like appendages absent from capitulum (Figure 3) Lepas anatifera
	Capitulum with two rudimentary (and often absent) plates; two tubular ear-like appendages occurring behind these two rudimentary plates (Figure 4)
5.(1)	Balanomorph with four discrete parietal plates in shell or with sutures between plates obliterated externally but visible internally (Figure 5)
	Balanomorph with six parietal plates in shell, sutures between plates visible externally
6.(5)	Rostrum with two alae (Figure 6) Chthamalus malayensis
	Rostrum with two radii 7
7.(6)	Opercular valves reduced, not occluding orifice; scutum and tergum (if present) not articulating; attached to marine mammals
	Opercular valves complete, occluding orifice; scutum and tergum present, articulating; attached to sponges and hard substrates
8.(7)	Shell flattened, parietal plates with broad, flat ribs; orifice small compared to basis (Figure 7) Cetopirus complanatus
	Shell tall, parietal plates with longitudinal, convex ribs; orifice larger than basis (Figure 8) Coronula diadema
9.(7)	Walls of parietal plates solid, not tubiferous 10
	Walls of parietal plates tubiferous, tubes in single uniform row
10.(9)	Attached to hard substrates; basis flat 11

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	Attached to sponges; basis cup-shaped 12
11.(10)	Parietal plates bright pink to pinkish to whitish, with transverse growth lines and narrow pink to brown longitudinal striations; orifice rhomboidal, deeply toothed (Figure 9)
	Parietal plates white, with faint transverse growth lines and some longitudinal striations in older specimens; orifice pentagonal, deeply but irregularly toothed (Figure 10) <i>Chirona tenuis</i>
12.(10)	Parietal plates orange-white or pinkish, externally with longitudinal ribs bearing small teeth which are less prominent in older specimens (Figure 11) Acasta pectinipes
	Parietal plates white, sometimes tinged pink towards apex, externally smooth or with small calcareous spines in irregular lines (Figure 12) Acasta sulcata
13.(9)	Parietal plates and basis tubiferous; radii not permeated by pores
	Parietal plates tubiferous; basis tubiferous or solid; radii well developed with transverse tubes between denticulate septae
14.(13)	Parietal plates externally white with groups of well- spaced purple, grey-brown or purple pink vertical stripes; carina not spout-like (Figure 13) Balanus amphitrite
	Parietal plates externally whitish, crosshatched with mauve-brown stripes and circular bands; carina spout-like (Figure 14) Balanus variegatus
15.(13)	Parietal plates smooth, roughened or plicated, pinkish white to pinkish purple, usually with reddish brown broken longitudinal striations (Figure 15)
	flexuous;parieties pinkish red to chocolate purple, ribs white (Figure 16)
D.S. Jones

Additional notes for species identification

Suborder Lepadomorpha Pilsbry, 1916 SCALPELLIDAE Pilsbry, 1916

Calantica studeri (Weltner, 1922) (Figure 1)

Scalpellum (Calantica) studeri Weltner, 1922: 100, Pl. 3 Figs 13-13b Calantica studeri; Utinomi 1968: 161



Figure 1 Calantica studeri (Weltner); lateral view.

Remarks

Capitulum with 13 plates. In life the integument of the capitulum is lemon yellow with some pinkish tinges, and the penduncle brownish yellow. Material described here is the first collected in Australian waters since collection of the type specimens. The present material was collected 153 km northwest of Shark Bay at a depth of 155 m from a sponge substrate.

C. studeri was originally described from specimens collected from three separate localities — off north-western Australia (85-110 m), five miles south of Three Kings Islands, New Zealand (165 m) and from Japan, probably from Sagami Bay (Weltner 1922). The Western Australian type locality is off Dirk Hartog Island, Shark Bay.

Distribution

Australia (W.A. - Shark Bay), New Zealand, ? Japan. Depth range 60-248 m.

Dimensions

Capitular height 13.0 mm, width 11.0 mm; peduncular length 7.0 mm.

Western Australian Records

Weltner 1922: 100; Foster 1978: 45; 1980: 524; Jones et al. (in press).

Smilium peronii Gray, 1825 (Figure 2)

Smilium peronii Gray, 1825: 100; 1830: Pl. 53 Fig. 10



Figure 2 Smilium peronii Gray; lateral view.

Remarks

In life the integument of the capitulum may sometimes be a characteristic royal or claret-purple, although it is usually dull brownish purple. In Western Australia the species has been found attached to seagrasses, corallines, wooden stakes and ascidians, on sandy substrates, in depths of 4 to 48 metres. Darwin (1851) reported on material collected in Australia (including the Swan River) by "Astrolabe", and Krüger (1914) described material collected from Shark Bay.

Distribution

Australia, Kei Is, Amboina Bay, Jedan Is. In Australia — W.A., Vic., N.S.W., Qld. Depth range 0-135 m.

Dimensions

Capitular height 19.0 mm, width 12.5 mm; peduncular length 12.5 mm.

Western Australian Records

Darwin 1851: 265; Hoek 1883: 32; Krüger, 1911: 15; 1914: 431; Broch 1931: 13, 126; Jones (in press); Jones *et al.* (in press).

LEPADIDAE Darwin, 1851

Lepas anatifera Linnaeus, 1758 (Figure 3)

Lepas anatifera Linnaeus, 1758: 668; Darwin 1851: 73, Pl. 1 Fig. 1a-c



Figure 3 Lepas anatifera Linnaeus; lateral view.

Remarks

Capitulum with five smooth or finely striated plates. In life capitular plates white-bluish, sometimes with diagonal band(s) of brown-green squares from umbo to carina, edges of orifice bright scarlet, areas between valves dull orangebrown. Pelagic habitat, attached to floating objects and pelagic animals and plants in open water; never found living on the shore.

Distribution

Cosmopolitan in temperate and tropical seas. In Australia – W.A., Tas., Vic., N.S.W., Qld.

Dimensions

Capitular height to 50.0 mm, capitular width 25.0 mm; peduncular length to 190.0 mm.

Western Australian Records

Nilsson-Cantell 1927: 752; Jones (in press); Jones et al. (in press).

Conchoderma auritum (Linnaeus, 1767) (Figure 4)

Lepas aurita Linnaeus, 1767: 1110 Conchoderma aurita; Darwin 1851: 141, Pl. 3 Fig. 4

Remarks

The two tubular, ear-like appendages behind the rudimentary (and often absent) terga on the capitulum are charactertistic for the species. In life the



Figure 4 Conchoderma auritum (Linnaeus); lateral view.

capitulum and peduncle are brown-grey, mottled with cream. The species is pelagic on floating objects, floating and usually living animals. It is specifically known to attach to whales where it is usually associated with the balanid *Coronula diadema. C. auritum* is also often found fouling slow-moving boats.

Distribution

Cosmopolitan in all seas. In Australia - W.A., N.S.W., Qld.

Dimensions

Capitular height 40.0 mm, width 25.0 mm; peduncular length 70.0 mm, diameter 18.0 mm.

Western Australian Records

Jones (in press); Jones et al. (in press).

Suborder Balanomorpha Pilsbry, 1916 CHTHAMALIDAE Darwin, 1854

Chthamalus malayensis Pilsbry, 1916 (Figure 6)

Chthamalus malayensis Pilsbry, 1916: 310, Pl. 72 Figs 5-5a

Remarks

Shell low, conical, parietal plates smooth or with a few broad ribs in young, uneroded specimens, markedly ribbed in young eroded specimens, or with black crosses in longitudinal rows in larger, eroded specimens. Epibiotic, occurring D.S. Jones



Figure 6 Chthamalus malayensis Pilsbry; apical view.

between high water spring and low water neap tidal levels in positions of semi to full wave exposure. Attached to mollusc shells, rocks, mangrove trees and harbour installations.

Distribution

Tropical and subtropical regions of Indo-Pacific. In Australia from Garden I., W.A., north to Shark Bay, north east and east along the tropical northern coasts to Torres Strait and south to Hervey Bay, Qld.

Dimensions

Carino-rostral diameter 17.0 mm; height 6.4 mm.

Western Australian Records

Krüger 1914: 435 (as C. stellatus var. communis); Broch 1916: 14 (as C. antennatus); Pope 1965: 51; Foster 1974: 43; Lewis 1981: 4; Jones et al. (in press).

CORONULIDAE Leach, 1817

Cetopirus complanatus (Mörch, 1852) (Figure 7)

Cetopirus complanatus Mörch, 1852: 67; Newman & Ross 1976: 45

Remarks

Shell depressed, six parietal plates with very flat, broad ribs, subdivided towards base, radii very thick, moderately wide. Thick opercular membrane supporting small terga and elongated, contiguous scuta. Attached to whales, barnacle well embedded in skin of the whale.

Distribution

Norway, Chile, West Africa, Cape of Good Hope, Kei Is, Amboina, Australia, Tasmania, Kerguelen I. In Australia — W.A., Tas., N.S.W.



Figure 7 Cetopirus complanatus Mörch; apical view (redrawn from Darwin 1854).

Dimensions

Basal diameter 74.0 mm; height 18.0 mm.

Western Australian Records

Jones et al. (in press).

Coronula diadema (Linnacus, 1767) (Figure 8)

Lepas diadema Linnacus, 1767: 1108 Coronula diadema; Lanarck 1818: 387; Darwin 1854: 417, Pl. 15 Figs 3-3b, Pl. 16 Figs 1, 2, 7



Figure 8 Coronula diadema (Linnacus); apical view.

Remarks

Shell symmetrical, tall and crown-like, six parietal plates externally with longitudinal convex ribs, transversed by narrow, beaded growth lines, radii very broad, opercular membrane thick, brown, supporting small scuta and vestigial (often absent) terga. Attached to fin, blue, sperm and humpback whales, with only basal regions of parietal plates embedded in the skin of the whale. D.S. Jones

Distribution

Probably cosmopolitan. In Australia - N.S.W., W.A.

Dimensions

Carino-rostral diameter 67.0 mm; height 40.0 mm.

Western Australian Records

Jones (in press); Jones et al. (in press).

TETRACLITIDAE Gruvel, 1903

Tetraclita squamosa squamosa (Bruguière, 1789) (Figure 5)

Balanus squamosus Bruguière, 1789: 170, Pl. 165 Figs 9-10 Tetraclita squamosa squamosa; Pilsbry 1916: 251



Figure 5 Tetraclita squamosa squamosa (Bruguière); apical view.

Remarks

Shell shape and colour variable, usually steeply conical, light gray to purpleblack. Four parietal plates obvious in juveniles but older, eroded specimens have sutures obliterated and outer lamina eroded, exposing partially filled parietal tubes which appear as finely beaded, longitudinal ridges. Epibiotic, in semisheltered situations, occurring from mid tidal areas to 5 m depth. Attached to rocks, coral reefs, molluscs, wooden posts and sometimes mangrove trees.

T. squamosa was first collected in 'Nouvelle-Hollande' by Péron in 1802 (Gruvel 1903; Lamy & André 1932) and three examples remain in the Muséum National d'Histoire Naturelle, Paris. The species was again collected in Western Australia at Shark Bay, as var. *viridis*, by the 1905 Hamburg Expedition to south-western Australia led by Michaelsen and Hartmeyer, "Station 26, Shark Bay, Surf Point, ½-3½ m; 16.vi.05 (1 Exemplar)." (Krüger 1914).

The external appearance (shape, size and colour) may vary in this species — for example on flat surfaces the barnacle assumes a low, spreading form; in younger specimens the outer lamina may be only partially removed from the shell; radii may be distinct or indistinct.

Distribution

Tropical and subtropical regions of the Indo-Pacific region. In Australia from Sandy Cape (north of Jurien Bay), W.A., north to N.T. and extending to Hayman I., Qld.

Dimensions

Basal diameter 50.0 mm; height 37.0 mm.

Western Australian Records

Krüger 1911: 60; 1914: 441; Broch 1916: 14; Jones et al. (in press).

ARCHAEOBALANIDAE Newman & Ross, 1976

Chirona (Striatobalanus) amaryllis (Darwin, 1854) (Figure 9)

Balanus amaryllis var. a, var. b Darwin, 1854: 279, Pl. 7 Figs 6a-c Chirona (Striatobalanus) amaryllis; Newman & Ross 1976: 50



Figure 9 Chirona (Striatobalanus) amaryllis (Darwin); lateral view.

Remarks

This species is usually bright pink but the colour can be variable. Habitat mostly sublittoral, although the species is known to extend into the low intertidal in north-western Australia and Queensland. Attached to stones, gorgonians, alcyonarians, molluscs, echinoids, crabs, wood and reefs. Also known as a fouling species on ships. D.S. Jones

Distribution

E Africa, Madagascar, Indian Ocean, Malayan Arch., Jedan Is, Arafura Sea, Australia, Torres Str., Philippines, S Japan, China, Hong Kong. In Australia – W.A., N.T., Qld.

Dimensions

Carino-rostral diameter 30.0 mm; height 35.0 mm.

Western Australian Records

Jones et al. (in press).

Chirona (Striatobalanus) tenuis (Hoek, 1883) (Figure 10)

Balanus tenuis Hoek, 1883: 154, Pl. 13 Figs 29-33 Chirona (Striatobalanus) tenuis; Newman & Ross 1976: 50



Figure 10 Chirona (Striatobalanus) tenuis (Hoek); lateral view.

Remarks

Shell glossy snow-white or dirty white. Sublittoral species, depth range 7 to 522 m. Attached to molluscs, bryozoans, decapod crustaceans and clinker.

Distribution

Indo-west Pacific. In Australia - W.A.

Dimensions

Carino-rostral diameter 18.0 mm; height 17.0 mm.

Western Australian Records

Jones et al. (in press).

Acasta pectinipes Pilsbry, 1912 (Figure 11)

Acasta pectinipes Pilsbry, 1912: 294



Figure 11 Acasta pectinipes Pilsbry; lateral view.

Remarks

Parietal plates orange-white or pinkish, curved towards orifice. Orifice small, toothed, sometimes blue-green due to algal growth. Occurring in sponges from 10 to 170 m, on sand and coral substrates.

The only record of this species occurring in Western Australia is that of Krüger (1914) who described *A. pectinipes* (as *A. nitida*) from material collected by the Hamburg South-Western Australian Expedition of 1905 led by Michaelsen and Hartmeyer, at Shark Bay, Western Australia — "Station 7, Sharks Bay, ca. 2½ engl. Meil, SW Denham; 10.vi.05 (1 Exemplar). — Station 28, Sharks Bay, vor Dirk Hartog bei Brown Station, 2½ - 4½ m; 17.vi.05 (2 Exemplare)".

Distribution

Indo-west Pacific. In Australia - W.A., Qld.

Dimensions

Basal diameter 6.5 mm; height 8.5 mm.

Western Australian Records

Krüger 1914: 438 (as A. nitida); Jones et al. (in press).

Acasta sulcata Lamarck, 1818 (Figure 12)

Acasta sulcata Lamarck, 1818: 398; Darwin 1854: 310, Pl. 9 Figs 2a-d

Remarks

Shell subglobular, white, sometimes with pink tinges apically. Found associated with sponges, depth range 4 to 25 m. This species was first described





Figure 12 Acasta sulcata Lamarck; lateral view.

from Western Australia in latitude 25°S by Lamarck (1818), from material collected by Péron at Shark Bay.

Distribution

Indo-west Pacific. In Australia - W.A., southern Australia, N.S.W.

Dimensions

Carino-rostral diameter 6.3 mm; height 8.0 mm.

Western Australian Records

Lamarck 1818: 398; Hoek 1883: 32; Gruvel 1905: 164; Krüger 1911: 57; Barnard 1924: 82; Jones (in press); Jones *et al.* (in press).

BALANIDAE Leach, 1817

Balanus amphitrite Darwin, 1854 (Figure 13)

Balanus amphitrite var. (1) communis Darwin, 1854: 240 (part.), Pl. 5 Figs 2a-d, Fig. i-k, m-o



Figure 13 Balanus amphitrite Darwin; lateral view.

Remarks

Shell round, conical, vertical striping on parieties characteristic. Intertidal to depth of 9 m, occurring in sheltered situations. Known as a fouling species of boats and harbour installations, and also attached to rocks, molluscs and crustaceans.

Distribution

Cosmopolitan in tropical and warm temperate seas. In Australia – W.A., S.Aust., Vic., N.S.W., Qld.

Dimensions

Basal diameter 12.8 mm; height 12.2 mm.

Western Australian Records

Broch 1916: 5 (as var. *communis*); Lewis 1981: 8; Jones 1987a: 147; 1987b: 159; Jones *et al.* (in press).

Balanus variegatus Darwin, 1854 (Figure 14)

Balanus amphitrite var. (8) variegatus Darwin, 1854: 241 Balanus variegatus; Harding 1962: 291, Pl. 10 Figs a-k



Figure 14 Balanus variegatus Darwin; lateral view.

Remarks

Shell steeply conical, tubular in crowded populations, cross-hatched bands on parietal plates characteristic. Occurring at low tidal levels to 9 m depth, in sheltered conditions. Attached to rocks and molluscs, and occasionally to crustaceans. Also known as a fouling species of harbour installations and boats.

Distribution

Australia, New Zealand. In Australia from Carnarvon, W.A., around southern coastline to Coffs Harbour, N.S.W.

D.S. Jones

Dimensions

Basal diameter 18.0 mm; height 25.0 mm.

Western Australian Records

Krüger 1914: 437 (as *B. amphitrite* var. *stutsburi*); Nilsson-Cantell 1931: 125 (as *B. amphitrite stutsburi*); Lewis 1981: 10; 1982: 14; Chalmer 1982: 75; Marine Research Group of Victoria 1984: 108; Lewis 1985: 119; Jones 1987a: 147; 1987b: 160; Jones *et al.* (in press).

Megabalanus tintinnabulum (Linnaeus, 1758) (Figure 15)

Lepas tintinnabulum Linnaeus, 1758: 668 Megabalanus tintinnabulum; Newman & Ross 1976: 68



Figure 15 Megabalanus tintinnabulum (Linnaeus); lateral view.

Remarks

Shell conic or tubulo-conic. Six parietal plates varying in colour from pinkish white to pinkish purple, radii blue violet to dark purple. Submerged epibiotic fouling species occuring from low water neap levels to 40 m depth. Attached to rocks, echinoids and molluscs and known as one of the most common ship fouling barnacles.

Distribution

Cosmopolitan fouling species. In Australia - W.A., N.S.W.

Dimensions

Carino-rostral diameter 35.0 mm; basal diameter 65.0 mm, height 50.0 mm.

Western Australian Records

Jones (in press); Jones et al. (in press).

Megabalanus validus (Darwin, 1854) (Figure 16)

Balanus tintinnabulum var. (3) validus Darwin, 1854: 195, Pl. 1 Megabalanus validus; Newman & Ross 1976: 69



Figure 16 Megabalanus validus (Darwin); lateral view (after Darwin 1854).

Remarks

Shell conical. Six parietal plates coarsely ribbed, colour varying from pale brown-purplish pink, pink to rich purple, ribs pale pink or white. Attached to rocks, stones and iron, depth range from low water mark to 13 m.

M. validus has been collected only once in Australia, by the 1905 Hamburg South-Western Australian Research Expedition under Drs W. Michaelsen and R. Hartmeyer. Krüger (1914: 435) recorded one specimen collected by the expedition at Shark Bay. "... Station 16, Sharks Bay, NW Heirisson Prong; 13.ix.05. 11-12½ m". Newman & Ross' record (1976) of *M. validus* in south-western Australia is presumably that of Krüger.

Distribution

Australia, Taiwan, Malay Arch., Gulf of Mannar, Andamans. In Australia - W.A.

Dimensions

Basal diameter 75.0 mm.

Western Australian Records

Krüger 1914: 435; Newman & Ross 1976: 69; Jones et al. (in press).

Discussion

Sixteen barnacle species are recorded from the Shark Bay area of Western Australia in the present report. From literature records the following species could also possibly occur in the area — Lepas anserifera Linnaeus, L. pectinata Spengler, Oxynaspis indica Annandale, Octolasmis orthogonia (Darwin), Chelonibia testudinaria (Linnaeus), Platylepas ophiophilus Lanchester, Acasta cyathus Darwin, Savignium dentatum (Darwin), Balanus trigonus Darwin, B. concavus Brown and *Megabalanus* rosa (Pilsbry) (Weltner 1897; Krüger 1914; Jones 1987c; Jones *et al.* in press).

The Shark Bay barnacles described in the present study show a large cosmopolitan element (six species) and an equally large component exhibiting affinities to species from the broad Indo-west Pacific region (six species). Two species have distinct faunal affinities with the Australia/Malay Archipelago region, and the remaining two species show temperate Australasian affinities. If the zoogeographic affinities of the 27 species which could possibly occur in the area are considered the following pattern emerges — distinct affinities with cirripede faunas of the Indo-west Pacific region and the Indian Ocean/Malay Archipelago area, and small numbers of species with faunal affinities to southern Australia and New Zealand species. This pattern contrasts with that described for barnacles collected from the Albany region, W.A. (Jones, in press) and for south-western Australian cirripedes in general (Jones 1987c), where distinct faunal affinities with southern Australian and New Zealand cirripedes are exhibited.

Considering the latitude of Shark Bay, the zoogeographic affinities displayed by the barnacles are not surprising. In Western Australia marine organisms fall into three general distributional patterns. A warm temperate fauna is present on the south coast of Western Australia, which is continuous with the fauna of the southern Australian coastline to the east. The majority of these temperate forms extend westwards to Cape Leeuwin. On the northern coast a tropical fauna occurs, which is part of the broad Indo-west Pacific faunal region. Most of these tropical species extend westwards to the North West Cape region. Between Cape Leeuwin and North West Cape the southern temperate and northern tropical faunas overlap along the west coast, with temperate species predominating in the south and tropical species predominating in the north. In general in western Australian coastal waters, sea currents tend to favour the spread of warm water species into cooler areas. The warm, southerly flowing Leeuwin current has been proposed as a possible vector for transporting various tropical marine species much further south then would otherwise be expected (Legeckis & Cresswell 1981). Temperate species are likely to be prevented from dispersing northwards by temperature and the availability of suitable substrata.

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Spiders of the Shark Bay area, Western Australia

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Abstract

The 21 species of spiders previously recorded from Shark Bay are listed and their present status and distribution noted. Mygalomorphs are recorded from the region for the first time; eight species including four new species are recorded.

Résumé

Les 21 espèces d'araignées recensées antérieurement dans la Baie des Chiens Marins sont énumérees et leur statut et répartition actuels sont notés. Les Mygalomorphes de la region sont répertoriés pour la première fois; huit espèces, y compris quatre nouvelles espèces, sont répertoriées.

Introduction

In spite of the Shark Bay region being the site of the first Australian landfall for Europeans, it is still not well known by arachnologists. The only published systematic records of spiders from the region are those of Simon (1908, 1909). The specimens on which Simon's records were based were collected by the Berlin & Hamburg Museums' joint expedition of 1905. The collections were divided between the Berlin, Hamburg, Paris and Western Australian Museums with most of the primary types being lodged in the Paris Natural History Museum. These species are listed in Table 1 and commented on in the following section.

The Western Austalian Museum and my collections contain specimens of species additional to those recorded by Simon. The araneomorph specimens have not been fully sorted and identified and will not be discussed here. No burrowing spiders apart from one lycosid and no mygalomorphs were recorded by Simon. Nor have any mygalomorphs from the region been recorded subsequently in the literature. Therefore those species of mygalomorphs which I have in my collection are listed below.

Araneomorphae

Simon (1908, 1909) recorded 21 species including 15 which he newly described and of which five were endemic to the area (see Table 1). Of the already named species, one, *Pholcus phalangioides* is cosmopolitan and was probably introduced to the area (Denham) by the settlers; at least three species, the *Nephila*, *Olios calligaster* and *Clubiona robusta* were already recognised as widely distributed

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 Table 1
 The 21 species recorded by Simon (1908, 1909) from the Shark Bay area. Of the five species noted by Simon as endemic to Shark Bay localities, only one (*Phryganoporus tubicola = Badumna candidus* (L. Koch)) has subsequently been recorded from elsewhere. *B. candidus* is widespread across the continent.

Simon's localities (& Expedition Station No., see map, p. 362, Simon 1908)	Species (Simon's designation) *endemic to locality at time of Simon's designation	Current taxonomic status (if changed) and authority	
65. Denham	*Clubiona laudabilis Simon, 1909 *Dipoena (Lasaeola) austera Simon, 1908 Homoeothele micans Simon, 1908 Lithyphantes niveo-signatus Simon, 1908 Nephila imperatrix L. Koch	= Steatoda niveo- signatus (Simon) (see Levi 1957, 1962) =Nephila edulis (Labil.) (see Bonnet 1958, p.3066)	
	Olios calligaster (Thorell) Pholcus phalangioides (Fuesslin) *Phryganoporus tubicola Simon, 1908	=Badumna candidus (L. Koch) (see Gray 1982)	
67. Dirk Hartog Island, Brown Station	Lycosa meracula Simon, 1909 *Aphyctoschaema veliferum Simon, 1908	=Badumna (Aphyctoschaema) veliferum (Simon) (see Lehtinen 1967, p.228)	
	Bomis larvata L. Koch Clubiona robusta L. Koch Dolophones conifera (Keyserling) Lampona quinqueplagiata Simon, 1908 Larinia eburneiventris Simon, 1908 *Paraplectanoides cerula Simon, 1908		
69. Edel Land, Baba Head	Ariadna thyrianthina Simon, 1908		
70. Edel Land, Tamala	Ariadna thyrianthina Simon, 1908 Isopoda nigrigularis Simon, 1908 Megamyrmaecion perpusillum Simon, 1908	<i>=Megamyrmecium</i> (emendation, see Bonnet 1957, p.2752)	
	Miturga occidentalis Simon, 1909 Rebilus castaneus Simon, 1908		

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across the continent. Dirk Hartog Island (the first European landfall) for this expedition yielded seven species, other sites eg Denham, nine species and Baba Head and Tamala (Edel land) one and five species respectively (of which one was common to both the latter sites). Several others were recorded from a wide range of other sites within Western Australia in Simon's study eg Lycosa meracula, Ariadna thyrianthina, Rebilus castaneus, Megamyrmaecion perpusil-lum, Isopeda nigrigularis and Miturga occidentalis.

Table 1 lists the species recorded by Simon (under the name used by him), indicates the endemics (to the Shark Bay area) and gives the localities. The current nomenclatural status of each species is also given. Of the endemics, one species, *Phryganoporus tubicola*, has subsequently been synonymised with *Badumna candidus* (L. Koch) (see Gray 1982), a species known to be widespread across the continent and of interest because of its social behaviour. There are no later records of the other four endemics. Of the other newly described species only *Lycosa meracula*, *Ariadna thyrianthina* and *Rebilus castaneus* have been recorded subsequently. *Lycosa meracula* has been collected from various localities on the peninsulas and islands of the Shark Bay area and islands farther north (McKay 1979). *Ariadna thyrianthina* and *Rebilus castaeneus* has each been recorded from a locality other than the Shark Bay region - Reevesby Island in South Australia and the Wongan Hills respectively (Hickman 1950; Main 1977). All of these species except the lycosid are foliage, litter or bark dwelling spiders and include both webweavers and vagrant spiders.

Mygalomorphae: species and localities

Barychelidae

Species 1

Identity uncertain. A juvenile specimen in poor condition. The almost square eye grouping and absence of a tubercle suggests it may be *Idioctis*. Absence of a stridulating lyre determines that at least it is not *Idiommata* which is the only other barychelid known from the region.

Dorre Island, Quoin Bluff campsite. 20 August 1977. R.I.T. Prince (BYM 1978/9).

Idiommata blackwalli (Cambridge) ?

Two trapdoors with attached parchment-like silk tubes from burrows clearly identify the presence of an *Idiommata*. To date the only species identified from the west coast is *blackwalli*.

Dirk Hartog Island, May 1978. R.I.T. Prince.

Ctenizidae

Eucyrtops sp.

A single male specimen of an undescribed species which bears no close morphological resemblance to any of the named (or recognised but unnamed species). Spiders

Carrarang Bay. False Entrance Well: near stone tank; from pit traps. 31 May 1980. J.D. Roberts. (BYM 1980/23).

Arbanitis hoggi (Simon)?

A single male specimen. The type locality of this species is Eradu (see Simon 1908; Main 1985). It is distributed throughout the valleys and salt lake systems cast of Geraldton (Main 1964). The Dirk Hartog Island specimen shows some differences from the type specimen of *A. hoggi* and may in fact be a different species.

Dirk Hartog Island. J. Warham. Early June 1957. (BYM 1957/188).

Dipluridae

Cethegus fugax (Simon) ?

To date the only species of *Cethegus* described from Western Australia is *fugax* (originally *Palaevagrus fugax* Simon) of which the type locality is Mt. Helena (formerly Lion Mill) (see Raven 1984; Main 1985). However the type series included some specimens from Geraldton (Simon 1908; Main 1960). Until the southern Western Australian specimens (author's collection) are fully examined they are included in this species.

Dirk Hartog Island. Quoin Bluff. 9 November 1976. R.I.T. Prince. Juvenile specimen (BYM 1976/11).

Bernier Island. Hospital Valley area. 13 March 1981. R.I.T. Prince. Two females. (BYM 1981/124, 125).

Nemesiidae

Chenistonia sp. (?)

A single female specimen of an undescribed species. This specimen is very tentatively attributed to *Chenistonia*. It possesses most characteristics of the genus but has several spines (instead of a pair) on the ventral face of the palp tarsus.

Bernier Island. Pit line west of Hospital Valley. Eucalypts. 14 March 1981. R.I.T. Prince (BYM 1981/126).

Aname diversicolor (Hogg)

This specific name is being used in the sense of Main (1982, 1985), not that of Raven (1985). The species as diagnosed by Main (1982) is widespread from Eyre Peninsula in South Australia to the west coast of Western Australia. However it is doubtful whether the species in question is correctly identified, the type (from Delta Station in Queensland?) is lost (see Main 1976, 1982, 1985 and Raven 1985 for discussion on the status of *Aname diversicolor* (Hogg)). Until a new name is formally proposed for Eyre Peninsula/Western Australian populations (Main in preparation) they will continue to be attributed to *A. diversicolor*.

Shark Bay Road, 44.25 kms west of "The Overlander". February 1970. Chuck Taylor. Single male specimen. (BYM 1970/2). Dirk Hartog Island. Gate between Two Wells and Big Horse Paddocks. 19 January 1978. R.I.T. Prince. Single male

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specimen, collected while specimen wandering on trail at 9.03 pm. (BYM 1978/20). Dirk Hartog Island. Ransonnet Yard. 21 September 1980. R.I.T. Prince. Single pre-penultimate male dug from wishbone shaped burrow. (BYM 1980/56).

A. diversicolor (?)

False Entrance. Carrarang Station. 1 November 1980. D. Roberts. Single female specimen from pitfall trap. Tentatively identified as conspecific with above specimens. (BYM 1980/55).

Aname undescribed species

Shark Bay Road, 44.25 kms west of "The Overlander". February 1970. Chuck Taylor. Single male specimen. (BYM 1970/3). False Entrance. Carrarang Station. 8-10 August 1980. D. Roberts. Three male specimens from pit trap. (BYM 1980/26, 27, 28). Hamelin Pool Station. 9 March 1983. S.D. Bradshaw. Single male specimen, wandering 9.30 pm. (BYM 1983/146). Hamelin and Nanga Stations boundary, 2 kms south of Denham Road. 2 March 1984. P. Kendrick. Single male specimen from pit trap. (BYM 1984/17).

Description of species in preparation (Main unpublished).

Aname sp.

Single specimen, poor condition, fragments only. Dorre Island, August 1978. R.I.T. Prince. (B.Y.M. 1978/8).

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A new genus and species of cicada (Insecta, Homoptera, Tibicinidae) from Western Australia

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Abstract

Chrysocicada franceaustralae gen. nov. et sp. nov. is described from the western Kimberley region of Western Australia.

Résumé

La Chrysocicada franceaustralae gen. nov. et sp. nov. vivant dans la région de Kimberley occidental en Australie-Occidentale est décrite.

Introduction

In the context of the "France-Australe Expedition" to Shark Bay, Western Australia, in July and August 1988, it was hoped to survey the insect fauna of this interesting region, first described by the French scientists accompanying the "Nicolas Baudin Expedition" of 1800-1804. However, because of inclement weather this proved impractical as few insects were active. Particular attention was given to cicadas (Cicadoidea) and tree-hoppers (Membracoidea) but none was collected at Shark Bay.

During a short exploratory trip in the Kimberley, east of Derby, one species of cicada was collected on a track to Meda Station. This represents a new genus and species belonging to the family Tibicinidae and the tribe Parnisini. It is described herein and named *Chrysocicada franceaustralae*, (Golden Cicada of the France-Australe Expedition) in honour of the French-Western Australian Expedition celebrating Australia's Bicentenary.

Systematics

Tibicinidae: Pamisini

Tymbal covers totally absent: family Tibicinidae.

Eyes not projecting beyond anterior angles of subquadrate pronotum; forewings with fused radial and median veins and first cubital vein emerging in two distinct points from basal cell: tribe Parnisini.

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A new cicada

Chrysocicada gen. nov.

Type-species: Chrysocicada franceaustralae sp. nov. (see below).

Diagnosis

Chrysocicada is most similar to the Gondwanan genus Quintilia Stål from which it differs in the shape of the abdomen (apex not strongly conical) and genitalia (hypandium not longer than 6 + 7 sternites; edeagus strong and short, without long spines as in Quintilia carinatus for instance.

Head: as wide as the mesonotum; antennal arcades with accentuated curves joining the dorsal part of the postclypeus nearly at right angles; ocelli relatively widely spaced lateral ocelli slightly more distant from each other than each eye; median ocellus situated quasi-dorsally.

Thorax: length 2.5 times that of head, without extended paranota.

Wings: fore wing with a long and wide basal cell, extremity forming a triangle; R+M about as long as basal cell; postcostal cell and apical cubital cell particularly broad; most cross veins oblique, that at base of apical area 5 usually meeting longitudinal vein at a right angle; 8 apical cells. Hind wing with anal area as wide or almost as wide as cubital cell; 6 apical cells.

Legs: anterior femora usually with three unequal subcarenal spines.

Abdomen: equal to or slightly longer than thorax plus head, not larger than mesonotum in male.

Male genitalia: phallicophore (urite X) without superior-posterior lobes, posterior lobes developed into sclerotised hooks. Phallus robust, tubular.

Chrysocicada franceaustralae sp. nov. Figures 1-10

Diagnosis

The uniform light yellow ochre colour, body sprinkled with short golden hairs, blackish antennae, obsolete mesonotal spots and relatively short transparent wings, easily distinguish *C. franceaustralae* from other Australian Parnisini.

Holotype

Male: WAM 89/435; near Meda Station (17°22'S, 124°12'E) Kimberley Division, Western Australia; collected Michel Boulard, 22/7/1988; Western Australian Museum.

Paratypes

Two males; Muséum national d'Histoire Naturelle de Paris (Entomologie); one male, Australian Museum, Sydney. Other details as for holotype.

Description of holotype

Head: bearing a mixture of black and golden hairs; vertex hunched. Eyes almost globular. Antennae with seven segments, scape yellow, apical half of pedicel dark brown, flagellum mottled with dark brown, the last segment minuscule and conical. Postclypeus prominent, very rounded, median groove



Figures 1 & 2 Chrysocicada franceaustralae sp. nov., male holotype; 1 = dorsal view, resting position, 2 = lateral view, characteristic posture of the species when calling. (Photographs by Michel Boulard).

A new cicada

long and deep, embedding even the dorsal part; anteclypeus dark brown apically; rostrum brown, becoming darker toward apex and reaching bases of intermediate trochanters.

Thorax: pronotum as long as head, the inner areas deeply obliquely grooved; outer area or pronotal collar narrow, produced into relatively wide suprahumeral lobes but not very overhanging. Mesonotum slightly longer than head and first thoracic segment together; subtriangular spots obsolete. Opercula slightly larger than half-moon shape, clearly separated (Figure 4).

Wings: hyaline; venation as in Figure 3. Apex of fore wings slightly amber; fore wing slightly exceeding apex of abdomen when retracted costa, cross veins, apical portion of the longitudinal veins and ambient vein blackish brown, remaining veins yellow; apical area slightly smoked, mainly at and around the cross veins. Hind wings veins dark brown except for yellow median and first anal veins.





Chrysocicada franceaustralae sp. nov., male holotype; 3 = dorsal view with wings spread; 4 = ventral view. (Drawings by Helene Le Ruyet-Tan, Muséum Paris).

Legs: almost entirely yellow, anterior tibiac brown with short, black spiny hairs; a few similar hairs on anterior femora, these with three short sub-carenal spines (Figure 5); apex of tarsi brown.

Abdomen: uniformly yellow; very rounded with seven long, brown, curved ribs and five short, brown, intermediate ribs (the first intercostal space has none) in the shape of an elongate S toward base of ribs a longitudinal groove runs the length of the tymbals, from which the principal ribs divide into two. (Figure 8);

Genitalia: Pygophore yellow, without caudal process but having two relatively long medio-posterior lateral lobes in finger shape. Phallicophore (urite X) yellow above, superior lobes barely developed and scarcely pigmented, the inferior lobes M. Boulard

hook-like, pigmented becoming ever darker. Phallus particularly robust, phallotreme in shape of wide crown with two opposed and sclerotized spinulae (Figures 6 and 7).



Figures 5 to 7 Chrysocicada franceaustralae sp. nov., male paratype; 5 = left anterior femur, 6 = genital urites in lateral view. UIX = pygophore; UX = phallicophore; (scale in millimetres). Drawings by Michel Boulard).



Figure 8 Chryocicada franceaustralae sp. nov., male holotype showing the tymbale of the right side. (Photographs by Michel Boulard).





Dimensions of holotype (in millimetres): total length (including wings when at rest) = 21.5; body length = 16.25; wingspan = 36; width of head (including eyes) = 4.6; width of mesonotum = 4.4; distance between the lateral ocelli = 0.7; distance from eye to nearest ocellus = 0.5; greatest width of fore wings = 6.

Female unknown.

Etymology

Named in honour of the "France-Australe" Expedition celebrating Australia's Bicentenary and the scientific links between the two nations.

Natural history notes

At the time of discovery, the Meda population of *Chrysocicada franceaustralae* appeared small with individuals widely dispersed. During two days of searching

only four males were collected, all of which appeared newly-emerged. The males called singly and were difficult to see because of their coloration which closely matched that of the dead grasses and small shrubs on which they perched, approximately 0.4 to 1.3 metres above the ground. The characteristic "singing posture" adopted by the males, with the wings pushed down and separated from body contact and the abdomen raised, is shown in Figure 2.

The call or "song" (in French: "cymbalisation") of the males is soft and low pitched to the human ear and of irregular duration lasting anywhere between one and three minutes, with short periods of silence interspersed. Two sonograms of the call are reproduced in Figures 9 and 10 and these show that the call has three distinctive components: a strong fundamental signal between 100 and 1300 Hz; a first harmonic between 1650 and 2200 Hz of much weaker intensity; and a second harmonic of medium intensity around 12,000 Hz.

Fishes and benthos of near-shore seagrass and sandflat habitats at Monkey Mia Shark Bay, Western Australia

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Abstract

In February and June 1983 fifty-eight species of fish were captured by beach seining in intertidal seagrass (*Amphibolis*) and adjacent sand flats characterised by benthos dominated by small gastropods and by larger gastropods and bivalves respectively. Catches in seine hauls covering 380m² contained an average of 224 individuals in seagrass, significantly more than the average of 139 caught on the sand flat, and more in February than in June (229 compared with 134). The average number of species, adjusted to catches of 100 individuals, was greatest in seagrass in February (15), and greater at night (13) than during the day (9). Seven of the 14 most abundant fishes were most numerous in seagrass, 4 were most abundant on the sand flat and 3 were equally abundant in the two habitats. Of the rare species, 23 were most abundant in seagrass at night and 10 in seagrass during the day; 9 species were most abundant on the sand flats at night but none were most abundant there during daytime.

Résumé

En février et juin 1983 cinquante-huit espéces de poissons furent prises par pêche à la seine dans des herbes marines intertidales (Amphibolis) et dans des bas-fonds sableux adjacents caractérisés par le benthos dominé respectivement par de petits gastropodes et par de plus grands gastropodes et des bivalves. Les prises par halage de seines couvrant 380 m² contenaient une moyenne de 224 individus dans les herbes marines, ce qui est largement supérieur à la moyenne de 139 pris sur le bas-fond sableux et plus en février qu'en juin (229 par rapport à 134). Le nombre moyen d'espèces, ajusté aux prises de 100 individus, était plus grand dans les herbes marines en février (15), et plus grand la nuit (13) que le jour (9). Sept des 14 poissons les plus abondants étaient plus nombreux dans les herbes marines, 4 étaient plus abondants sur le bas-fond et 3 étaient plus abondantes dans les herbes marines le jour; 9 espèces étaient plus abondantes sur les bas-fonds la nuit mais aucune n'y étaient plus abondantes le jour.

Des 50 espèces identifiées de facon précise, 7, 5 et 30 sont respectivement réparties en Australie méridionale, occidentale et septentrionale. Peut-être que ce mélange d'espèces avec des affinités géographiques différentes contribue-t-il à rendre les poissons littoraux de Monkey Mia plus variés que ceux d'habitats similaires ailleurs même si l'abondance de poissons n'est pas grande.

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Of the 50 specifically identified species, 7, 5 and 30 have distributions in southern, western and northern Australia, respectively. Perhaps this mixture of species with different geographic affinities helps make the near-shore fishes from Monkey Mia more diverse than those from similar habitats elsewhere even though the abundance of fish is not great.

Introduction

Shark Bay is characterised by two important features: extensive intertidal and shallow subtidal sandflats with seagrass beds containing a remarkable number of species of plants and a gradient of increasingly saline water which reaches 65 ppt in the distal parts of the bay farthest from the open sea (Logan and Cebulski 1970, Smith and Atkinson 1983, Walker *et al.* 1988). Shark Bay is the subject of an increasing number of studies which focus on the consequences of these unusual features (Harlin *et al.* 1985, Kimmerer *et al.* 1985, Smith and Atkinson 1983, Walker 1985).

The species of phytoplankton and zooplankton found in the eastern gulf of Shark Bay in winter were listed in Kimmerer et al. (1985). The invertebrate fauna of the intertidal sand flats and subtidal *Posidonia* seagrass beds sand have been documented (Wells et al. 1985) at Monkey Mia, mid way along the salinity gradient in Shark Bay on the eastern shore of the Peron Peninsula which divides the bay into two main gulfs. Other studies on the growth rates of intertidal. suspension-feeding bivalves and their interactions with each other and small macroinvertebrates provide additional information about the fauna (Black and Peterson 1988, Peterson and Black 1987, 1988). Besides some information available about the fish caught commercially in Shark Bay (Johnson, Moran & Creagh 1986), the only published record known to us for fish of the bay is Lenanton (1977), which describes the few fish found in the extremely high salinities of Hamelin Pool at the extreme southern end of eastern gulf of the bay. In this paper we contribute detailed additional information about the fish caught by beach-seining in intertidal beds of the seagrass *Amphibolis* spp. and on adjacent sand flats at Monkey Mia and about the benthic fauna occurring in these two habitats. In particular, we provide quantitative estimates of densities and volumes of the benthic invertebrate animals and biomass of the seagrass in summer, as well as abundances of the fishes occurring during the day and night and in both summer and winter in Amphibolis beds and sand flats.

Materials and methods

Study Site

We conducted this study at the same "Subtidal site" to the west of the Monkey Mia Caravan Park on the Peron Peninsula of Shark Bay that is described in Peterson and Black (1987, Figure 1) and that is within about 800 m of the subtidal site studied by Wells *et al.* (1985). During extreme spring tides in summer the sand flats and beds of *Amphibolis* around this site are exposed, but they remained flooded during neap tides and the winter spring tides. The site was very gently sloping at the low spring tide level where we conducted our sampling. The beach rose abruptly at its landward margin so that most of the intertidal area was flat at the lower tidal levels.

Samples of fishes

Our basic equipment was a 14 m wide seine of 8 mm stretch mesh, 1.8 m high, with a footrope of light chain, a headrope with enough floats to keep the top of the seine at the surface and with a pocket in the middle extending 3.5 m from the footrope to the cod end. We carried the seine to the location of the sample, stretched it to its full width, hauled it 50 paces (38 m) with the ends of the seine 10 m apart, on average, brought the wings together rapidly and lifted the entrance to the cod end out of the water and carried the trapped fish back to shore. On shore we emptied the catch and identified and counted all individuals. We preserved the entire catch of early samples so we could confirm our identifications and retain voucher species. In later samples we kept all the rarer species but released most individuals of abundant species.

The design of our seining scheme was to sample the two habitats (intertidal beds of *Amphibolis* and adjacent sand flats), at two times (day and night)) and at two seasons (summer (14-16 February 1983) and winter (26 June 1983)); we took 3 replicate samples for each of these eight categories, making 24 seine hauls in total.

Samples of benthos

Seagrass beds are thought to provide food, shelter and protection from predators for fishes which live there. In order to describe the habitats where we caught fishes, we used three separate techniques in obtaining the information about the plants and animals on and in the substratum of the seagrass beds and sand flats. First, on 15 and 16 February 1983 we sampled ten 1 m² areas as described in Peterson and Black (1987) by excavating the top 10 cm of sediments with our fingers to remove the large animals and by sieving these sediments through a 3 mm metal sieve to remove the smaller animals. In addition to counting the animals, we also used graduated cylinders to determine the displacement volume of all the individuals of each species. These samples are, in fact, a subset of those reported for the subtidal site in February in Peterson and Black (1987, Table 4).

Second, on 14 and 15 February 1983 we used a 27 cm diameter metal pail with the bottom removed as a coring device to take samples of 0.057 m^2 , 20 cm deep. We sieved the material from six cores taken from the beds of *Amphibolis* through a 1 mm square-mesh screen and counted and measured the volume of the animals, of the above — and below — ground portions of the *Amphibolis* and of the detritus, as described previously for the animals on the sand flats.

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Finally, on 15 February 1983 we used a small plastic coring device 85 cm² in area and 15 cm deep to collect 6 samples of the seagrass which we weighed after shaking to remove superficial water.

Results

Benthic organisms of the seagrass and sandflat

Compared with the subtidal seagrass beds, composed largely of *Posidonia* spp. the intertidal *Amphibolis* beds at our study site did not appear lush. Nevertheless,

Table 1. Mean abundance of plants and animals in seagrass (*Amphibolis*) beds at Monkey Mia, Shark Bay in February 1983 listed in order of decreasing volume retained on a sieve with 1 mm mesh. The estimates expressed per 1 m² came from 6 cores of 0.057 m², 20 cm deep for the volume of seagrass and volume and numbers of animals and from 6 cores 85 cm², 15 cm deep for the biomass of plants. Numbers in parentheses after totals are standard errors of the means, and after species names are taxonomic codes (P = polychaete, G = gastropod, B = bivalve, C = crustacean).

Plants	Volume (ml/m ²)	Biomass (wet g/m ²)	
Amphibolis above ground	1618	2334.4	
detritus	1385	117.6	
Amphibolis below ground	510	245.0	
Total Total in original	3515	2697.0	
unit of measurement	$200.8(19.9)/0.057m^2$	22.9(1.95)/85cm ²	
Animals	Volume (ml/m²)	Number/m ²	
holothurian	52.5	5.8	
ascidian	35.0	5.8	
Clypeomorus cf.			
moniliferum (G)	32.1	186.7	
Clypeomorus sp. 1 (G)	32.1	81.7	
Portunis pelagicus (C)	14.6	8.8	
Rhinoclavis kochi (G)	13.7	35.0	
anemone	8.8	2.9	
Thalotia modestum (G)	7.0	8.8	
Clypeomorus sp. 2 (G)	5.9	40.8	
Cantharus erythrostoma (G)	5.8	2.9	
Rhinoclavis vertagus (G)	5.8	8.8	
hermit crab	3.4	5.8	
Morula marginalba (G)	1.5	5.8	
Fragum hemicardium (B)	0.1	2.9	
Nephtys sp. (P)	0.1	5.8	
spider crab	0.1	5.8	
urchin	0.1	5.8	
Total animals			
$/m^2$	206.4	417.1	
/0.057 m ²	11.8 (4.61)	23.8 (17.75)	

there was about 3.5 litres of plant material in each square metre of seagrass bed, or about 2.7 kg of wet material (Table 1).

In contrast to the plants, the fauna of the seagrass bed took up very little volume, only about 0.2 litres, and numbered only 400 individuals per square metre (Table 1). The two biggest species averaged less than 10 ml volume in aggregate and all the others were much smaller. Gastropods were the most abundant individuals, and bivalves were represented by one rare species (Table 1).

Volumetrically, bivalves dominated the sand flats with four species averaging more than 10 ml per species and with all 12 species of bivalves (out of 24) making up 60% of the total volume (Table 2). The numerically most abundant species was a gastropod which alone made up about 55% of the total number of

Table 2. Abundances of animals found in February 1983 in ten $1m^2$ quadrats on sand flats at Monkey Mia, Shark Bay listed in order of decreasing mean volume. The quadrats were sieved to a depth of 8 cm with 3 mm mesh. Species with Latin bionomials are bivalves unless indicated otherwise (G = gastropods, S = scaphopod).

Species	Volume	(ml/m ²)	Number/m ²		
•	Mean	S.E.	Mean	S.E.	
Callista impar	93.9	15.78	5.1	0.94	
Rhinoclavis fasciata (G)	93.7	8.53	26.3	2.31	
Circe lenticularis	19.6	4.81	1.7	0.30	
Placamen gravescens	17.0	3.61	2.8	0.55	
Anomalocardia squamosus	14.9	2.82	2.0	0.39	
hermit crab	2.3	1.07	3.1	1.14	
anemone	1.5	1.49	0.1	0.10	
Dosinia sculpta	1.2	0.81	0.2	0.13	
Pitar citrina	0.8	0.79	0.2	0.13	
Clypeomorus cf.					
moniliferum (G)	0.7	0.49	2.2	1.27	
Circe sulcata	0.6	0.60	0.1	0.10	
Dosinia biscocta	0.6	0.60	0.1	0.10	
Fragum unedo	0.5	0.40	0.2	0.13	
Rhinoclavis kochi (G)	0.3	0.10	1.3	0.39	
Clypeomorus spp. (G)	0.2	0.11	0.2	0.13	
Dentalium sp. (S)	0.1	0.06	0.4	0.16	
Thalotia modestum (G)	0.1	0.10	0.2	0.13	
Tellina robusta	0.1	0.05	0.2	0.13	
Eucithara sp. (G)	0.1	0.04	0.2	0.13	
Clypeomorus cf.					
zonatus (G)	0.01	0.05	0.1	0.10	
Tellina perna	0.04	0.04	0.1	0.10	
Polychaete sp.	0.02	0.01	0.4	0.22	
Odostomia sp. (G)	0.02	0.02	0.2	0.20	
Linga pisiformis	0.01	0.01	0.2	0.20	
Total	248.21	18.86	47.9	2.87	

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individuals, and, at an average of 3.5 ml each, was very much larger than the very small gastropods of the seagrass bed (Table 2).

In summary, the fauna of the two habitats occupied about the same volume, but differed in both dominant species and average size: there were large bivalves and gastropods on the sand flats and small gastropods in the seagrass. Therefore, besides the presence of the seagrass and the three dimensional structure it provides, the seagrass habitat differed considerably in the community of animals compared to that of the sand flats.

Numbers of individuals and species of fish

16

Error

Figure 1 shows the relationship between the numbers of species caught in each of the 24 seine hauls and the number of individual fish, and it follows the pattern of all such collections; the more individuals caught at once, the more species there were. Furthermore, given the scatter of all the points on the graph, there is no obvious tendency for the number of species to stop increasing as the number of individuals increases. On the other hand, if the samples from the seagrass and sand flat are considered separately, the increase in species with increase in individuals is not great. Nevertheless, our samples probably did not collect all

Table 3a. Mean number of individual fish at Monkey Mia, Shark Bay caught in seines stretched 10 m wide and hauled 38 m. Sample size in each combination of Month (February or June), Habitat (Scagrass Bed or Sand Flat) or Time (Day or Night) is three. The analysis of variance is for all three factors fixed and orthogonal. The magnitudes of experimental effects were calculated following methods in Winer 1971, pp. 428-430.

	Mean Number of individuals						
		Scagrass Bed			Sand Flat		Total
	Day	Night	Total	Day	Night	Total	
February	274.7	242.3	258.5	189.0	209.3	199.2	228.8
June	152.0	228.0	190.0	81.0	75.3	78.2	134.1
Total	213.3	235.2	224.3	135.0	142.3	138.7	181.5
			174.2 Day			188.8	Night
		Ana	alysis of varia	nce			
Source:	df	Mean Square	F-test		P value	Magn experimen	nitude of ntal effect (%)
Month (M)	1	53865.375	15.525		0.0012	2	28.3
Habitat (H)	1	43947.042	12.666		0.0026	22.7	
M x H	1	4134.375	1.192		0.2912	0.4	
Time (T)	1	1276.042	0.368		0.5527		
M x T	1	2542.042	0.733		0.4047	2	
НхТ	1	315.375	0.091		0.7669		
MXHXT	1	6767.042	1.950		0.1816		1.9

3469.667

49.8
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Table 3b. Mean expected number of species of fish at Monkey Mia, Shark Bay caught in seines stretched 10 m wide and hauled 38 m. The expected number of species was calculated using the rarefaction method of Simberloff (1978) for a sample of 100 individuals in each seine; in 4 seine hauls in which the catch was less than 100 individuals we used the observed number of species as a conservative estimate of how many species a catch of 100 individuals would have contained. Sample size in each combination of Month (February or June), Habitat (Seagrass Bed or Sand Flat) or Time (Day or Night) is three. The analysis of variance is for all three factors fixed and orthogonal. The magnitudes of experimental effects were calculated following methods in Winer 1971, pp. 428-430.

		Seagrass Bed			Sand Flat		Month
	Day	Night	Total	Day	Night	Total	Total
February	12.3	16.8	14.5	8.5	10.0	9.3	11.9
June	9.2	11.9	10.6	7.0	12.0	9.5	10.0
Total	10.8	14.4	12.6 9.3 Day	7.8	11.0	9.4 12.7	11.0 Night
Analysis of varia Source:	nce df	Mean Square	F-test		P value	Magr experimer	nitude of ntal effect (%
Month (M)	1	20.535	5.575		0.0312		6.5
Habitat (H)	1	60.167	16.335		0.0009	5	21.9
M x H	1	26.882	7.298		0.0157		9.0
Time (T)	1	70.042	19.016		0.0005	1	25.7
MxT	1	1.307	0.355		0.5598		
НхТ	1	0.202	0.055		0.818		
MxHxT	1	10.667	2.896		0.1082		2.7
Error	16	3.683				1	34.2

the rare species of fish occurring in the intertidal habitats at Monkey Mia. The second pattern obvious in Figure 1 is that the samples form two groups with those from the seagrass having more individuals and species than those from the sand flats. We analysed this feature of our collections in two ways.

First, we analysed the variability in the number of individuals caught per seine haul associated with the three factors of our sampling design (Table 3a). The patterns in the mean numbers of individual fish per seine are uncomplicated and supported by the formal analysis of variance. Averaged over both habitats and both months, the time of day made no difference in the number of fish caught, about 180 per seine haul. On the other hand, the catches were more than 1.5 times greater in February than in June, averaged over both time of day and both habitats, and more than 1.6 times greater in seagrass than on the sand flat averaged over both months and both times of day (Table 3a).

A general pattern in collections of organisms, which also appear to be displayed by Figure 1, is that the number of species increases with the number

of individuals so that the number of species in a sample depends on the number of individuals in the sample. We corrected for this pattern by using the rarefaction technique described by Simberloff (1978) to estimate how many species of fish all our samples would have had if they had contained 100 individuals, and Table 3b shows the average expected number of species for all combinations of the levels of the three factors in our sampling design. The interpretation of these data depends on the significant statistical interaction between the factors of month and habitat. The mean number of species expected in a sample of 100 individuals was about the same at 9 to 11 on the sand flat in February and June and in the seagrass in June, but was more than 14 species in the seagrass in February. The influence of the February seagrass combination extends to the overall means for the different months and habitats, making the expected number of species larger in February than in June and larger in the seagrass than on the sand flats. In contrast to the result for number of individuals, the expected number of species was significantly greater in the night than in the day, a pattern that was consistent in both habitats and both months (Table 3b). In summary, these results follow the conventional wisdom about the fish: they are more abundant and more diverse in vegetated habitats and at night than in open habitats or in daytime.



Figure 1. The relationship between number of individuals and the number of species of fish caught at Monkey Mia, Shark Bay in seines stretched 10 m wide hauled 38 m.Water depth varied from 0.75 to 1.25 m. There are three replicates of each combination of month (February (F) or June (J)), habitat (seagrass (G) or sand flat (S)) and time of day (day (D) or night (N)); the filled square point (FSD) for 170 individuals and 10 species is coincident with the third filled circle point (FSN).

Table 4. Mean numbers of the 14 most abundant fishes at Monkey Mia, Shark Bay caught in seines stretched 10 m wide hauled 38 m. Sample size in each combination of habitat and time is six (3 in each of February and June). Superscripts after the mean totals indicate the results of two-way analyses of variance on the raw numbers of the log (x+1) transformations necessary to reduce heterogeneity of variances as tested by Cochran's C test: main effect of habitat significant, with fish more abundant in seagrass (1) or on the sand flat (2), main effect of time of day significant, with fish more abundant during the day (3) or at night (4), and interaction between habitat and time of day significant (5). Water depth varied depending on the state of the tide from 0.75 - 1.25 m. * indicates the species which are in Hutchins and Swainston (1986) + indicates the species which are in Allen and Swainston (1988). Pelates spp. are * P. sexlineatus (Quoy & Gaimard, 1824) and *† Pelates quadrilineatus (Bloch, 1790) and Callionymus spp. are † C. grossi Ogilby, 1910, and C. calliste Jordan and Fowler; these pairs of species were not distinguished in the field.

Family and Species	Seagrass		Sand	Total (S.E.)	
, 1	Day		Day	Night	
Teraponidae					
Pelates spp.	47.8	64.8	0.3	0	28.2 (8.0) 1
Gerreidae					
*+Gerres subfasciatus Cuvier,					
1830	0.7	4.5	47.2	46.8	24.8 (6.2) 2
Apogonidae					
* Apogon rueppellii Gunther,					
1859	38.2	52.8	0	2.2	23.3 (7.4) ¹ , ⁴
Sillaginidae					10.3499 - 3571448916
*+Sillago maculata Quoy &					
Gaimard, 1824	0.5	3.8	49.5	34.8	22.2 (6.3) 2
Monacanthidae					1994 - 1994 - 199
* Monacanthus chinensis					
(Osbeck, 1765)	26.8	39.3	0.7	0	16.7 (3.8)1,4,5
Atherinidae					
<i>†Allanetta mugiloides</i>					
(McCuloch, 1913)	42.8	2.3	0	1.3	11.6 (5.9) 3
Tetrodontidae					
*Polyspina piosae Whitley, 1955	1.2	0.3	18.7	25.5	$11.4(3.5)^2$
Nemipteridae					1
*Pentapodus vitta Quoy & Gai-					
mard, 1824	15.2	9.8	5.2	1.5	7.9 (1.5) 1,3
Serranidae					CONTRACTOR OF A
Centrogenys vaigiensis (Quoy					
& Gaimard, 1824)	3.7	20.2	0.3	0.3	$6.1 (3.1)^{-1}$
Gobiidae					
*Amblygobius phalaena (Valen-					
ciennes, 1837)	6.0	8.6	0.2	0.3	4.4 (1.8)
Atherinidae					
*+Pranesus ogilbyi Whitley, 1930	0.2	3.2	13.0	1.0	4.3 (1.8) 5
Cynoglossidae					
Cynoglossus maculippinis Ren-					
dahl, 1921	0	13.3	0	0	3.3 (1.9)

Table 4 (continued)

Family and Species	Scagrass		Sand Flat		Total (S.E.)	
	Day	Night	Day	Night		
Gobiidae						
Youngeichthys nebulosus						
(Forsskal, 1775)	2.7	6.7	0.2	3.2	3.2 (1.1) 1,4	
Callionymidae						
Callionymus spp.	0.3	0.8	4.3	3.2	$2.2 (0.7)^{-2}$	

Table 5. Total numbers of rare fishes at Monkey Mia, Shark Bay caught in seines stretched 10 m wide hauled 38 m. Sample size in each combination of habitat and time is six (3 in each of February and June). Water depth varied depending on the state of the tide from 0.75 - 1.25 m.

* indicates the species which are in Hutchins and Swainston (1986). † indicates the species which are in Allen and Swainston (1988). There were no rare species which were most abundant on the sand flat during the day.

(A) Sand Flat Night					
Family and Species	Scagrass		Sand Flat		Total
	Day	Night	Day	Night	
Gobiidae					
unidentified sp.	0	3	7	19	29
Bothidae					
Grammatobothus sp.	0	5	0	12	17
Tetrodontidae					
* Torquigener pleurogamma					
(Regan, 1903)	0	0	0	8	8
Soleidae					
Aseraggodes sp.	0	1	0	7	8
Sillaginidae					
* Sillago schomburgkii					
Peters, 1865	0	0	2	3	5
Monacanthidae					
+ Anacanthus barbatus					
(Gray, 1836)	1	1	0	3	5
Hemirhamphidae					
+ Hyporhamphus guoyi					
(Valenciennes, 1847)	0	1	1	2	4
Pleuronectidae					
* Pseudorhombus jenynsii					
(Bleeker, 1855)	0	1	2	2	5
Urolophidae					
+ Himantura uarnak					
(Forsskal, 1775)	0	0	0	1	1

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Table 5 (continued)

(B) Seagrass Day					
Family and Species	Seag	grass	Sand 1	Flat	Total
	Day	Night	Day	Night	
Labridae					
* Halichoeres brownfieldi					
(Whitley, 1945)	17	0	0	0	17
Blenniidae					
*+ Petroscirtes brevicebs					
(Valenciennes, 1836)	11	6	0	0	17
Clupeidae	1012	3760	386	6729	22.8
Herklotsichthys sp	7	2	1	0	10
Platycephalidae					30 M
*+ Platycephalus					
endrachtensis Quoy &					
Caimard 1894	4	0	8	0	7
Neminteridae	1	0	5	0	
* Scagning milii (Popy 1992)	2	0	1	2	7
Provide Scale of the second se	5	0	1	5	'
* the Tachassian Linesters					
(Castalacinus linealius	0	0	0	0	0
(Castelliau, 1875)	2	0	0	0	2
Scorpididae					
* Microcanthus strigatus	0	0	0	0	0
(Cuvier, 1831)	2	0	0	0	2
Syngnathidae					
† Festucalex scalaris			2		0
(Gunther, 1870)	1	1	0	0	2
Ostraciidae					
<i>†</i> Rhyncostracion nasus					
(Bloch, 1785)	1	0	0	0	1
Orectolobidae					
Orectolobus sp.	1	0	0	0	1
(C) Scagrass Night					
Family and Species	Seas	rass	Sand 1	Flat	Total
· · · · · · · · · · · · · · · · · · ·	Day	Night	Day	Night	
Apogonidae					
* Apogon victoriae Gunther,					
1859	0	19	0	0	19
Platycephalidae					
Cymbacephalus					
nematophtalmus (Gunther,					
1860)	0	16	0	3	19
Mullidae					
*+ Ilbeneus tragula					
Richardson 1846	8	11	9	4	20
Siganidae	5	11	4	19 4 0	20
+ Signatus fuscascons					
(Houttyp 1789)	2	10	0	0	19
(110uttyn, 1762)	5	10	0	0	15

continued

Fishes and benthos of seagrass and sand flat habitats

Table 5 (continued)

100	C	N1: 1	
(\mathbf{C})	Scagrass	Nigi	n

Family and Species	Scar	77355	Sand	Flat	Total
ranny and opcos	Day	Night	Day	Night	
Labridae					
Choerodon sp	4	0	0	0	19
Platycenbalidae		.5	0	0	13
Platycephalus isacanthus					
Cuvier 1890	0	7	0	0	10
Centropomidae	U	· ·	0	Э	10
*+ Prominobarca zugiorianeie					
(Cuvier 1898)	0	5	0	0	
Sobwaanidaa	0	5	U	0	9
Sphyraena (lanicanda					
(Puppell 1835)	0	5	1	0	~
People Pe	0	5	1	0	0
+ Penulochromic translature					
(Pichardson 1820)	0	0	0	0	
(Kichardson, 1650) Clinidao	2	Э	0	0	5
Chindae Hatawalinna antinadar					
(Courther)	00	0	0		
(Guniner)	1	3	0	0	4
1.commoac					
Lethrinus fraenatus				- 25	
(valenciennes, 1830)	3 .	2	0	0	3
Apogonidae					
† Apogon cooki (Macleay,	<i>2</i> 4				
1881)	1	2	0	0	3
Teraponidae					
* Amniataba caudavittatus	25	100			
(Richardson, 1845)	1	2	0	0	3
Apogonidae					
Siphamia cuneiceps (Whitley,					
1941)	0	2	0	0	2
Monacanthidae					
† Colurodontis paxmani					
Hutchins, 1977	1	2	0	0	3
Scorpaenidae					
+ Paracentropogon vespa					
(Ogilby, 1910)	0	2	0	0	2
Chaetodontidae					
† Parachaetodon ocellatus					
(Cuvier & Valenciennes, 1831)	0	1	0	0	1
Plotosidae					
* Paraplotusus albilabris					
(Valenciennes, 1840)	0	1	0	0	1
Ophichthyidae					
unidentified sp.	0	1	0	0	1
Pomatomidae					
* Pomatomus saltator					
(Linnaeus, 1766)	0	1	0	0	1
					continued

Table 5 (continued) (C) Seagrass Night Total Family and Species Seagrass Sand Flat Night Day Night Day Chaetodontidae * Chelmon rostratus 0 1 0 0 1 (Linnaeus, 1758) Callionymidae *+ Dactylopus dactylopus (Valenciennes, 1837) 0 1 0 0 1 Syngnathidae 1 0 0 unidentified sp. 0 1

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Identity and distribution of fishes

Although Figure 1 shows no more than 23 species of fish in a single seine haul, the 24 catches yielded 4357 individuals distributed among 58 species belonging to 38 families. However, most of these species were rare and 52 species were represented by 29 or fewer individuals each in the total catch. The 14 most abundant species are listed in Table 4 together with their average abundance per seine and the mean numbers caught in the four combinations of habitat and time of day. Seven fishes were clearly fish of the seagrass (*Pelates* spp., *Apogon rueppellii*, *Monacanthus chinensis*, *Pentapodus vitta*, *Centrogenys vaigiensis*, *Amblygobius phalaena* and *Youngeichthys nebulosus*), four species were found on the sand flats (*Gerres subfasciatus*, *Sillago Maculata*, *Polyspina piosae* and *Callionymus* spp.) and *Pranesus ogilbyi* was most abundant in seagrass at night and on the sand flat during the day (Table 4). In addition, *Pentapodus vitta*, was most abundant in the day and *Youngeichthys nebulosus* was most abundant at night. The remaining abundant species were absent or rare on the sand flat.

It is more difficult to judge the habitat preferences of the rare species of fish, but the 42 rare species are listed in Table 5 according to the combination of habitat and time of day in which they were most abundant. Nine species were most abundant on sand flats at night compared to 23 species in seagrass at night; the remaining 10 species were fish of the seagrass in daytime (Table 5).

Discussion

Benthos

Although many studies have estimated the abundance of benthic fauna in seagrass beds and on sand flats, only a few have measured the volume occupied by the animals and, therefore, it is difficult to compare our data with other studies. Nevertheless, as a rough guide, the mean volume of animals in the seagrass at Monkey Mia (11.8 ml/0.057 m²) is about the same as the volume on the sand flats (8.9, 12.5, 12.4 ml/0.057 m², depending on water depth) but very much less than in the intertidal *Heterozostera* beds (105.7 ml/0.057 m²) at Careening Bay, Western Australia (32°S) (Peterson and Black 1986). Interestingly, in contrast to expectations from studies elsewhere, the mean volume of animals in the seagrass was no greater than on the sand flat despite the use of a smaller mesh size (1 mm instead of 3 mm) in the seagrass sampling.

These observations bear on two major ideas about the benthos in seagrass beds and sand flats. First, if we assume that the animals live in the top 5 cm of sediments, they occupy only about 4% of the volume of our 0.057 m² samples. This is a very small proportion and as well the absolute volumes are low. Perhaps it is not surprising that Black and Peterson (1988) failed to detect competitive interactions among benthic groups when space is apparently not in short supply. Second, benthos is usually more abundant in seagrass beds than on sand flats (see Wells et al. 1985 and references cited in Peterson and Black 1986) and several experimental studies have examined mechanisms that produce this pattern. Seagrasses provide structural complexity which can inhibit predation and thus protect invertebrates and juvenile fish, and which may enhance availability of food and intensity of settlement of invertebrates and fish (for example, Peterson 1982, 1986; Reise 1977; Summerson and Peterson 1984). The differential between abundances of benthos inside and outside intertidal *Amphibolis* beds at Monkey Mia does not seem as great as might be expected from other studies, even in comparison to the patterns around subtidal Posidonia beds at Monkey Mia (Wells et al. 1985).

Diversity and abundance of fishes

Table 6 helps put the samples of fishes from Monkey Mia, Shark Bay into a perspective provided by other studies of near-shore fish. Clearly, compared with these other studies, the number of individual fish collected in our study is small, an order of magnitude less than the other studies listed. Even so, the diversity of fishes caught in our study is largest, judged by the actual number of species caught or very much larger, judged by the expected number of species in a collection of 4000 individuals (Simberloff 1978). One reason for such a diversity of fishes may be that the fauna is a mixture of temperate, tropical and endemic species. Forty-three of the 50 fishes identified to the species level are well known from Western Australia (Allen and Swainston 1988, Hutchins and Swainston 1986); 70, 16 and 12% respectively have northern, southern and western Australian distributions. In addition, only 9 species of fishes at Monkey Mia occur in seinecaught fish in the Peel Harvey system in south-west Australia, the site closest to Monkey Mia with published information on extensive collections of fish shown in Table 6. Although the diversity of fish is high, the density of fish at Monkey Mia seems rather low, with a rank of third lowest of the six values shown in Table 6.

The 1.6-fold greater abundance of fish in the seinings in the seagrass compared with the sand flats at Monkey Mia also agrees with a similar pattern observed for seagrass beds elsewhere (eg. Orth and Heck 1980, Orth *et al.* 1984). However, in contrast to the many other studies reviewed in Pollard (1984), our preliminary studies in intertidal seagrass beds did not indicate that they are important nursery areas for commercially important species. None of the 14 most abundant species captured in our study are harvested commercially. Further work will be required to determine whether this is generally true for seagrass beds in Shark Bay.

Table 6. Summary of selected studies of diversity and abundance of near-shore fishes caught in habitats with seagrass beds and sand or mud flats. A "--" indicates that the original data were not in a form appropriate for calculating the missing parameter.

Location & Latitude	Habitats	Number Individuals	of Species	Estimated Species per 4000 individuals	Density (m- ²)	Reference
N.E. United States		0				1.200.0000
Rehoboth and Indian River Bays, Delaware, 38.5°N	sand with some red and green algae, <i>Ruppia</i>	28308 13440	38 41	28.2 32.9	-	Derickson & Price 1973
Lower Chesapeake Bay, 37.3°N	eelgrass with some <i>Ruppia</i>	24182	48	35.5	-	Orth & Heck 1980
West Coast, North America						
Morro Bay, California, 35.2°N	mud-sand covered by eel- grass, red and green algae	11627	21	18.2	0.21	Horn 1979
Mugu Lagoon, California, 34.2°N	sand, muddy sand, mud, eelgrass	-	36	-	0.81	Onuf & Quammen 1983
Huizache-Caimanero Lagoon, Mexico, 23°N	fine mud	73192	44	<u>12</u> 2	2.73	Warburton 1978
Australia						
Western Port Bay, Victoria, 38.3°S	eelgrass and bare mudflats	-	48	-	1.00	Robertson 1980
Peel-Harvey Estuary Western Australia 32.7°S	mud, green algae	69818	43	33.6	0.26	Potter et al. 1983
Monkey Mia, Shark Bay, Western Australia, 25.8°S	seagrass and sand flats	4357	58	54.2	0.48	This study

The apparently great diversity of near-shore fishes at Shark Bay also provides an as yet unexplored opportunity to investigate the mechanisms, including dietary specialisation, determining the observed patterns of temporal and habitat segregation among these fishes; comparisons with less diverse assemblages of fishes could provide important insights into how much of the diversity of these fishes can be attributed to competitive partitioning of resources as opposed to alternative explanations.

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Fish survey of South Passage, Shark Bay, Western Australia

J. Barry Hutchins*

Abstract

In April 1979, 323 species of fish were recorded from the South Passage area of Shark Bay. The majority of these are tropical species (83%), with smaller numbers of warm temperate (11%) and cool temperate (6%) species. Many of the tropical species, however, were found to be present in only low numbers, while some warm temperate and one cool temperate species were abundant. The fishes of South Passage, therefore, are considered to belong to an impoverished tropical fauna. Furthermore, South Passage is the southernmost mainland area of Western Australia which supports a predominantly tropical fish fauna. Its fauna is even more diverse than that of the Houtman Abrolhos, a very much larger area of offshore islands and coral reefs located to the south off Geraldton.

Résumé

En avril 1979, 323 espèces de poissons furent répertoriées dans la région de South Passage de la Baie des Chiens Marins. La majorite d'entre elles sont des espèces tropicales (83%), avec de plus petits nombres d'espèces tempérées chaudes (11%) et tempérées froides. Beaucoup d'espèces tropicales, cependant, furent trouvées présentes en petits nombres seulement, tandis que certaines espèces tempérées chaudes et une seule espèce tempérée froide abondaient. Les poissons de South Passage, par conséquent, sont considérés comme appartenant à une faune tropicale appauvrie. En outre, South Passage est la région continentale la plus méridionale d'Australie-Occidentale qui entretient une faune de poissons principalement tropicaux. Sa faune est même plus variée que celle de Houtman Abrolhos, une région beaucoup plus vaste d'iles continentales, et aussi de récifs coralliens situé au sud de Geraldton.

Introduction

Although some of the earliest collections of Australian fishes were made in the Shark Bay area (e.g. Dampier in 1699), the fish fauna of this region is still poorly known. Many new species descriptions have been published based on material from the area, but these are scattered throughout the literature. The only published fish list for Shark Bay reports a small collection of species from Hamelin Pool (Lenanton 1977). Collections made during the 1960's by staff of the Fisheries Department, mostly of trawl-caught material, remain largely unreported. In 1979, the present author conducted a survey of the South Passage area of Shark Bay (Figure 1) as part of a zoogeographical study of the coastal reef fish fauna of Australia's southern half. This paper reports the results of the survey as a contribution to the knowledge of the fish fauna of Shark Bay. It is also supplemented by a report on the near-shore fishes at Monkey Mia included elsewhere in this publication (Black *et al.*).

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Methods

Study Site

South Passage is that portion of Shark Bay located between the southern extremity of Dirk Hartog Island and the mainland. For the purposes of this investigation the passage is delineated by Surf Point and Steep Point to the west, and Cape Ransonnet and Wright's anchorage to the east (Figure 1). It is approximately six km long by four km at its widest point. The passage is mostly shallow, the main channel being up to 12 m deep in parts. A rocky bar approximately 6 m in depth is located in the western portion, to the northeast of Monkey Rock. The bottom falls away rather quickly to the west of this bar, with a prominent vertical drop-off to 18 m just to the north of Monkey Rock. This drop-off continues westward to the base of Steep Point where, on the western side, the bottom drops almost vertically to 28 m. The seaward side of Surf Point is 11-14 m in depth. During spring tides, the current in the centre of the channel is strong, and creates an obvious area of disturbed water over the shallow bar (the spring range for Denham, located in the middle of Shark Bay (Figure 1), is about 1.2 m). Coral growth is concentrated in the shallow area to the south-east of Surf Point, where colonies of staghorn Acropora predominate, and in the lee of Steep Point where plate Acropora is common. Turbinaria coral is concentrated in the eastern end of the passage, particularly around Ransonnet Rocks (see Marsh, this publication, for further details on the coral fauna of South Passage). The northern and southern portions of the passage to the east of the bar are shallow, with low rocky ledges, some coral growth, and also areas of Sargassian weed. Meadows of Amphibolus and Posidonia are also present in the eastern portion of the passage on both sides. Mangroves are located to the east of the passage in the Mount Direction area.

The investigation occupied 17 days (4-20 April), although one day's work was lost due to inclement weather. A base camp was established at Wright's anchorage, with transportation being provided by vessels from the Fisheries Department and the Western Australian Museum (6.4 and 5.4 m respectively).

Sampling

The method of survey was based on the visual census technique described by Wilson and Marsh (1979). During the course of a dive, all observed fishes were identified to species, classed into several categories (i.e. juvenile, female, and male), habitat preferences noted, and subjective graded estimates of their relative abundance tabulated (i.e. abundant, frequent, occasional, and rare). A brief description of each site was also made, including data on air and water temperatures, nature of the substrate, water movements, wind direction and approximate strength, water clarity, and depth range. This method enabled reasonably accurate correlations to be made between the numerous sites surveyed. In addition, collections were made with spear, nets, and rotenone. Details of all visual surveys and collections are provided in Table I, and their locations

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Figure 1. Map of the South Passage area of Shark Bay. Numbers 1-49 refer to the sites sampled (see Table 1) and letters A-D denote areas where three or more surveys took place (see box in lower right hand corner). Insert shows position of South Passage in relation to Denham and Monkey Mia.

are indicated in Figure 1 (these positions were checked using an aerial photograph, but some are possibly not precisely located). The surveys concentrated on areas of coral and rocky reef, but some seagrass, sand, and mangrove areas were also investigated. The deepest dive was to 28 m at the western entrance to the passage.

Stat- ion	Date	Locality	Habitat	Depth (m)	Method
1	4.4	Monkey Rock	Coral, rock	1-6	Visual
2	4.4	Monkey Rock, N of	Coral, rock	8-21	Visual
3	4.4	Passage, S side	Weed, rock	3-4	Visual, spear
4	5.4	Surf Point, W of	Rock, coral	11-14	Visual
5	5.4	Surf Point, E of	Coral, sand	2	Visual, spear
6	5.4	Surf Point, inside	Sand, rock, coral	1	Visual, spear
7	6.4	Monkey Rock, E of	Coral, rock	12	Visual, spear
8	6.4	Passage, N side	Coral, rock, weed	1-5	Visual, spear
9	6.4	Wright's anchorage	Rock, sand	1	Hand net
10	7.4	Monkey Rock, E of	Coral, rock	9-15	Visual
11	7.4	Ransonnet Rocks	Rock, weed, coral	5-10	Visual, spear
12	7.4	Passage, N side	Coral, rock, weed	5	Visual, spear
13	8.4	Steep Point, W of	Rock, coral, sand	28	Visual
14	8.4	Steep Point, N side	Rock, coral	15	Visual
15	8.4	Mount Direction, N of	Sand, mangrove, rock	1	Visual
16	9.4	Steep Point, N side	Rock, coral	15	Visual
17	9.4	Steep Point, N side	Rock, coral	13-15	Rotenone
18	9.4	Passage, N side	Sand, weed	5-6	Dredge
19	9.4	Passage, N side	Sand, weed	5-6	Dredge
20	9.4	Cape Ransonnet, NE of	Sand	5-6	Dredge
21	10.4	Steep Point, N of	At sea's surface	0	Hand net
22	10.4	Monkey Rock, N of	Rock, coral	15-18	Visual
23	10.4	Monkey Rock, N of	Cave	12-15	Rotenone
24	10.4	Monkey Rock	Rock, coral	6	Spear
25	10.4	Wright's anchorage, E of	Sand	1-5	Dredge
26	11.4	Steep Point, N side	Rock, coral	15-20	Visual
27	11.4	Steep Point, N side	Rock, coral	14	Roteone, spear
28	11.4	Wright's anchorage	Sand, weed, rock	1-7	Visual
29	12.4	Ransonnet Rocks	Weed, rock, sand	4-9	Visual
30	12.4	Surf Point, E of	Coral, sand	1-2	Visual, spear, hand
31	12.4	Wright's anchorage	Sand, weed	1-12	Visual, spear, hand
32	13.4	Sunday Island	Sand, coral, weed	1-2	Visual
33	13.4	Sunday Island	Coral, weed	1-2	Rotenone,
34	13.4	Wright's anchorage, N of	Sand, weed	10	spear Visual
35	14.4	Surf Point, E of	Coral	2	Rotenone
36	14.4	Monkey Rock, N of	Rock, coral	15-18	Visual

Table L. Sampling stations at South Passage, Shark Bay (see Figure 1)

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Stat- ion	Date	Locality	Habitat	Depth (m)	Method
37	15.4	Monkey Rock, N of	Rock, coral	15-18	Visual
38	15.4	Monkey Rock, N of	Rock, coral	14	Rotenone, spear
39	15.4	Wright's anchorage	Rock, coral	1	V isual
40	15.4	Wright's anchorage	Rock	Intertidal	Visual
41	17.4	Wright's anchorage	Sand, weed	2	Box trawl
42	17.4	Ransonnet Rocks	Weed, rock, sand	1-2	Visual
43	17.4	Wright's anchorage	Sand, weed	1-2	Set net
44	17.4	Wright's anchorage			Washed up
45	18.4	Surf Point, W side	Rock	Intertidal	Rotenone
46	18.4	Surf Point, inside	Sand, rock	1	Rotenone
47	19.4	Wright's anchorage	Rock, coral	1-2	Rotenone
48	19.4	Wright's anchorage	Weed, sand	1-2	Rotenone
49	20.4	Monkey Rock, N of	Rock, coral	15-19	Visual

Table 1 (continued)

Presentation

The fish list presented below follows the phylogenetic arrangement of Paxton *et al.* (1989) up to and including the family Carangidae, and thereafter mostly follows Nelson (1976). Of the species recorded visually, only those positively identified to species are included (an additional ten species were observed, but their correct identities could not be determined). Species which are possibly undescribed are listed under the most appropriate genus as "species". The graded estimates of relative abundance are based on the estimated numbers found in the study area during the investigation. However, estimates of secretive species are always difficult to determine, and must here be considered as only tentative. A more thorough collecting program would probably reveal some of the species listed as rare to be considerably more numerous.

All the material collected during this survey is at the Western Australian Museum.

List of Fishes

Key to symbols:

Number = sampling station where collected (see Table 1); p = photographed; + = collected but not retained; * = report from team member other than JBH; blank = visual record; a = abundant; f = frequent; o = occasional; and r = rare.

	Method	Relative Abundance
DASYATIDIDAE		
Dasyatis brevicaudata (Hutton, 1875)	р	о
Himantura uarnak (Forsskål, 1775)		r

Fishes o	South	Passage
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	Method	Relative Abundance
MYLIOBATIDIDAE		
Aetobatus narinari (Euphrasen, 1790) MOBULIDAE		r
Manta birostris (Donndorff, 1798) RHINOBATIDAE	р	0
Rhynchobatus djiddensis (Forsskål, 1775)	р	r
CARCHARHINIDAE		
Carcharhinus brevipinna (Müller and Henle, 1839)		г
Galeocerdo cuvier (Péron and Lesueur, 1822)	*	r
Rhizoprionodon acutus (Rüppell, 1837)	44	r
ORECTOLOBIDAE	04	
Chiloscyllium punctatium Müller and Henle, 1838	24	r
Orectolobus ornatus (De Vis, 1883)		0
RHINCODON LIDAE.		1927
MUDAENIDAE		T
Commothoray guractus (Abbot 1861)	17 93 97	0
G prasinus (Richardson, 1848)	17.97	r r
G undulatus (Lacepède, 1803)	33	r
Siderea thyroideus (Richardson, 1845)	D	0
CLUPEIDAE		
Herklotsichthys quadrimaculatus (Rüppell, 1837)	31	r
Sardinella gibbosa (Bleeker, 1849)	46	r
Spratelloides robustus Ogilby, 1897		r
PLOTOSIDAE		
Paraplotosus albilabris (Valenciennes, 1840)	48	r
Plotosus lineatus (Thunberg, 1791)	\mathbf{p}	0
SYNODONTIDAE		
Synodus variegatus (Lacepede, 1803)	р	O
BATRACHOIDIDAE		
ANTENNADIDAE		r
ANTENNARIDAE Antonomico manufar (Cunium 1817)	99	2.
BYTHITIDAE	20	515
Dibulus caecus Waite 1905	17 93	F
ATHERINIDAE		
Allanetta mugiloides (McCulloch, 1912)	46	r
Atherinomorus ogilbyi (Whitley, 1930)	9, 31, 46	o
Craterocephalus pauciradiatus (Günther, 1861)	46	r
HOLOCENTRIDAE		
Myripristis murdjan (Forsskål, 1775)	р	r
Sargocentron rubrum (Forsskål, 1775)	р	r
FISTULARIIDAE		
Fistularia commersonii Rüppell, 1838		0
SYNGNATHIDAE	40	
<i>Pestucatex scataris</i> (Gunther, 1870)	48	0
Hibbogambus precise	45	T
110ppocumpus species	1.7	

	Method	Relative Abundance
SCORPAENIDAE		
Dendrochirus zebra (Cuvier, 1829)	17	0
Pterois volitans (Linnaeus, 1758)	47	ſ
Scorpaena picta Kuhl and van Hasselt, 1829	8, 33	0
Scorpaena species	17, 23, 27,	
	35, 38, 47, 48	а
Scorpaenodes scaber (Ramsay and Ogilby, 1886)	17, 23, 27, 38	а
Scorpaenopsis venosa (Cuvier, 1829)	27	r
APLOACTINIDAE		
Neoaploactis tridorsalis Eschmeyer and Allen, 1978	33	r
PLATYCEPHALIDAE		
Leviprora inops (Jenyns, 1840)	8	r
Platycephalus endrachtensis Quoy and Gaimard, 1825	46	r
CENTROPOMIDAE		
Psammoperca waigiensis (Cuvier, 1828)		1
SERRANIDAE		
Acanthistius pardalotus Hutchins, 1981	27	f
Anthias cooperi Regan, 1902	7, 17, 38	а
Cephalopholis miniata (Forsskål, 1775)	38	1
C. sonnerati (Valenciennes, 1828)		r
Chromileptes altivelis (Valenciennes, 1828)		\mathbf{r}
Ellerkeldia rubra Allen, 1976	17, 23, 27, 38	а
Epinephelides armatus (Castelnau, 1875)		r
Epinephelus bilobatus Randall and Allen, 1987		0
E. fasciatus (Forsskål, 1775)	р	0
E. lanceolatus (Bloch, 1790)	p	o
E. multinotatus (Peters, 1877)	р	r
E. quoyanus (Valenciennes, 1830)		r
E. rivulatus (Valenciennes, 1830)	р	0
E. suillus (Valenciennes, 1828)	р	0
Plectropomus maculatus (Bloch, 1790)	\mathbf{p}	r
Variola louti (Forsskål, 1775)	p	r
GRAMMISTIDAE		
Grammistes sexlineatus (Thunberg, 1792)		r
PSEUDOCHROMIDAE		
Blennodesmus scapularis Günther, 1871	17, 23, 30,	
	33, 35	f
Congrogadus subducens (Richardson, 1843)		r
Labracinus lineatus (Castelnau, 1875)	23, 33	f
Pseudochromis punctatus (Richardson, 1846)	33	о
P. wilsoni (Whitley, 1929)	33, 47	0
TERAPONTIDAE		
Amniataba caudavittata (Richardson, 1845)		r
Pelates sexlineatus (Quoy and Gaimard, 1824)		r
PRIACANTHIDAE		
Heteropriacanthus cruentatus (Lacepede, 1801)	27	r
APOGONIDAE		
Apogon aureus (Lacepède, 1802)	38, 47	f

J.B. Hutchins

Fishes	of	South	Passage
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	Method	Relative Abundance
A. coccineus Rüppell, 1838	17, 23, 33,	
	38, 47	ſ
A. cookii Macleay, 1881	12	ſ
A. cyanosoma (Bleeker, 1853)		0
A. doederleini Jordan and Snyder, 1901	38	ſ
A fraenatus Valenciennes 1832	00.52	
A ruebbellii Günther 1859	D	0
A semiornatus Peters 1876	17 97 85 88	r r
A tamiobhorus Pagun 1008	17, 27, 55, 56	1
A suctoring Cinthem 1850	17, 55	C C
A mainer	L1	1;
A. species	ci ci	r
Archamia Jucala (Cantor, 1850)	р	1
Cheitodipterus tineatus Lacepede, 1801	\mathbf{p}	1.
Siphamia cephalotes (Castelnau, 1875)	20	r
SILLAGINIDAE	1222	
Sillago schomburgku Peters, 1865	43	r
POMATOMIDAE		
Pomatomus saltatrix (Linnaeus, 1766)		0
ECHENEIDAE		
Echeneis naucrates Linnaeus, 1758		r
CARANGIDAE		
Carangoides fulvoguttatus (Forsskål, 1775)	D	0
Caranx ignobilis (Forsskål, 1775)	p	0
C. sexfasciatus Quoy and Gaimard, 1825	1	0
Decapturus macrosoma Bleeker 1851	D	0
Gnathanodon speciosus (Forsskål 1775)	P	0
Pseudocarany dentex (Bloch and Schneider 1801)		
Selevoides leptolepis (Kuhl and van Hasselt 1833)	D	1
Sectorates reproteepts (Ruth and Van Hassen, 1855) Sectora dumerili (Pisso, 1810)	р	0
Schibbas Cüsther 1976	91	г
S. httpps Gunther, 1870	21	0
S. talandi valenciennes, 1833	10	0
Trachinolus bolla (Shaw, 1803)	46	Г
Trachurus novaezelandiae Richardson, 1843		0
CAESIONIDAE		
Caesio caerulaurea Lacepède, 1801		0
C. cuning (Bloch, 1791)		1°
Pterocaesio diagramma (Bleeker, 1865)		0
CAESIOSCORPIDIDAE		
Caesioscorpis theagenes Whitley, 1945		f
LUTJANIDAE		
Lutjanus bohar (Forsskål, 1775)		r
L. carbonotatus (Richardson, 1842)		ſ
L. (ulviflamma (Forsskål, 1775)	+	f
L. kasmira (Forsskål, 1775)		r
I lemniscatus (Valenciennes 1828)		0
NEMIPTER IDAE		
Pentabodus porosus (Valenciennes 1830)	n	
P with Own and Caimard 1994	P	
r. onu Quoy and Gamaid, 1044	P	a

	Method	Relative Abundance
Scaevius milii (Bory, 1823)		0
Scolopsis bilineatus (Bloch, 1793)		1
HAEMULIDAE		
Diagramma pictum (Thunberg, 1792)		r
Plectorhinchus flavomaculatus (Ehrenberg, 1830)	р	а
P. multivittatum (Macleay, 1878)	48	0
P. schotaf (Forsskål, 1775)	р	f
LETHRINIDAE	(22)	
Lethrinus atkinsoni Seale, 1909		1
L. genivittatus Valenciennes, 1830	р	r
L. laticaudis Alleyne and Macleay, 1877		r
L. miniatus (Schneider, 1801)		f
L. nebulosus (Forsskål, 1775)		r
SPARIDAE		
Acanthopagrus latus (Houttuyn, 1782)	+	0
Chrysophrys auratus (Schneider, 1801)	\mathbf{p}	0
Rhabdosargus sarba (Forsskal, 1775)	43	ſ
SCIAENIDAE		
Argyrosomus hololepidotus (Lacepède, 1801)	р	0
MULLIDAE		
Parupeneus chrysopleuron (Temminck and Schlegel, 1843)		ſ
P. indicus (Shaw, 1803)		0
P. pleurostigma (Bennett, 1831)		r
P. signatus (Günther, 1867)	р	a
Upeneus tragula Richardson, 1846		0
MONODACTYLIDAE		
Schuettea woodwardi (Waite, 1905)	р	0
PEMPHERIDAE		
Parapriacanthus ransonneti Steindachner, 1870		0
Pempheris analis Waite, 1910	р	0
P. klunzingeri McCulloch, 1911	Pi	1.
P. oualensis Cuvier, 1831	6, 35	a
P. schwenkii Bleeker, 1855	6	f
KYPHOSIDAE		
Kyphosus cornelii (Whitley, 1944)	35	a
K. gibsoni Ogilby, 1912		a
K. sydneyanus (Günther, 1886)	21, 30, 46	0
SCORPIDIDAE		
Microcanthus strigatus (Cuvier, 1831)	р	a
Neatypus obliguus Waite, 1905	#2-3	0
Scorpis aequipinnis Richardson, 1848	р	r
EPHIPPIDAE	1 4 000	
Platax teira (Forsskål, 1775)		r
CHAETODONTIDAE		
Chaetodon assarius Waite, 1905		а
C. auriga Forsskål, 1775		f
C. lineolatus Cuvier, 1831	р	0
C. lunula (Lacepède, 1802)	<u> </u>	f

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	Method	Relative Abundance
C. plebeius Cuvier, 1831		ſ
C. speculum Cuvier, 1831	D	r
C. trifascialis Quoy and Gaimard, 1824	35	r
Chelmon rostratus (Linnaeus, 1758)	8, 47	ŕ
Chelmonops curiosus Kuiter, 1987	р	0
Coradion chrysozonus (Cuvier, 1831)	p	г
Forcipiger flavissimus Jordan and McGregor, 1898	D	r
Heniochus acuminatus (Linnaeus, 1758)	47	0
Heniochus diphreutes Jordan, 1903		r
Heniochus sigularius Smith and Radcliff, 1911	p	ľ
POMACANTHIDAE	0 4 .5	
Centropyge tibicen (Cuvier, 1831)	38	0
Chaetodontoplus duboulayi (Günther, 1867)	p	0
C. personifer (McCulloch, 1914)	p	0
Pomacanthus imperator (Bloch, 1787)	p	ľ
P. semicirculatus (Cuvier, 1831)	35	ſ
P. sexstriatus (Cuvier, 1831)		ľ
ENOPLOSIDAE		
Enoplosus armatus (Shaw, 1790)		r
POMACENTRIDAE		
Abudefduf bengalensis (Bloch, 1787)	р	ſ
A. sexfasciatus (Lacepède, 1802)	46	ſ
A. sordidus (Forsskål, 1775)	45	r
A. vaigiensis (Quoy and Gaimard, 1824)	21, 35	ſ
Amphiprion clarkii (Bennett, 1830)	р	1
Chromis atripectoralis Welander and Schultz, 1951		r
C. margaritifer Fowler, 1946	р	r
C. weberi Fowler and Bean, 1928	17	0
C. westaustralis Allen, 1976	23	a
Dascyllus reticulatus (Richardson, 1846)	38	0
D. trimaculatus (Rüppell, 1828)		f
Neopomacentrus azysron (Bleeker, 1877)	17, 23, 35, 47	а
N. cyanomos (Bleeker, 1856)	р	ſ
N. filamentosus (Macleay, 1882)	23, 33, 47	а
Parma occidentalis Allen and Hoese, 1975	23, 47	ſ
Plectroglyphidodon dickii (Lienard, 1839)		0
P. johnstonianus Fowler and Ball, 1924	р	r
P. lacrymatus (Quoy and Gaimard, 1824)		0
P. leucozona (Bleeker, 1859)		Q
Pomacentrus coelestis Jordan and Starks, 1901	35	ſ
P. milleri Taylor, 1964	33	ſ
P. molluccensis Bleeker, 1853		r
P. vaiuli Jordan and Seale, 1906		r
Stegastes obreptus (Whitley, 1948)	17, 47	ſ
CIRRHITIDAE		
Cirrhitichthys aprinus (Cuvier, 1829)	р	f
C. oxycephalus (Bleeker, 1855)	p	r
Cyprinocirrhites polyactis (Bleeker, 1875)	38	r

Fishes of South Passage

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v	reaccinitis	

Paracirrhites forsteri (Schneider, 1801)prCHEILODACTYLIDAEpoCheilodactylus gibbosus Richardson, 1841poC. rubrolabiatus Allen and Heemstra, 1976fSPHYRAENIDAEpoSphyraena obtusata Cuvier, 1829poLABRIDAE17rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rrA. meleagrides Valenciennes, 1839rrAustrolabrus maculatus (Macleay, 1881)23rBodianus axillaris (Bennett, 1831)ooB. bilunulatus (Lacepède, 1802)ooC. chlorurus (Bloch, 1791)ooC. chilor inermis (Forsskål 1775)oo	Abu	
CHEILODACTYLIDAE Cheilodactylus gibbosus Richardson, 1841poC. rubrolabiatus Allen and Heemstra, 1976fSPHYRAENIDAE Sphyraena obtusata Cuvier, 1829pOLABRIDAEAnampses caeruleopunctatus Rüppell, 182917rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23B. bilunulatus (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oC. chlorurus (Bloch, 1791)oC. chlorurus (Bloch, 1791)o	n) p	Paracirrhites forsteri (Schneider, 1801)
Cheilodactylus gibbosus Richardson, 1841poC. rubrolabiatus Allen and Heemstra, 1976fSPHYRAENIDAEfSphyraena obtusata Cuvier, 1829pLABRIDAEpAnampses caeruleopunctatus Rüppell, 182917rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23B. bilunulatus (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oC. chlorurus (Bloch, 1791)oC. chlorurus (Bloch, 1791)oC. cherilio inermis (Eorsskål 1775)o		CHEILODACTYLIDAE
C. rubrolabiatus Allen and Heemstra, 1976fSPHYRAENIDAESphyraena obtusata Cuvier, 1829pSphyraena obtusata Cuvier, 1829poLABRIDAEAnampses caeruleopunctatus Rüppell, 182917rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rrA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23rBodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oC. chlorurus (Bloch, 1791)oC. chlorurus (Bloch, 1791)oC. cherines (Eorsskål 1775)o	n, 1841 p	Cheilodactylus gibbosus Richardson, 1841
SPHYRAENIDAEpoSphyraena obtusata Cuvier, 1829poLABRIDAEAnampses caeruleopunctatus Rüppell, 182917rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rrA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oC. chlorurus (Bloch, 1791)oC. chlorurus (Bloch, 1791)o	ra, 1976	C. rubrolabiatus Allen and Heemstra, 1976
Sphyraena obtusata Cuvier, 1829poLABRIDAE17rAnampses caeruleopunctatus Rüppell, 182917A. geographicus Valenciennes, 183927A. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oCheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilio inermis (Eorsskål 1775)o		PHYRAENIDAE
LABRIDAEAnampses caeruleopunctatus Rüppell, 182917A. geographicus Valenciennes, 183927A. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)0B. bilunulatus (Lacepède, 1802)0Cheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)0Cheilio, inermis (Eorsskål, 1775)0	р	Sphyraena obtusata Cuvier, 1829
Anampses caeruleopunctatus Rüppell, 182917rA. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oCheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilinus (Energetia, 1775)o		ABRIDAE
A. geographicus Valenciennes, 183927fA. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oCheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilio inermis (Forsskål, 1775)o	ell, 1829 17	Anampses caeruleopunctatus Rüppell, 1829
A. lennardi Scott, 1959rA. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oCheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilio inermis (Forsekål, 1775)o	27	A. geographicus Valenciennes, 1839
A. meleagrides Valenciennes, 1839rAustrolabrus maculatus (Macleay, 1881)23Bodianus axillaris (Bennett, 1831)0B. bilunulatus (Lacepède, 1802)0Cheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)0Cheilio inermis (Eorschält 1775)0		A. lennardi Scott, 1959
Austrolabrus maculatus (Macleay, 1881)23rBodianus axillaris (Bennett, 1831)0B. bilunulatus (Lacepède, 1802)0Cheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)0Cheilio inermis (Forsekål, 1775)0		A. meleagrides Valenciennes, 1839
Bodianus axillaris (Bennett, 1831)oB. bilunulatus (Lacepède, 1802)oCheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilio inermis (Eorschält 1775)o	881) 23	Austrolabrus maculatus (Macleay, 1881)
B. bilunulatus (Lacepède, 1802) o Cheilinus bimaculatus Valenciennes, 1839 r C. chlorurus (Bloch, 1791) o Cheilio inermis (Forsekål, 1775) o		Bodianus axillaris (Bennett, 1831)
Cheilinus bimaculatus Valenciennes, 1839rC. chlorurus (Bloch, 1791)oCheilio inermis (Forsekål, 1775)o		B. bilunulatus (Lacepède, 1802)
C. chlorurus (Bloch, 1791) o Cheilio inermis (Forsekål, 1775)	s, 1839	Cheilinus bimaculatus Valenciennes, 1839
Chailio inermis (Forschill 1775)		C. chlorurus (Bloch, 1791)
G_{10}		Cheilio inermis (Forsskål, 1775)
Choerodon cauteroma Gomon and Allen, 1987 p a	Allen, 1987 p	Choerodon cauteroma Gomon and Allen, 1987
C. jordani (Snyder, 1908)	1	C. jordani (Snyder, 1908)
C. rubescens (Günther, 1862) p a	р	C. rubescens (Günther, 1862)
C. schoenleinii (Valenciennes, 1839) o		C. schoenleinii (Valenciennes, 1839)
Cirrhilabrus temmincki Bleeker, 1852 7, 38 f	52 7. 38	Cirrhilabrus temmincki Bleeker, 1852
Coris auricularis (Valenciennes, 1839) 23, 35 f	(9) 23, 35	Coris auricularis (Valenciennes, 1839)
C. avgula Lacepède, 1802	-, -,,,	C. avgula Lacepede, 1802
C. caudimacula (Quoy and Gaimard, 1834) 3 o	rd. 1834) 3	C. caudimacula (Ouoy and Gaimard, 1834)
Gomphosus varius Lacepède, 1802		Gomphosus varius Lacepede, 1802
Halichoeres brownfieldi (Whitley, 1945) 48 f	945) 48	Halichoeres brownfieldi (Whitley, 1945)
H. marginatus Rüppell, 1835		H. marginatus Rüppell, 1835
H. nebulosus (Valenciennes, 1839)		H. nebulosus (Valenciennes, 1839)
Hemigymnus fasciatus (Bloch, 1792)	2)	Hemigymnus fasciatus (Bloch, 1792)
H. melapterus (Bloch, 1791)	16	H. melapterus (Bloch, 1791)
Hologymnosus annulatus (Lacepède, 1801)	e. 1801)	Hologymnosus annulatus (Lacepède, 1801)
Labroides dimidiatus (Valenciennes, 1839) 38 f	. 1839)	Labroides dimidiatus (Valenciennes, 1839)
Macropharvngodon ornatus Bandall, 1978 27 0	11. 1978 27	Macropharyngodon ornatus Randall, 1978
Notolabrus parilus (Bichardson, 1850) 30, 48 o	350) 30, 48	Notolabrus parilus (Richardson, 1850)
Pseudojuloides elongatus Avling and Russell 1977 3	nd Russell, 1977 3	Pseudojuloides elongatus Ayling and Russell, 1977
Pteragogus flagellifera (Valenciennes 1830) 3 48 f	s 1839) 3 48	Pteragogus flagellifera (Valenciennes, 1839)
Stethoiulis bandanensis (Bleeker, 1851) 33 a	351) 33	Stethojulis bandanensis (Bleeker, 1851)
S interruta (Bleeker 1851) 48	48	S interrubta (Bleeker, 1851)
S. strigging ter (Bennett 1832)	10	S. strigizenter (Bennett 1832)
Suerichthys cyanolaemus Russell 1985 12 23 27 38	1985 19 93 97 38	Suezichthys cyanolaemus Russell 1985
Thalassoma amhlycethalum (Bleeker 1856)	rer 1856)	Thalassoma amblycephalum (Bleeker, 1856)
T hardwichei (Bennett 1830)	p	T hardwichei (Bennett 1830)
T iangenii (Bleeker 1856)		T jansenji (Bleeker 1856)
T lungre (Linnaeus, 1758)	88	T Junare (Linnaeus, 1758)
T lutescens (Lav and Bennett 1839)	9)	T lutescens (Law and Bennett 1839)
$T_{burbureum}$ (Forskål, 1775)		T burbureum (Forsskål, 1775)
T. septemfasciata Scott, 1959		T. septemfasciata Scott, 1959

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	Method	Relative Abundance
SCARIDAE		
Leptoscarus vaigiensis (Ouoy and Gaimard, 1824)	48	0
Scarus festious Valenciennes, 1840	D	0
S. frenatus Lacepède, 1802	A 2.	г
S. ghobban Forsskäl, 1775		a
S. gibbus Rüppell, 1828		0
S. rivulatus Valenciennes, 1839		r
S. rubroviolaceus Bleeker, 1849		0
S. schlegeli (Blecker, 1861)		0
S. sordidus Forsskål, 1775		0
MUGILOIDIDAE		
Parapercis clathrata Ogilby, 1910		0
P. haackei (Steindachner, 1884)	5	0
P. nebulosa (Onov and Gaimard, 1824)	31	0
CREEDIIDAE	20.8	
Squamicreedia obtusa Rendahl, 1921	20	r
RLENNHDAF		
Ashidontus taeniatus Quoy and Gaimard, 1834	38	. P.
Cirribectes filamentosus (Allevne and Macleav, 1877)	35 47	
C. Intchinsi Williams 1988	17	ř
Ecsenius bicolor (Day, 1888)	17 23 38	0
E oculus Springer 1971	35	r
Entomacrodus striatus (Quov and Gaimard 1836)	45	ŕ
Istiblennius edentulus (Bloch and Schneider 1801)	45 46	r
L melenoris (Valenciennes 1836)	46	
Liabhognathus multimaculatus Smith 1955	23 38	o r
Mejacanthus grammistes (Valenciennes 1836)	23, 50	
Omohranchus germaini (Sauvage 1883)		0
Petroscirtes brevicebs Valenciennes 1836	11 21 48	0
P mitratus Rüppell 1830	11, 41, 10	0
Planiotremus rhinorhynchos (Bloeker 1859)	17 93 38	÷.
P tabainosonna (Bloekay 1857)	22, 20, 00	1
Salarias fasciatus (Bloch 1786)	55	r v
Standus Jaboti Springer 1968	35	
TRIPTERVCHDAF		
Helcogramma decurrens McCulloch and Waite 1918	17 98 97	
Thuoghanna acturns accuroch and wate, 1510	35 45 47	<i>(</i>)
Helcogramma species	98	n n
Norfolkia hrachyletiis (Schultz, 1960)	19 17 93	
Norjoikia oracnyiepis (Schuiz, 1500)	97 35 38	
Enneablements species	33	a r
CLINIDAE	55	
Heteroclinus species	48	r
COBIDAE	10	
Ambhaohius phalaena (Valenciennes 1827)		0
Rathygobius cocosensis (Riceker 1854)	45	r
Cryptocentrus (asciatus (Playfair 1866)	31	
Eviota himaculata Lachner and Karnella 1980	D	-

	Method	Relative Abundance
E smaragdus Iordan and Seale, 1906	38	ſ
$F_{\rm storthynx}$ (Rofen, 1959)	33	r
Eviola species 1	17. 23	0
Eviota species 2	17, 23, 27,	
Leton opered a	33, 35, 47	0
Fusigobius duospilus Hoese and Reader, 1985	23, 38	ſ
Fusigobius species	33, 47	0
Gnatholepis inconsequens Whitley, 1958	38, 47	a
Gobiodon citrinus (Rüppell, 1838)	30	0
G. auinquestrigatus (Valenciennes, 1837)	30	0
Istigobius decoratus (Herre, 1927)		0
I. nigroocellatus (Günther, 1873)		0
Priolepis cinctus (Regan, 1908)	23, 38	0
P. nuchifasciatus (Günther, 1873)	23, 35	r
P. semidoliatus (Valenciennes, 1837)	17. 23	r
P. species	23	r
Ptereleotris evides (Jordan and Hubbs, 1925)		r
Trimma okinawae (Aoyagi, 1949)	23. 38	0
Valenciennea immaculatus Ni Yong, 1981	31	r
V. longipinnis (Lay and Bennett, 1839)	р	0
V. puellaris (Tomiyama, 1956)	31	0
V. species	31	0
ACANTHURIDAE		
Acanthurus grammoptilus Richardson, 1843	30	f
A mata (Cuvier, 1829)	D	0
A. olivaceus Schneider, 1801	P	r
A. triostegus (Linnaeus, 1758)		0
Naso tuberosus Lacepède, 1802		r
N. unicornis (Forsskål, 1775)		r
Zebrasoma veliferum (Bloch, 1797)		0
SIGANIDAE		
Siganus fuscescens (Houttuyn, 1782)		0
SCOMBRIDAE		
Grammatorcynus bicarinatus (Quoy and Gaimard, 1824)		0
Scomberomorus commerson (Lacepède, 1800)	р	0
GOBIESOCIDAE		
Lepadichthys sandaracatus Whitley, 1943	17.23	0
CALLIONYMIDAE	11, 15	
Callionymus calcaratus Macleay, 1881	31	r
C. goodladi (Whitley, 1944)	31, 46	r
BOTHIDAE		
Engubrosopon species	19	r
CYNOGLOSSIDAE	10	
Cynogiossus maculipinnis Kendahl, 1921 BALISTIDAE	48	r
Sufflamen chrysopterus (Bloch and Schneider, 1801)	\mathbf{p}	ſ
S. fraenatus (Latreille, 1804)	p	0

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	Method	Relative Abundance
MONACANTHIDAE		
Cantherhines fronticinctus (Günther, 1866)	D	0
C. pardalis (Rüppell, 1835)	p	ſ
Colurdontis paxmani Hutchins, 1977	3, 11, 48	ſ
Monacanthus chinensis (Osbeck, 1765)	18, 19	r
Oxymonacanthus longirostris (Bloch and Schneider, 1801)	35	0
Pervagor janthinosoma (Bleeker, 1854)	17	0
Stephanolepis species	21	r
ARACANIDAE		
Anoplocapros robustus (Fraser-Brunner, 1941)	+	r
OSTRACIIDAE		
Ostracion cubicus Linnocus, 1758	23, 47	0
O. meleagris Shaw, 1796	p	r
TETRAODONTIDAE		
Arothron hispidus (Linnaeus, 1758)	р	ſ
A. stellatus (Bloch and Schneider, 1801)	31	0
DIODONTIDAE		
Diodon holocanthus Linnaeus, 1758		1

Discussion

A total of 323 fish species were recorded for the South Passage area of Shark Bay during this survey. The fauna is predominently tropical (83%), with small warm temperate (11%) and cool temperate (6%) elements. The area with the greatest diversity of species was in the region of the Monkey Rock drop-off (70-80 species observed per dive). However, prominent numbers of fishes were also found on the South Passage bar, in the shallow area to the east of Surf Point, and at Ransonnet Rocks. Surveys of areas to the west of both Steep Point and Surf Point produced relatively low numbers of fish species (both of these areas are subjected to constant pounding by large waves, and consequently have a much poorer habitat diversity). Sunday Island, to the north-east of South Passage, was found to support a relatively rich fish fauna, although considerably lower in both species and numbers of individuals when compared to similar sites in the passage. Species with the largest numbers of observed individuals were mostly tropical (e.g. Parupeneus signatus, Neopomacentrus filamentosus, Stethojulis bandanensis, and Thalassoma lunare), but many tropicals which are common in more northern areas of the state, such as the Ningaloo region (latitude $22^{\circ}42'$ S). were rarely sighted (e.g. Chaetodon trifascialus, Pomacanthus sextriatus, Chromis atripectoralis, and Gomphosus varius). Some warm temperate species were also abundant (e.g. Chromis westaustralis, Choerodon rubescens, and Kyphosus cornelii), but cool temperate species were mostly found in low numbers, Helcogramma decurrens being the only exception to this. Many of the species which were rarely sighted are considered to be transients from breeding

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populations to the north of Shark Bay, in the case of tropicals, and to the south of the bay for cool temperate species. Therefore the fish fauna of South Passage could be best classed as an impoverished tropical fauna with an obvious warm temperate element.

Comparison with other surveys conducted along the west coast of Western Australia indicate that South Passage is the most southerly mainland region of the state which supports a diverse tropical fish fauna. The tropical element at Kalbarri (latitude 27°42'S) was found to be 42%, while at Port Gregory (latitude 28°12'S), where areas of rich coral growth occur in a lagoonal situation, it was 55%. However, in the latter area, the most conspicuous fishes were found to consist equally of tropical and temperate species. The survey of Port Denison (latitude 29°16'S) produced a tropical element of only 37%, and at Jurien Bay (latitude 30°18'S), this had fallen to 28%. However, at the offshore location of the Houtman Abrolhos (latitudinal range 28°18'S - 29°00'S), tropical species made up 69% of the fauna. As at South Passage, the most conspicuous fishes at the Houtman Abrolhos were tropical, but many of the temperate species, particularly those belonging to the warm temperate element (14% of the fauna), were also in very large numbers. Nevertheless, the fish fauna at the Houtman Abrolhos was not as diverse as that found in South Passage during this study. A total of only 254 fish species were recorded from the former region employing the same techniques as used at South Passage (36 additional species have been recorded from the Houtman Abrolhos (Allen 1984), mostly on the basis of collections taken by trawlers). The area surveyed at the Houtman Abrolhos was many times larger in size, possessed a far greater diversity of habitats, especially with respect to corals (see Wilson and Marsh 1979), and was subjected to a much greater sampling effort (Allen, 1984). The close proximity to South Passage of the rich northern breeding grounds for tropical fishes (e.g. the Ningaloo area (Allen, pers. comm.)), in addition to its lower latitude and therefore higher water temperatures, obviously contribute to this difference in fish diversity.

Brief surveys were also conducted in other parts of Shark Bay, particularly near Denham and Monkey Mia (Figure 1). These indicated that the more internal areas of Shark Bay possess far less diverse fish faunas than South Passage, the tropical element being considerably smaller (Hutchins, unpublished data). This lack of tropical species led Logan and Cebulski (1970) to describe the Shark Bay fauna as "subtropical" (warm temperate). Shark Bay is located near the northern limit of a transistion region between temperate and tropical faunas (see Wilson and Gillett 1971), the northernmost limit being just to the north of Coral Bay (latitude 23°05′S) (Hutchins, unpublished data). Whereas the fauna inhabiting the more protected portions of Shark Bay may have a higher proportion of temperate species, and therefore be more "subtropical", there is little doubt that the more exposed South Passage area has a predominently tropical fauna.

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Acknowledgements

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Amphibians and reptiles of the Shark Bay area, Western Australia

G.M. Storr* and G. Harold+

Abstract

Brief notes are given on the 118 species and subspecies recorded from the area.

Résumé

Des notes brèves sont données sur les 118 espèces et sous-espèces recensées dans la région.

Introduction

This paper is based on Storr and Harold (1978). They divided the area into three longitudinal zones.

The western zone comprises the large islands Dirk Hartog, Dorre and Bernier, Edel Land and the small islands in Freycinet Estuary. The soils are mainly white sands over limestone. Mean annual rainfall is about 30 cm, most of it falling in winter. There is no surface fresh water. The vegetation consists of the coarse dune grass *Spinifex longifolius* and low shrubs.

The central zone comprises Peron Peninsula, Faure Island and the country immediately south and south-east of Freycinet Estuary. The soils are mostly reddish sands and sandy loams. Mean annual rainfall ranges from 20 to 28 cm, and there is ordinarily no surface fresh water. In the south the dunes and swales are densely wooded with low trees and tall shrubs of *Acacia, Eucalyptus, Melaleuca* and various Proteaceae, broken by glades of soft spinifex *Plectrachne*. Further north the country is more open — mainly rolling plains of hard spinifex *Triodia* and saltbush *Atriplex*; open *Acacia* scrubs are more plentiful in the far north of Peron Peninsula.

The eastern zone comprises the coastal plains east of Hamelin Pool. Red clays and loams predominate. Mean annual rainfall ranges from 19 to 23 cm, much more of it falling in summer than further west. Lowlying areas are covered with fresh water after heavy rain. In the south there are moderately dense *Acacia* scrubs. Northwards the vegetation becomes more open and dominated by chenopods, Aizoaceae and grasses. The Gascoyne and Wooramel Rivers are lined with river gums *Eucalyptus camaldulensis*. The lowlying muddy coasts between these rivers are fringed by the mangrove *Avicennia marina*.

Brief notes are given on local distribution, habitat preferences and abundance, including data from Storr and Harold (1980*a*,*b*), King and Roberts (1982), Maryan *et al.* (1984), Shea (1985), Morris and Alford (in press), recent taxonomic revisions by G.M. Storr and recent surveys by P.G. Kendrick and G. Harold. We are grateful to M. Peterson for criticizing the manuscript.

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Amphibians and reptiles

Annotated List

Leptodactylidae (ground frogs)

Arenophryne rotunda Tyler. Confined to western zone (Edel Land and Dirk Hartog I.).

Neobatrachus centralis (Parker). This and the following five frogs are confined to eastern zone.

Neobatrachus sutor Main. Neobatrachus wilsmorei (Parker). Pseudophryne occidentalis Parker.

Hylidae (tree frogs)

Cyclorana maini Tyler and Martin. Litoria rubella (Gray).

Cheloniidae (marine turtles)

Caretta caretta (Linnaeus). Apart from stragglers, marine turtles do not occur south of Shark Bay.

Chelonia mydas (Linnaeus).

Cheluidae (side-necked turtles)

Chelodina steindachneri Siebenrock. Confined to eastern zone.

Gekkonidae (geckos)

Crenadactylus ocellatus horni (Lucas and Frost). Common in western and central zones, mainly in spinifex and limestone.

Diplodactylus alboguttatus Werner. Common on Peron Peninsula, uncommon on Edel Land; mainly in Triodia and open Acacia.

Diplodactylus michaelseni Werner. Common in far south of Peron Peninsula; also further north at Eagle Bluff.

Diplodactylus ornatus Gray. Moderately common in western and central zones.

Diplodactylus pulcher (Steindachner). Mainly in eastern zone; also on Peron Peninsula and Faure I.

Diplodactylus rankini Storr. Confined to Bernier I. and extreme north of eastern zone.

Diplodactylus spinigerus spinigerus Gray. Common in western zone.

- Diplodactylus squarrosus Kluge. Moderately common in Acacia scrubs of eastern zone; also on Faure I.
- Diplodactylus strophurus (Duméril and Bibron). Mainly Acacia scrubs of Peron Peninsula. Also far north of eastern zone.
- Gehyra variegata (Duméril and Bibron). This and the next species are very common throughout the area.

Heteronotia binoei (Gray).

Nephrurus levis occidentalis Storr. Common in western and central zones. Phyllodactylus marmoratus marmoratus (Gray). Confined to Edel Land.

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Rhynchoedura ornata Günther. Central and eastern zones, where rare. Underwoodisaurus milii (Bory). Common in western zone, mainly in limestone.

Pygopodidae (legless lizards)

Aclys concinna major Storr. Endemic to far south of central zone.

Aprasia haroldi Storr. Endemic to Edel Land.

Aprasia smithi Storr. Confined to far south of Edel Land.

Delma australis Kluge. Far south of central zone.

Delma butleri Storr. Western and central zones, where rare.

Delma fraseri Gray. Far south of Edel Land.

Delma nasuta Kluge. Confined to central zone, where rare.

Delma tincta DeVis. Confined to eastern zone, where scarce.

Lialis burtonis Gray. Common in much of area, but not Peron Peninsula.

Pletholax gracilis edelensis Storr. Endemic to Edel Land.

Pygopus lepidopodus lepidopodus (Lacepède). Uncommon in western and central zones, mainly in Triodia.

Pygopus nigriceps nigriceps (Fischer). Mainly in open Acacia in eastern zone.

Agamidae (dragons)

Ctenophorus inermis (DeVis). Common in sparsely wooded parts of eastern zone.

- Ctenophorus maculatus badius (Storr). Moderately common on low ridges of sandy loam in northern half of eastern zone.
- Ctenophorus maculatus maculatus (Gray). Western and central zones, in low open vegetation.
- Ctenophorus reticulatus (Gray). Common in coastal limestone and all well-vegetated habitats.
- Ctenophorus rubens (Storr). Confined to small area of Eucalyptus-Triodia between Hamelin and Coburn.

Ctenophorus scutulatus (Stirling and Zietz). Eastern zone, especially where soil lighter and woody vegetation better developed.

Gemmatophora longirostris (Boulenger). Eastern zone, mainly in river gums. Moloch horridus Gray. Uncommon in central and eastern zones.

Pogona minor minor (Sternfeld). Moderately common in a wide variety of habitats.

Tympanocryptis butleri (Storr). Common in low open vegetation on Edel Land and Dirk Hartog I.

Tympanocrytis parviceps Storr. Common in low open vegetation on Bernier I.

Scincidae (skinks)

Cryptoblepharus carnabyi Storr. Mainly in coastal limestone of western zone.

Cryptoblepharus plagiocepahlus (Cocteau). Only recorded from far south of Edel Land.

Ctenotus fallens Storr. Moderately common in western zone and on both coasts of Peron Peninsula.

- Ctenotus lesueurii (Duméril and Bibron). Moderately common on Bernier, Dorre, Dirk Hartog and Salutation Is and in Edel Land; mainly in white coastal dunes.
- Ctenotus mimetes Storr. Uncommon in far south of eastern zone.
- Ctenotus pantherinus pantherinus (Peters). Moderately common in Triodia on Peron Peninsula; scarce in far south of eastern zone.
- Ctenotus schomburgkii (Peters). Rare.
- Ctenotus severus Storr. Scarce in south of eastern zone.
- *Ctenotus youngsoni* Storr. Endemic to Dirk Hartog I. and Edel Land including Salutation and Three Bays Is.
- *Ctenotus zastictus* Storr. Endemic to small area of *Eucalyptus-Triodia* between Hamelin and Coburn.
- Cyclodomorphus branchialis (Günther). Common in western zone on coasts and on Peron Peninsula.
- Egernia badia Storr. Confined to Dirk Hartog I.
- *Egernia bos* Storr. Confined to Bernier I., where common on sparsely vegetated sandplains.
- Egernia depressa (Günther). Confined to castern zone, where uncommon.
- Egernia formosa Fry. Confined to far south of eastern zone, where rare.
- *Egernia inornata* Rosén. Only known from one locality in central zone (a sand dune 17 km SE Nanga).
- Egernia kingii (Gray). Confined to Three Bays I. in Freycinet Estuary.
- *Egernia stokesii aethiops* Storr. Endemic to Baudin I. in Freycinet Estuary, where common under slabs of limestone.
- Eremiascincus richardsonii (Gray). Confined to eastern zone, where rare.
- Lerista connivens Storr. Far south of western zone and Faure I.
- Lerista elegans (Gray). Widespread in lightly wooded sandy country.
- Lerista kendricki Storr. Common in central zone and south of eastern zone.
- Lerista lineopunctulata (Duméril and Bibron). Common in western zone.
- Lerista macropisthopus fusciceps Storr. Common in central and eastern zones.
- Lerista maculosa Storr. Endemic to far south of eastern zone. Apparently very rare.
- Lerista muelleri (Fischer). Moderately common in Acacia scrubs in south of mainland.
- Lerista planiventralis decora Storr. Confined to central zone.
- Lerista planiventralis planiventralis (Lucas and Frost). Moderately common in western zone.
- Lerista praepedita (Boulenger). Very common in sandy country.
- Lerista uniduo Storr. Common in eastern zone.
- Lerista varia Storr. Western and central zones.
- Menetia amaura Storr. Endemic to Edel Land, where rare.
- Menetia greyii Gray. Widespread and moderately common.

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Menetia surda Storr. Moderately common in spinifex on Bernier I. and Peron Peninsula.

Morethia butleri (Storr). Far south of eastern zone, where rare.

Morethia lineoocellata (Duméril and Bibron). Common in coastal dunes and limestone of western zone; patchily distributed further east.

Morethia obscura Storr. Uncommon in Edel Land and south of Peron Peninsula.

Tiliqua occipitalis (Peters). In low open *Acacia* on sandy loams in north of Peron Peninsula and far north of eastern zone.

Tiliqua rugosa rugosa (Gray). Moderately common in western zone, northern Peron Peninsula and extreme north of eastern zone.

Varanidae (monitors)

Varanus brevicauda Boulenger. In Triodia on central Peron Peninsula.

- Varanus caudolineatus Boulenger. Uncommon in eastern zone in open Acacia scrub.
- Varanus eremius Lucas and Frost. Scarce in eastern zone and northern Peron Peninsula in open Acacia scrub.

Varanus giganteus (Gray). Confined to eastern zone, where rare.

Varanus gouldii (Gray). Widespread, including Bernier, Dorre, Dirk Hartog and Faure Is.

Typhlopidae (blind snakes)

Ramphotyphlops australis (Gray). Confined to Edel Land.

Ramphotyphlops grypus (Waite). Central and eastern zones.

Ramphotyphlops leptosoma (Robb). Confined to eastern zone.

Ramphotyphlops waitii (Boulenger). Confined to far south of western zone.

Boidae (pythons)

Aspidites ramsayi (Macleay). One record from Peron Peninsula.

Morelia stimsoni stimsoni (L.A. Smith). Moderately common in western and eastern zones; also central zone.

Elapidae (elapid snakes)

Demansia calodera Storr. Widespread and moderately common.

Demansia psammophis cupreiceps Storr. Uncommon in eastern zone.

Demansia psammophis reticulata (Gray). Confined to Dirk Hartog I. and Edel Land, where moderately common.

Denisonia fasciata Rosén. Confined to eastern zone, where rare.

Furina ornata (Gray). Rare in central and eastern zones.

Pseudechis australis (Gray). Moderately common in western and eastern zones.

Pseudonaja modesta (Günther). Moderately common in open Acacia in eastern zone.

Pseudonaja nuchalis Günther. Common in eastern zone and northern Peron Peninsula. Recently found on Dirk Hartog I. Rhinoplocephalus monachus (Storr). Uncommon in eastern zone and on Peron Peninsula.

Vermicella approximans (Glauert). Confined to eastern zone, where rare.

Vermicella bertholdi (Jan). Confined to eastern zone, where uncommon.

- Vermicella bimaculata (Duméril, Bibron and Duméril). Confined to far south of Edel Land.
- Vermicella fasciolata fasciolata (Günther). Only recorded from Dirk Hartog I., northern Edel Land and northern Peron Peninsula.
- Vermicella littoralis Storr. On white coastal sands of western zone, Peron Peninsula and Faure I.

Hydrophiidae (sea snakes)

Aipysurus pooleorum L.A. Smith. Endemic to Shark Bay, where common.

Emydocephalus annulatus Krefft. Only one record.

Ephalophis greyii M.A. Smith. Only reported from Carnarvon, where possibly common in mangrove creeks.

Hydrophis elegans (Gray). Common.

Hydrophis major (Shaw). Very common.

Pelamis platura (Linnaeus). Only one record.

Discussion

Few parts of Western Australia have so diverse a herpetofauna as the Shark Bay area. This richness is partly due to the location of Shark Bay at the meeting point of the State's three main natural regions: the south-western with its relatively mild summers and wet winters; the northern with its hot rainy summers and warm winters; and the eremaean with its hot summers, cold winters and low rainfall.

Many southern species are at their northern limit at Shark Bay, viz. the leptodactylid frog *Pseudophryne occidentalis*, the geckos *Diplodactylus michaelseni*, *D. spinigerus*, *Phyllodactylus marmoratus* and *Underwoodisaurus milii*, the pygopodid lizards *Aclys concinna*, *Aprasia smithi*, *Delma australis*, *D. fraseri*, *Pletholax gracilis* and *Pygopus lepidopodus*, the agamid lizard *Tympanocryptis butleri*, the skinks *Ctenotus fallens*, *C. lesueurii*, *Egernia badia*, *E. bos*, *E. kingii*, *E. stokesii*, *Morethia obscura* and *Tiliqua rugosa*, the blind snake *Ramphotyphlops leptosoma*, the python *Aspidites ramsayi* and the elapid snakes *Vermicella bimaculata and V. fasciolata*. The southern element is largely confined to the western and central zones, i.e. to the country west and south of the mulga-eucalypt line.

Northern species at their southern limit in the Shark Bay area include the hylid frog *Litoria rubella*, the pygopodid *Delma nasuta*, the agamid *Ctenophorus rubens*, the blind snake *Ramphotyphlops grypus*, the elapid *Demansia calodera* and all the marine turtles and sea snakes.

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Several species characteristic of the arid interior reach the coast in the Shark Bay area, e.g. the leptodactylid *Neobatrachus wilsmorei*, the hylid *Cyclorana maini*, the geckos *Diplodactylus squarrosus* and *D. strophurus*, the skinks *Egernia depressa*, *E. formosa*, *E. inornata*, *Lerista muelleri* and *Morethia butleri* and the monitors *Varanus brevicauda*, *V. caudolineatus*, *V. eremius and V. giganteus*. The eremaean element is almost entirely restricted to the eastern zone.

The islands, peninsulas and gulfs of the area provide a refuge for nine relict or endemic species and subspecies: the pygopodids *Aclys concinna major, Aprasia haroldi* and *Pletholax gracilis edelensis*, the skinks *Ctenotus youngsoni, C. zastictus, Egernia stokesii aethiops, Lerista maculosa* and *Menetia amaura* and the sea snake *Aipysurus pooleorum*.

The area is rich in old Australian elements, e.g. 12 species of diplodactyline geckos and 12 species of pygopodid lizards. It is especially rich in fossorial species, viz. the frog *Arenophryne* (almost endemic), two species of the pygopodid genus *Aprasia* (one endemic, one almost so), ten species of the scincid genus *Lerista* (two endemic, one almost so), four blind snakes (*Ramphotyphlops*) and five species of the elapid genus *Vermicella*.

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The biology of Arenophryne rotunda (Anura: Myobatrachidae): a burrowing frog from Shark Bay, Western Australia

J. D. Roberts *

Abstract

This paper summarises current knowledge of the natural history, breeding biology, population structure, physiology and relationships of *Arenophryne rotunda*. This frog has only been known to science since 1976 but it has been extensively studied in the last twelve years and it is the only anuran currently listed as rare or in need of special protection in Western Australia.

Résumé

Cet article résume la connaissance actuelle sur l'histoire naturelle, la biologie reproductrice, la structure de population, la physiologie et les relations de *l'Arenophryne rotunda*. Cette grenouille n'est connue de la science que depuis 1976 mais elle a été considérablement étudiée durant ces douze derniéres années et est le seul grenouille classé actuellement parmi les espèces rares ou nécessitant une protection spéciale en Australie-Occidentale.

Introduction

The frog fauna of southwestern Australia contains 22 described species (excluding taxa with a primarily desert range, Tyler *et al.* 1984) with most species being restricted to the wetter southwest forest block. Only six widespread species, *Limnodynastes dorsalis, Heleioporus albopunctatus, Neobatrachus pelobatoides, Myobatrachus gouldii, Pseudophryne guentheri* and *Crinia pseudinsignifera* occur in the drier areas of the eastern and north-eastern wheatbelt. The fauna is discrete with the southwest fauna being rapidly replaced geographically along the eastern and northeastern boundaries of the wheatbelt by species which are widespread in the western and central deserts (Tyler *et al.* 1984). The most recent addition to the southwest fauna is *Arenophryne rotunda, (Arenophryne* is a monotypic genus) described by Tyler (1976) from Shark Bay, Western Australia. This species has a relatively restricted range from Kalbarri north to Shark Bay and Dirk Hartog Island (Figure 1; Roberts 1985).

The isolated range of *A. rotunda* clearly contributed to its failure to be recognised earlier as it is the only species occurring outside the major forest blocks which lacks a wide distribution over a major portion of the southwest land division (Figure 1; see distribution maps for other species in Tyler *et al.* 1984; Roberts 1985 for a detailed distribution for *A. rotunda*).

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Figure 1. Probable distribution of *A. rotunda* (black, after Roberts 1985) related to total annual rainfall (isohyets in mm).

A. rotunda occurs on the northern margin of the southwest botanical province (Beard 1978) and therefore on the edge of the arid zone but does not extend into areas traditionally recognised as desert in classifications of the Australian climate (Gentilli 1971; Bradshaw 1986). However, the range of *A. rotunda* is in a region where severe summer droughts are only occasionally broken by cyclonic rains (rainfall data summarised in Burbidge and George 1978; Roberts 1984). This is a demanding environment for frogs and from the areas where *A. rotunda* was initially collected at the northern end of its range (Tyler 1976; Tyler *et al.* 1980). *A. rotunda* is the only frog species known: none of the desert species occur there (Storr and Harold 1978; 1980). Therefore, it is not surprising that *A. rotunda* has a number of unique features in its biology. These are summarised below.

Natural History

A. rotunda is unusual in many respects. It burrows but it burrows forward rather than the more usual backwards burrowing found in frogs (Tyler *et al.* 1980). In the family Myobatrachidae this habit is only shared with *Myobatrachus gouldii* (Tyler *et al.* 1980). *A. rotunda* is active at night on the dune systems close to
the coast and evidence of that activity is readily seen in the frequent tracks found on the dunes (Tyler *et al.* 1980; Roberts 1984). This feature makes this species particularly amenable to sampling by pit traps or a combination of pits and drift fences (Roberts 1985). During daylight frogs were found at the dry/moist sand interface when excavated at the end of tracks in August (Tyler *et al.* 1980). Over summer, frogs dig deeper as the summer progresses but always are deep enough to be found in noticeably moist sand (Roberts 1984). There is no evidence of a cocoon found in many desert frogs that burrow (e.g. Lee and Mercer 1967) or of any other devices that might reduce water loss.

Analysis of 74 faecal samples from 92 juveniles and 65 adults collected in July-August 1981 and 8 adults collected in May-June 1980 showed that the diet consists mainly of ants (*Aphaenogaster* spp): workers occurred in 92% of faecal samples, winged, breeding males in 31% and winged queens in 20% of the samples. Beetles occurred in 49% of the same samples, arachnids in 8%, hemipterans in 2.7% and one sample contained part of a mollusc shell. Prey items vary dramatically in size: male ants averaged 7.9 mm long (n = 4, S.E. = .36), females 12.9 mm (n = 4, S.E. = .31) but workers only 3.7 mm (n = 5, S.E. = .14). Composition of 8 faecal samples from adults was compared with data from 22 juvenile samples using four prey categories: worker ants, males, queens and others. There was no significant difference (Chi² = 0.38, p>0.9). Dietary items reported here are similar to those recorded by Tyler *et al.* (1980). The diet is probably catholic and opportunistic.

There is no direct evidence of predation on this species though it occurs sympatrically with the carnivorous dasyurid *Sminthopsis murina* (King and Roberts 1982) and is often seen with the gecko *Nephrurus levis* which has a gape large enough to consume at least juvenile frogs. Roberts (1985) reported injuries to toes of 5.8% of frogs captured in pit traps suggesting the frogs may be subject to some predator pressure. When severely provoked, e.g. by blood sampling, the frogs release a clear yellow liquid with a strange smell which may help to deter predators.

Breeding biology

Roberts (1984) has described the breeding biology of this species in some detail. *A. rotunda* has direct-developing eggs which are deposited ca. 80 cm underground. However, egg deposition and pairing are separated by at least 5 months. Scattered calling males have been heard in July-August and in November but serious calling activity has only been observed after rain in late August (Baynes, pers. comm.). The call of this species has three phases with varying pulse rates and is very similar to the published calls of *Pseudophryne* species. However, it is important to note that this basic call type with a low pulse rate introductory section and a faster pulse rate in latter sections also occurs in many other myobatrachine frogs and may represent a primitive call type for this subfamily (c.f. calls of some *Crinia* species, Littlejohn 1959; some *Uperoleia* species, Tyler

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et al. 1981). Pairs form by early November but the mechanism of pairing and the events that lead to localised aggregations of pairs are unknown. In November 1980, pairs were excavated at two sites from mean depths of 41 and 45 cm with 4 and 8 pairs found at each site. These aggregations were still apparent in February at the end of summer but frogs were considerably deeper in the sand (an average depth of 78 cm; Roberts 1984). The sizes of members of a pair is significantly correlated (Roberts 1984) but the significance of this fact is unclear. In other anurans with aquatic egg deposition, close correlations of the sizes of members of a pair facilitate effective fertilization of the eggs (e.g. Davies and Halliday 1977). Presumably *Arenophryne* has external fertilisation of the eggs but in *Eleutherodactylus coqui*, which also has direct developing eggs, there is evidence of internal fertilization (Townsend *et al.* 1981). The eggs of Arenophryne are large, with an external diameter of 5.5 mm at field hydration levels (Roberts 1984).

Detailed data on clutch sizes are not available but one pair that deposited in captivity laid 11 eggs. Development is intracapsular and took 73 days at room temperature (15 - 20°C). Two hatchlings had a mean weight of .234 g and a mean snout-vent length of 10.2 mm. This development period results in hatching dates that coincide with the wettest period of the year (Figure 2). Little else is known of development except that unfertilised eggs mature in females over summer when males and females are paired underground. The breeding biology of this species is summarised in Figure 2, redrawn from Roberts (1984).



Figure 2. Breeding biology of A. rotunda related to the monthly distribution of rainfall.

Population size and structure

Roberts (1984, 1985) reported data on population structure along with estimates of density for this species. Populations in late winter (July) are split about half

and half between juveniles, presumably hatched the preceding autumn, and frogs that are large enough to be breeding (based on sizes of pairs excavated in November). The size dichotomy is marked but there is no direct evidence that all animals in the lower size category are less than one year old. This might be obtained from controlled studies on growth rings in bones (c.f. Halliday and Verrell 1988). Comparing sizes of animals found paired with the population size distribution, Roberts (1984) concluded that most breeding frogs were at least two years old but that some males may have been paired at less than one year old and therefore might have been breeding at an age of about one year. Comparable data on age at first breeding are only available for Heleioporus species amongst the Australian frog fauna (Lee 1967) where a very similar situation applies: most frogs probably first breed at two years of age but some may be large enough to breed at one year. Age structure data are limited to Heleioporus (Lee 1967) and Myobatrachus (Davidge 1980). However, unless the analysis of age structure is developed further into an analysis of survival, age structure data tell us little in isolation as the structure is most likely largely determined by the proximity of sampling to breeding and subsequent patterns of mortality in the young: commonly high in aquatic breeding anurans (e.g. Calef 1973: Smith 1983) but not documented for species with direct-developing eggs. Comparisons of direct-developing forms with conventional pond breeders may provide interesting data on the proximate factors maintaining terrestrial egg deposition in frogs.

Population densities are frequently high, at least in comparison with data published for other Australian frogs. However, it is difficult to make broader comparisons as most published data on frog populations are based on numbers of animals aggregated at breeding sites rather than densities of animals spread over a uniformly used habitat (Duellman and Trueb 1986). Roberts (1985) reported density estimates as high as 277.6 frogs.ha-1 based on frogs known to be alive. Density estimates from mark-release-recapture population estimates were much higher. There are no comparable data available for other Australian frog species as most other studies generating data of this type have not concentrated on frogs and have not necessarily been designed to maximise capture rates by working at relevant times of the year. For example, Davidge (1979) trapped all terrestrial vertebrates in March to early May when most anurans are not active in southwestern W.A. The limited data are summarised in Roberts (1985). By comparison with direct-developing forms found in tropical habitats. A. rotunda is abundant: the average density of seven *Eleutherodactylus* species in Costa Rica was only 77.5 frogs.ha-1 (Scott 1976; quoted in Duellman and Trueb, 1986). The densities of A. rotunda are more comparable with the very high densities of many terrestrial salamander species (see summary in Table 11.6 of Duellman and Trueb 1986). However, the dearth of data for Australian frog species experiencing similar climates makes it impossible to assess accurately the status of A. rotunda as rare

or endangered fauna, though this species is clearly locally abundant (Roberts 1985).

Water relations

The habitat of this frog is seasonally arid and even in periods of peak activity, in spring, the dune surface is generally dry and may subject the frogs to dehydration stress. Burrowing anurans commonly respond to water stress by elevation of plasma urea levels resulting in enhanced water uptake from even relatively dry soils or the prevention of loss of water to soils (e.g. McClanahan 1972; Katz and Gabbay 1986). As noted above, there is no evidence of cocoons of the form seen in other burrowing anurans but one cannot exclude the possible occurrence of waterproof barriers like the lipid layer found in *Phyllomedusa* (Blaylock *et al.* 1976). I investigated the physiological response of frogs to seasonal aridity by sampling blood and urine on four occasions during the period 1980 - 1981 and measuring total osmolalities and urea levels. These data are presented below in some detail and their significance discussed. An abstract summarising these data was published by Roberts and Bradshaw (1981).

For this study blood plasma and urine samples were collected from animals in the field, either when they were active at night on the surface, or from frogs excavated from sites underground. Not all frogs collected were successfully sampled for both blood and urine. Some samples were too small for analysis of both osmolality and urea levels: osmolalities were measured preferentially. Sample sizes therefore differ between the four categories in the data presented below. Samples were collected on four occasions: 31.v to 1.vi 1980; 7-12.viii 1980; 28.x - 2.xi 1980 and 11-15.ii 1981. Blood was collected into heparinized capillary tubes after puncturing the orbital sinus. Plasma was separated from red cells by centrifugation in the field and stored frozen until analysed. Urine was sampled by inserting a glass capillary tube into the cloaca and gently stimulating the bladder papillae. Plasma and urine osmolalities were measured on a Wescor Model 5100B Vapor Pressure Osmometer. Urea levels were determined by an urease technique. I assume that no frogs were resampled and have treated the four samples as being independent though as frogs were not marked the possibility of recapture cannot be excluded. The data are presented in Table 1.

Analysis of variance with *a posteriori* comparisons amongst means by the Student-Newman-Keuls test shows that for three of the four data sets there were significant differences between the mean values for one or more of the four seasonal samples. The sets of means not differing significantly are given in Table 1 along with details of anova.

Plasma osmolalities vary little with only the extreme values differing significantly. Interestingly, the highest values occurred in August when animals were all collected active on the dunes at night or were excavated at the end of trails indicating recent activity. In May-June frogs were again active but in heavy rain. All frogs sampled in February were excavated from sites where pairs were found

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Table 1. Plasma and urine osmolalities (mOsm.kg⁻¹) and urea levels (mM). Data are given as mean ± S.E. Means are ranked from lowest to highest with means that do not differ significantly bracketed (S.N.K. test at the .05 significance level). Sample sizes are given as a number in brackets under each month.

Plasma Osmolalit	у			
June (9)	February (17)	November (16)	August (14)	F ^{3,52}
257 ± 6	291 ± 8	307 ± 17	326 ± 16	$3.55 \ (p < 0.05)$
Urine Osmolality				
June (6)	November (8)	February (12)	August (8)	F ^{3,30}
84 ± 17	124 ± 12	137 ± 15	203 ± 21	7.36 (p < 0.01)
Plasma Urea				
February (14)	November (17)	August (14)	June 	F ^{2,40}
13.6 ± 1.6	25.4 ± 2.1	57.7 ± 7.9	no data	20.42 (p $< 0.01)$
Urinary Urea				
February (8)	June (4)	November (8)	August (6)	F.3.20
21.4 ± 4.9	25.1 ± 11.1	36.6 ± 4.2	38.8 ± 9.3	1.72 (p > 0.05)

(see section on Breeding biology above) and ten of seventeen frogs sampled in November were excavated from similar sites. If high plasma osmolalities reflect water shortage, then water stress must be highest in August when frogs were most active on the dune surface (see Roberts 1984 for detailed data on activity from track analysis).

Urine osmolalities exhibited much more seasonal variation with highest and lowest values in June and August differing significantly and both values differing significantly from the November and February samples. The low values in May-June may reflect high water uptakes from very moist soils or rainfall. The high value in August may again reflect a seasonal water stress but there is a partial contribution from the relatively high urea level.

Insufficient blood plasma was available to assess urea levels in the May-June sample. All other mean values differed significantly. However, contrary to the prediction in the introduction to this section, highest values do not occur in summer but again are found in August. This may reflect patterns of metabolism with animals actively ingesting insects with a relatively high protein input in

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August but with a reliance on fat metabolism in aestivating animals excavated in November and February. The lowest values occurring in February are consistent with this interpretation as there may have been some recent feeding in some of the animals sampled in November but none in February.

Urinary urea levels did not vary significantly between the four samples.

In conclusion, elevated plasma osmolalities in August may reflect seasonal water stress due to activity with a small elevation due to increased protein metabolism causing high production rates for urea. These predictions could easily be tested as the potential for examination of field water loss rates and water turnover is high in this species because of the relative ease with which it can be tracked across the dunes. This means that individuals could be followed with minimal disturbance through marking. Lee (1968) published data consistent with *Haleioporus eyrei* losing water during nightly activity and this might be a problem for many active anurans, *A. rotunda* among them.

Evolution and relationships

Tyler (1976) suggested from morphological comparisons that *Arenophryne* was closely related to *Myobatrachus* or *Pseudophryne*. Analysis of relationships using an immunological technique (micro-complement fixation, MC F) for comparison of serum albumins, (Maxson and Roberts, 1985) confirms this suggestion with a further refinement that the relationship of *Arenophryne* is closer to *Myobatrachus* and to *Metacrinia* than to *Pseudophryne* (Maxson and Roberts 1985). Analysis of breeding biologies confirms this relationship as both *Myobatrachus* and *Metacrinia* have direct developing eggs and from limited data it seems that *Myobatrachus* also has a separation of male-female pairing time (spring) and egg deposition (autumn; Roberts 1981; Maxson and Roberts 1985). However, complete details of the breeding biology of *Metacrinia* are unknown.

This pattern of relationships is not contradicted by data on chromosome morphology and nucleolar organiser region position (Mahony and Robinson 1986).

As the amino acid sequence of albumin evolves at an approximately constant rate as a function of time (Wilson *et al.* 1977; Thorpe 1982) divergence in albumin structure can be used to estimate divergence dates for related species of frogs. Maxson and Roberts (1985) applied this technique to the albumin comparisons made by MC'F and concluded that *Arenophryne* and *Myobatrachus* last shared a common ancestor 8-9 million years ago - i.e. in the mid-Miocene. The divergence date from *Pseudophryne* was estimated as even earlier, dating to the early Miocene. If these dates are even approximately correct, it implies that similarities of call structure found between *Arenophryne* and *Pseudophryne* are symplesiomorphies, i.e. retained primitive similarities, and that there has been little selection acting on call structure in this group of frogs. However, the divergence in other aspects of breeding biology is dramatic as in all *Pseudophryne* species

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pairing and egg deposition occur close together, and in all species except *P. douglasi*, eggs may undergo partial development on land but completion of development involves an aquatic tadpole (Pengilley 1973). *P. douglasi* has aquatic egg deposition and development (Main 1964).

Prospects for the future

Arenophryne rotunda is the only frog species currently listed as rare or in need of special protection under the W.A. Wildlife Conservation Act. As such, assessment of its true range and population densities is of some importance. The preliminary study reported by Roberts (1985) demonstrates the feasibility of at least short-term population studies. Track counts might be useful as an indicator of relative abundance (c.f. Roberts 1984). The most relevant comparisons are probably with Myobatrachus gouldii as this species shares many features of breeding biology and natural history. Comparisons might also be usefully made with *Pseudophryne* species, critically *P. guentheri*, as this species occupies at least part of a similar climatic zone. An understanding of factors limiting the distribution of A. rotunda will also contribute to an appreciation of how this species might respond to the climatic changes predicted as a result of the Greenhouse Effect. These are particularly relevant in areas like Shark Bay where reduced winter rainfall and enhanced summer rain from cyclonic activity are predicted, shifting the climate towards that currently experienced by desert areas to the north and northeast (Arnold 1988; Pittock 1988).

A. rotunda also offers some interesting prospects for work on water loss/gain in a field situation. Although not subject to severe seasonal water stress associated with summer drought, the relatively high plasma osmolalities found in spring suggest this frog may have a chronic problem with water loss during activity.

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Birds of Shark Bay area, Western Australia

G.M. Storr*

Abstract

Brief notes are given on the 236 species reliably recorded from the area.

Résumé

Des note brèves sont données sur les 236 espèces d'oiseaux recensées avec fiabilité dans la région.

Introduction

This paper is based on Storr (1985). It also incorporates data in subsequent publications, notably Brooker (1989).

Local status is given for each species and subspecies. Distribution is also indicated where a taxon is locally restricted to one or two of the three zones, namely the western (Bernier, Dorre and Dirk Hartog Islands, Edel Land and the small islands of Freycinet Estuary), the central (Peron Peninsula, Faure Island and the country immediately south and south-east of Freycinet Estuary) and eastern (the coastal plains between Carnarvon and Hamelin).

Annotated List

Casuariidae

Emu (Dromaius novaehollandiae). Resident throughout mainland and on Faure I.

Diomedeidae

Yellow-nosed Albatross (Diomedea chlororhynchos bassi). Common winter visitor to open seas.

Procellariidae

Southern Giant Petrel (Macronectes giganteus). Scarce winter visitor to open seas.

Cape Petrel (Daption capense). Scarce winter visitor to open seas.

White-headed Petrel (Pterodroma lessonii). Rare winter visitor to seas well offshore.

Soft-plumaged Petrel (Pterodroma mollis). Common winter visitor to seas well offshore.

Streaked Shearwater (Calonectris leucomelaena). Summer visitor to open seas.

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Wedge-tailed Shearwater (*Puffinus pacificus*). Common breeding visitor to islands in Freycinet Estuary and adjacent seas. This is the only dimorphic population in Australia, 20% of the birds being white-breasted.

Little Shearwater (Puffinus assimilis). Rare visitor to open seas.

Oceanitidae

Wilson's Storm Petrel (Oceanites oceanicus). Moderately common passage migrant over open seas.

Podicipedidae

Black-throated Grebe (*Tachybaptus novaehollandiae novaehollandiae*). Rare visitor to eastern zone.

Hoary-headed Grebe (Poliocephalus poliocephalus). Rare visitor to eastern zone.

Fregatidae

Lesser Frigatebird (Fregata ariel). Vagrant.

Phalacrocoracidae

Great Cormorant (Phalacrocorax carbo novaehollandiae). Uncommon visitor.

- Pied Cormorant (*Phalacrocorax varius*). Very common resident of sheltered seas (but not the highly saline Hamelin Pool), breeding mainly on small islands off Dirk Hartog I. and in Freycinet Estuary.
- Little Black Cormorant (*Phalacrocorax sulcirostris*). Uncommon visitor to the lower Gascoyne.
- Little Pied Cormorant (*Phalacrocorax melanoleucos*). Uncommon resident, breeding on islands in Freycinet Estuary.

Anhingidae

Darter (Anhinga melanogaster novaehollandiae). Uncommon along the lower Gascoyne.

Sulidae

Australian Gannet (Morus serrator). Rare winter visitor.

Pelecanidae

Australian Pelican (*Pelecanus conspicillatus*). Common visitor to sheltered seas. Breeding on Pelican I.

Ardeidae

Pacific Heron (*Ardea pacifica*). Uncommon visitor to eastern zone. White-faced Heron (*Ardea novaehollandiae*). Common resident. Great Egret (*Ardea alba*). Moderately common along the lower Gascoyne. Intermediate Egret (*Ardea intermedia*). Vagrant.

- Little Egret (Ardea garzetta nigripes). Moderately common resident of coast between the Gascoyne and Wooramel Rivers.
- Eastern Reef Heron (Ardea sacra). Moderately common resident of most coasts, but not Hamelin Pool.

Mangrove Heron (Butorides striatus stagnatilis). Common resident of mangroves.

Rufous Night Heron (Nycticorax caledonicus hilli). Moderately common on the lower Gascoyne.

Threskiomithidae

Glossy Ibis (*Plegadis falcinellus*). Only recorded at bore overflow near Hamelin. Sacred Ibis (*Threshiornis aethiopicus moluccus*). Vagrant.

Straw-necked Ibis (*Threskiornis spinicollis*). Visitor, mainly to eastern zone. Yellow-billed Spoonbill (*Platalea flavipes*). Uncommon visitor to eastern zone.

renow-billed spoonbill (*Futurea futorpes*). Oncommon visitor to eastern

Anatidae

Pied Goose (Anseranas semipalmata). Vagrant.

Plumed Whistling Duck (Dendrocygna eytoni). Rare visitor to eastern zone.

Black Swan (Cygnus atratus). Uncommon visitor to eastern zone.

Freckled Duck (Stictonetta naevosa). Rare visitor to the lower Gascoyne.

Mountain Duck (Tadorna tadornoides). Uncommon visitor.

Wood Duck (Chenonetta jubata). Uncommon visitor.

Grey Teal (Anas gracilis). Moderately common breeding visitor.

Chestnut Teal (Anas castanea). Formerly occurring in mangrove creeks near Carnarvon.

Black Duck (Anas superciliosa). Uncommon visitor.

Blue-winged Shoveler (Anas rhynchotis rhynchotis). Scarce visitor.

Pink-eared Duck (Malacorhynchus membranaceus). Scarce visitor.

Hardhead (Aythya australis). Scarce visitor.

Accipitridae

Osprey (Pandion haliaetus cristatus). Common resident on islands.

Black-shouldered Kite (Elanus caeruleus notatus). Uncommon visitor.

Black-breasted Kite (Hamirostra isura). Uncommon visitor.

Black Kite (Milvus migrans affinis). Rare visitor to the lower Gascoyne.

Whistling Kite (Haliastur sphenurus). Common resident of eastern zone.

Brahminy Kite (Haliastur indus girrenera). Uncommon resident at Carnarvon.

White-bellied Sea Eagle (Haliaeetus leucogaster). Resident, common on larger islands.

Spotted Harrier (Circus assimilis). Uncommon visitor.

Swamp Harrier (Circus approximans). Rare visitor.

Brown Goshawk (Accipiter fasciatus fasciatus). Uncommon resident.

Collared Sparrowhawk (Accipiter cirrocephalus cirrocephalus). Uncommon resident.

Birds

Wedge-tailed Eagle (Aquila audax). Common resident.

Little Eagle (Aquila morphnoides morphnoides). Uncommon resident of central and eastern zones.

Falconidae

Brown Falcon (Falco berigora berigora). Common resident.
Australian Kestrel (Falco cenchroides cenchroides). Common resident and autumn-winter visitor.
Australian Hobby (Falco longipennis longipennis). Moderately common resident and autumn-winter visitor.

Grey Falcon (Falco hypoleucos). Rare visitor to eastern zone. Peregrine (Falco peregrinus macropus). Scarce visitor.

Megapodiidae

Mallee Fowl (Leipoa ocellata). Now confined to far south of central zone.

Phasianidae

Stubble Quail (Coturnix novaezelandiae pectoralis). Uncommon visitor. Brown Quail (Coturnix ypsilophora australis). Reported near Carnarvon.

Turnicidae

Little Button-quail (Turnix velox). Visitor to eastern zone, common in wet years.

Gruidae

Brolga (Grus rubicunda). Rare visitor to eastern zone.

Rallidae

Buff-banded Rail (Gallirallus philippensis mellori). Rare visitor.
Baillon's Crake (Porzana pusilla palustris). Uncommon resident of eastern zone.
Spotted Crake (Porzana fluminea). Common resident of eastern zone.
Spotless Crake (Porzana tabuensis). Uncommon resident of eastern zone.
Purple Swamphen (Porphyrio porphyrio). Reported near Yaringa.
Black-tailed Native Hen (Gallinula ventralis). Irregular visitor, common in wet years.
Const (Fadice also sustralis). Uncommon president of castern zone.

Coot (Fulica atra australis). Uncommon resident of eastern zone.

Otididae

Australian Bustard (Otis australis). Uncommon.

Rostratulidae

Painted Snipe (Rostratula benghalensis australis). Reported near Carnarvon.

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Haematopodidae

Pied Oystercatcher (*Haematopus ostralegus longirostris*). Resident on most coasts, but not Hamelin Pool.

Sooty Oystercatcher (Haematopus fuliginosus). Resident, mainly on rocky coasts.

Charadriidae

Banded Lapwing (Vanellus tricolor). Common resident and autumn-winter visitor.

Grey Plover (*Pluvialis squatarola*). Uncommon summer visitor to most coasts. Eastern Golden Plover (*Pluvialis fulva*). Rare summer visitor.

Red-capped Plover (Charadrius ruficapillus). Common resident.

Mongolian Plover (Charadrius mongolus mongolus). Rare summer visitor.

Large Sand Plover (Charadrius leschenaultii). Moderately common summer visitor.

Black-fronted Plover (Charadrius melanops). Moderately common resident of eastern zone.

Oriental Plover (Charadrius veredus). Rare summer visitor to eastern zone.

Red-kneed Dotterel (Erythrogonys cinctus). Uncommon visitor to eastern zone.

Australian Dotterel (Peltohyas australis). Scarce visitor, mainly to eastern zone.

Scolopacidae

Little Whimbrel (Numenius minutus). Rare visitor to eastern zone.

- Whimbrel (Numenius phaeopus variegatus). Common visitor to most coasts, but not Hamelin Pool.
- Eastern Curlew (Numenius madagascariensis). Moderately common visitor to most coasts, but not Hamelin Pool.

Black-tailed Godwit (Limosa limosa melanuroides). Rare summer visitor.

Bar-tailed Godwit (Limosa lapponica baueri). Common visitor to most coasts, but not Hamelin Pool.

Marsh Sandpiper (*Tringa stagnatilis*). Uncommon visitor, mainly to eastern zone. Greenshank (*Tringa nebularia*). Moderately common visitor.

Wood Sandpiper (Tringa glareola). Summer visitor to eastern zone.

Terek Sandpiper (Tringa terek). Scarce summer visitor to eastern zone.

Common Sandpiper (Tringa hypoleucos). Moderately common summer visitor.

Grey-tailed Tattler (*Tringa brevipes*). Moderately common visitor to most coasts, but not Hamelin Pool.

Ruddy Turnstone (Arenaria interpres interpres). Moderately common visitor to most coasts, but not Hamelin Pool.

Red Knot (*Calidris canutus*). Moderately common summer visitor to most coasts, but not Hamelin Pool.

Great Knot (Calidris tenuirostris). Moderately common summer visitor to most coasts, but not Hamelin Pool.

Sanderling (Calidris alba). Rare summer visitor.

Red-necked Stint (Calidris ruficollis). Common visitor.

Long-toed Stint (Calidris subminuta). Rare visitor, mainly to eastern zone.

Sharp-tailed Sandpiper (Calidris acuminata). Moderately common summer visitor.

Curlew Sandpiper (*Calidris ferruginea*). Moderately common summer visitor. Ruff (*Philomachus pugnax*). Reported at Hamelin bore overflow.

Recurvirostridae

Black-winged Stilt (*Himantopus himantopus leucocephalus*). Visitor to eastern zone, common and breeding in wet years.

Banded Stilt (*Cladorhynchus leucocephalus*). Uncommon visitor. Red-necked Avocet (*Recurvirostra novaehollandiae*). Uncommon visitor.

Burhinidae

Bush Stone-curlew (Burhinus grallarius). Uncommon resident.

Glareolidae

Australian Pratincole (*Stiltia isabella*). Rare visitor to eastern zone. Oriental Pratincole (*Glareola maldivarum*). Rare summer visitor to eastern zone.

Laridae

Great Skua (Stercorarius skua lonnbergi). Rare winter visitor to sheltered seas. Silver Gull (Larus novaehollandiae novaehollandiae). Common resident, mainly

on islands and around towns.

Kelp Gull (Larus dominicanus). Vagrant.

Pacific Gull (Larus pacificus georgii). Moderately common resident, mainly on islands and around towns.

Gull-billed Tern (Sterna nilotica macrotarsa). Scarce visitor, mainly to eastern zone.

Caspian Tern (Sterna caspia). Moderately common in most seas, but not Hamelin Pool.

Crested Tern (Sterna bergii). Common in most seas, but not Hamelin Pool.

Lesser Crested Tern (Sterna bengalensis). Rare visitor to far northern seas.

Common Tern (Sterna hirundo longipennis). Moderately common summer visitor to seas around Carnarvon.

Roseate Tern (Sterna dougallii). Moderately common resident of blue-water seas.

Bridled Tern (Sterna anaethetus anaethetus). Common visitor to blue-water seas, breeding on small rocky islands.

Whiskered Tern (Sterna hybrida javanica). Moderately common visitor, mainly to eastern zone.

White-winged Black Tern (Sterna leucoptera). Irregular summer visitor to eastern zone.

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Little Tern (Sterna sinensis). Probably rare summer visitor, but only reported from Carnarvon.

Fairy Tern (Sterna nereis nereis). Uncommon resident of sheltered blue-water seas.

Columbidae

Laughing Dove (Streptopelia senegalensis senegalensis). Occasional visitor, sometimes breeding.

Peaceful Dove (Geopelia striata placida). Resident on the lower Gascoyne.

Diamond Dove (Geopelia cuneata). Uncommon visitor to eastern zone.

Common Bronzewing (Phaps chalcoptera). Uncommon resident.

Flock Pigeon (Phaps histrionica). Irregular visitor to Carnarvon district.

Crested Pigeon (Ocyphaps lophotes). Moderately common resident.

Psittacidae

Regent Parrot (*Polytelis anthopeplus westralis*). Rare visitor to central zone. Ring-necked Parrot (*Platycercus zonarius zonarius*). Moderately common along

the lower Gascoyne.

Mulga Parrot (Platycercus varius). Scarce resident of eastern zone.

Elegant Parrot (Neophema elegans). Scarce autumn visitor to eastern zone.

Rock Parrot (Neophema petrophila). Very common resident on small islands in Freycinet Estuary.

Bourke's Parrot (Neophema bourkii). Scarce resident of eastern zone.

Budgerigar (*Melopsittacus undulatus*). Visitor to eastern zone, common and breeding in wet years; uncommon visitor to central zone.

Cockatiel (*Nymphicus hollandicus*). Visitor to eastern zone, moderately common and breeding in wet years.

Red-tailed Black Cockatoo (Calyptorhynchus magnificus samueli). Uncommon resident of far south-east.

Galah (Cacatua roseicapilla roseicapilla). Resident, common in eastern zone, uncommon on Peron Peninsula.

Little Corella (*Cacatua sanguinea westralensis*). Resident of eastern zone, common on the lower Gascoyne.

Major Mitchell's Cockatoo (Cacatua leadbeateri). Formerly occurring on the Wooramel.

Cuculidae

Pallid Cuckoo (Cuculus pallidus). Uncommon breeding visitor.

Black-eared Cuckoo (Chrysococcyx osculans). Uncommon breeding visitor.

Horsfield's Bronze Cuckoo (Chrysococcyx basalis). Moderately common breeding visitor.

Shining Bronze Cuckoo (Chrysococcyx lucidus plagosus). Rare passage migrant.

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Strigidae

Barn Owl (Tyto alba delicatula). Rare visitor. Boobook Owl (Ninox novaeseelandiae boobook). Uncommon visitor or passage migrant in eastern zone.

Podargidae

Tawny Frogmouth (Podargus strigoides brachypterus). Uncommon, mainly in eastern zone.

Aegothelidae

Australian Owlet-nightjar (Aegotheles cristatus cristatus). Uncommon resident, mainly of eastern zone.

Caprimulgidae

Spotted Nightjar (Eurostopodus argus). Scarce autumn-winter visitor.

Apodidae

Fork-tailed Swift (Apus pacificus pacificus). Uncommon summer visitor.

Alcedinidae

Blue-winged Kookaburra (Dacelo leachii leachii). Resident on the lower Gascoyne and Wooramel Rivers.

Red-backed Kingfisher (Halcyon pyrrhopygia). Moderately common resident, mainly in eastern zone.

Sacred Kingfisher (Halcyon sancta sancta). Uncommon passage migrant.

Meropidae

Rainbow Bee-eater (Merops ornatus). Scarce breeding visitor and passage migrant.

Alaudidae

Horsfield's Bushlark (Mirafra javanica javanica). Uncommon resident of north of eastern zone.

Hirundinidae

White-backed Swallow (Cheramoeca leucosterna). Common resident. Barn Swallow (Hirundo rustica gutturalis). Rare summer visitor to Carnarvon. Welcome Swallow (Hirundo neoxena). Common resident. Tree Martin (Hirundo nigricans nigricans). Mainly a passage migrant. Fairy Martin (Hirundo ariel). Uncommon resident of eastern zone.

Motacillidae

Richard's Pipit (Anthus novaeseelandiae australis). Common resident.

Campephagidae

Black-faced Cuckoo-shrike (Coracina novaehollandiae). Common resident and passage migrant.

White-winged Triller (Lalage sueurii tricolor). Visitor and passage migrant, common and breeding in wet years.

Pachycephalidae

Red-capped Robin (Petroica goodenovii). Scarce, mainly a winter visitor.

Hooded Robin (Petroica cucullata). Uncommon resident.

- Yellow Robin (Eopsaltria australis griseogularis). Uncommon resident of far south.
- Golden Whistler (Pachycephala pectoralis fuliginosa). Moderately common resident of far south.

Rufous Whistler (Pachycephala rufiventris rufiventris). Moderately common resident and winter visitor in eastern zone; scarce winter visitor to central zone.

- White-breasted Whistler (Pachycephala lanioides). Scarce resident in mangroves around Carnarvon.
- Grey Shrike-thrush (Colluricincla harmonica rufiventris). Moderately common resident.

Crested Bellbird (Oreoica gutturalis). Common resident.

Western Wedgebill (Psophodes occidentalis). Common resident.

Monarchidae

- Mangrove Grey Fantail (*Rhipidura phasiana*). Common resident of mangroves of Carnarvon district and northern Peron Peninsula.
- Grey Fantail (Rhipidura fuliginosa preissi). Common winter visitor.
- Willie Wagtail (Rhipidura leucophrys leucophrys). Common resident, winter visitor and passage migrant.
- Australian Magpie-lark (Grallina cyanoleuca). Uncommon resident and winter visitor, mainly in eastern zone.

Orthonychidae

- Chestnut Quail-thrush (Cinclosoma castanotum). Common resident of far south of Peron Peninsula.
- Southern Scrub-robin (Drymodes brunneopygius). Common resident of central zone.

White-browed Babbler (Pomatostomus superciliosus). Common resident.

Acanthizidae

- Southern Whiteface (Aphelocephala leucopsis castaneiventris). Common resident of eastern zone.
- Western Flyeater (Gerygone fusca fusca). Uncommon winter visitor and passage migrant.

- Dusky Flyeater (Gerygone tenebrosa). Common resident of mangroves of Carnarvon district.
- Weebill (Smicrornis brevirostris). Moderately common resident of far southern mallee scrubs.
- Broad-tailed Thornbill (*Acanthiza apicalis*). Moderately common resident (but not on Edel Land or islands).
- Chestnut-rumped Thornbill (Acanthiza uropygialis). Common resident of eastern zone.
- Samphire Thornbill (*Acanthiza iredalei iredalei*). Resident, mainly on nearcoastal flats between the Gascoyne and Wooramel Rivers.
- Yellow-rumped Thornbill (Acanthiza chryorrhoa). Uncommon resident in far south.
- Redthroat (Pyrrholaemus brunneus). Moderately common resident.
- White-browed Scrub-wren (Sericornis frontalis balstoni). Common resident.
- Striated Fieldwren (Calamanthus fuliginosus campestris). Moderately common resident.

Maluridae

- Thick-billed Grasswren (Amytornis textilis textilis). Common resident of far north of Peron Peninsula. Extinct on Dirk Hartog I.
- Splendid Fairy-wren (Malurus splendens splendens). Common resident of eastern zone.
- Variegated Fairy-wren (*Malurus lamberti*). The subspecies *M. l. assimilis* is common on mainland and Dirk Hartog I., and the subspecies *M. l. bernieri* is common on and endemic to Bernier and Dorre Is.
- Blue-breasted Fairy-wren (Malurus pulcherrimus). Common resident of far south.
- White-winged Fairy-wren (Malurus leucopterus). The subspecies M. l. leuconotus is common on mainland. The subspecies M. l. leucopterus is common on and endemic to Dirk Hartog I.
- Southern Emu-wren (Stipiturus malachurus hartogi). Moderately common on and endemic to Dirk Hartog I.

Sylviidae

- Clamorous Reed Warbler (*Acrocephalus stentoreus australis*). Resident in eastern zone, where suitable habitat is very limited.
- Little Grassbird (*Megalurus gramineus*). Moderately common resident of coastal areas in eastern zone.
- Rufous Songlark (*Cincloramphus mathewsi*). Uncommon visitor to eastern zone. Brown Songlark (*Cincloramphus cruralis*). Visitor, common and breeding in wet years.

Dicaeidae

Mistletoebird (*Dicaeum hirundinaceum hirundinaceum*). Uncommon breeding visitor.

Pardalotidae

Striated Pardalote (Pardalotus striatus westraliensis). Moderately common resident in mallee scrubs of far south.

Zosteropidae

Yellow White-eye (Zosterops lutea). Common resident of mangroves of Carnarvon district and northern Peron Peninsula.

Grey-breasted White-eye (Zosterops lateralis gouldi). Common resident.

Meliphagidae

Brown Honeyeater (Lichmera indistincta indistincta). Uncommon resident of western and central zones.

Black Honeyeater (Certhionyx niger). Rare visitor to eastern zone.

Pied Honeyeater (*Certhionyx variegatus*). Irregular visitor, common in wet years. Singing Honeyeater (*Meliphaga virescens*). Very common resident.

Yellow-fronted Honeyeater (Meliphaga plumula). Common resident of mallee scrubs in far south.

White-plumed Honeyeater (Meliphaga penicillata). Resident of eastern zone, common on the lower Gascoyne and Wooramel Rivers.

Brown-headed Honeyeater (Melithreptus brevirostris leucogenys). Moderately common resident of mallee scrubs in far south.

White-fronted Honeyeater (*Phylidonyris albifrons*). Irregular visitor, common in wet years.

Yellow-throated Miner (Manorina flavigula). Uncommon resident of eastern zone. Spiny-cheeked Honeyeater (Acanthagenys rufogularis). Scarce.

White-fronted Chat (Epthianura albifrons). Moderately common resident.

Orange Chat (Epthianura aurifrons). Moderately common resident, mainly in eastern zone.

Crimson Chat (Epthianura tricolor). Irregular visitor, common in wet years.

Ploceidae

Zebra Finch (*Taeniopygia guttata castanotis*). Common resident of pastoral country (owing to availability of water).

Star Finch (Neochmia ruficauda). Rare visitor to the lower Gascoyne.

Artamidae

White-breasted Woodswallow (Artamus leucorhynchus). Common resident of vicinity of Carnarvon.

Masked Woodswallow (Artamus personatus). Visitor, common and breeding in wet years.

Black-faced Woodswallow (Artamus cinereus melanops). Uncommon resident. Dusky Woodswallow (Artamus cyanopterus). Scarce winter visitor to far south. Little Woodswallow (Artamus minor). Scarce visitor.

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Cracticidae

Grey Butcherbird (*Cracticus torquatus torquatus*). Moderately common resident. Australian Magpie (*Cracticus tibicen dorsalis*). Moderately common about the lower Wooramel.

Grey Currawong (Strepera versicolor plumbea). Scarce resident of far south.

Corvidae

Western Crow (Corvus cecilae). Uncommon resident of eastern zone (mainly about the lower Gascoyne and Wooramel Rivers).

Little Crow (Corvus bennetti). Common resident.

Discussion

Considering its dry climate, physiographic uniformity and scarcity of fresh water and woodlands, the Shark Bay area has a moderately rich avifauna. Some of this diversity is due to its straddling the mulga-eucalypt line, which marks the boundary between acacia-dominated vegetation to the north and eucalyptdominated vegetation to the south. Several southern birds attain their northern limit at or near the mulga-eucalypt line, e.g. Regent Parrot, Yellow Robin, Golden Whistler, Southern Scrub-robin, Blue-breasted Fairy-wren, Striated Pardalote (subspecies *westraliensis*) and Brown-headed Honeyeater. Additionally Mallee Fowl, Chestnut Quail-thrush, Yellow-fronted Honeyeater and Grey Currawong do not cross the line in this area (although they extend north of it further east in the State). Also the Rock Parrot and Southern Emu-wren occur no further north than Shark Bay.

Apart from small stands in the Houtman Abrolhos and near Bunbury, there are no mangroves south of Shark Bay. Consequently seven northern birds wholly or largely dependent on mangroves have their southern limit in the area: Mangrove Heron, Brahminy Kite, White-breasted Whistler, Mangrove Grey Fantail, Dusky Flyeater, Yellow White-eye and White-breasted Woodswallow. Four other northern species extend south to Shark Bay: Brolga, Flock Pigeon, Blue-winged Kookaburra and Horsfield's Bushlark.

Eleven marine birds breed in the area: Wedge-tailed Shearwater, Pied Cormorant, Eastern Reef Heron, Osprey, White-bellied Sea Eagle, Silver Gull, Pacific Gull, Caspian Tern, Crested Tern, Bridled Tern and Fairy Tern. It will be noticed that this list does not include such widespread warm-water birds as the Red-tailed Tropicbird, Common Noddy and Sooty Tern. Yet these species nest in the Houtman Abrolhos, despite the more southerly location of those islands. The explanation lies in the fact that the Abrolhos, but not the landlocked waters of Shark Bay, are warmed by the south-flowing Leeuwin Current. Seabirds shun the highly saline waters of Hamelin Pool, and its beaches and mudflats are almost bereft of shorebirds.

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Three insular birds (all malurids) are endemic to the area: the Bernier and Dorre race of the Variegated Fairy-wren and the Dirk Hartog races of the Whitewinged Fairy-wren and Southern Emu-wren.

Two birds are now locally extinct, namely the Chestnut Teal and Major Mitchell's Cockatoo. The Thick-billed Grasswren, no longer extant on Dirk Hartog Island (or in most parts of its former range in Western Australia), is still plentiful in the far north of Peron Peninsula.

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The mammals of Shark Bay, Western Australia

Alexander Baynes*

Abstract

Seven marine mammal species have been recorded from Shark Bay, and 37 native terrestrial mammal species have been recorded from the islands, peninsulas and mainland around the Bay. The islands are all landbridge islands cut off from the mainland by rising sea level since the last glacial. The numbers of native species recorded from islands is as follows: Dirk Hartog Island: 7 marsupials, 5 rodents and 2 bats; Dorre Island: 4 marsupials, 1 rodent and 1 bat; Bernier Island: 4 marsupials, 3 rodents and 2 bats. Although Shark Bay marks the northern range limit of southwestern mammal species, the distributions of only five of these reach the Bay. The majority of the native land mammal fauna is composed of species that were originally widespread in both the south-west and arid zone. Shark Bay is thus not as biogeographically significant for mammals as it is for plants.

Résumé

Sept espèces de mammifères marins ont été recensées dans la Baie des Chiens Marins, et 37 espèces de mammifères terrestres indigènes ont été recensées sur les iles, les péninsules et le continent autour de la Baie. Toutes les iles sont un chapelet d'iles continentales séparées du continent par la montée du niveau de la mer depuis la dernière glaciation. Les nombres d'espèces indigènes recensés sur les iles sont les suivants: Ile Dirk Hartog: 7 marsupiaux, 5 rongeurs et 2 chauves-souris; Ile Dorre: 4 marsupiaux, 1 rongeur et 1 chauve-souris; Ile Bernier: 4 marsupiaux, 3 rongeurs et 2 chauves-souris. Bien que la Baie des Chiens Marins marque la limite septentrionale des répartitions des mammifères du sud-ouest, seulement cinq d'entre eux atteignent la Baie. La majorité de la faune mammifère terrestre indigène est composée d'espèces qui étaient originellement répandues à la fois dans la zone du sud-ouest et la région aride. La Baie des Chiens Marins n'est donc pas aussi biogéographiquement importante pour les mammifères qu'elle ne l'est pour les plantes.

Introduction

Shark Bay is a significant area from the biogeographic point of view. It has been known since the mid 19th century that it marks the northern limit of the South-west Botanical Province, through the work of von Mueller and Diels, with later refinements by Gardner and Beard (Beard 1980).

The pattern of land mammal distribution has been less clearly understood. Some of the mammals that occur on the islands were amongst the earliest Australian species known to Europeans, following the publications of the scientists and illustrators accompanying the French explorers, but few mammals were collected on the mainland. Shortridge (1910) noted that by the beginning of the 20th century many mammal species had become very rare on the mainland,

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but considered that the faunas of the Shark Bay islands held the key to the original mainland distributions of the species occurring on them, and regarded the island faunas as corresponding with that of the sand plain habitats of south-western Australia.

The situation described by Shortridge for south-western Australia is part of an Australia-wide pattern of devastating local or general extinction which many native mammal species have suffered since the arrival of European man (Ride 1968). For some decades it has no longer been possible to make meaningful studies of mammal zoogeography by collecting from living populations in most of mainland Australia. It is one of the main reasons for the ignorance of mainland mammals in the Shark Bay area. Fortunately this problem can be largely overcome by making use of mammal remains from the surface of deposits in small caves and rock shelters, which are quite common around Shark Bay. A substantial proportion of the data presented in the faunal tables in this paper is derived from such surface deposits. Full details of sources and materials will be published elsewhere (Baynes and Smith in prep.). The majority of such deposits are the remains of pellets cast by Barn Owls (*Tyto alba*); consequently, small mammals tend to have been sampled more completely than medium to large-sized species.

The climate at Shark Bay (Beard 1976) varies from dry warm Mediterranean on the western peninsula (Edel Land) and the western islands, to hot semi-desert Mediterranean on the Peron Peninsula and the mainland on the eastern side. Mean annual rainfall exceeds 300 mm on the west coast and decreases rapidly to less than 200 mm on the eastern side. The limestone cliffs of the west coast probably cause an orographic effect which locally increases the quantity of rainfall from the reliable winter westerly wind systems, and thereby create a rainshadow which exaggerates the gradient to the east, where rainfall is much more variable and includes a substantial summer component. The eastern side of Shark Bay marks the western edge of the arid zone (Slatyer and Perry 1969).

Mammal faunas

The nomenclature used for the mammal species follows that of Walton (1988), except for bats of the genus *Eptesicus* which follows Kitchener, Jones and Caputi (1987), and the Shark Bay Mouse which is discussed in some detail below.

The mammal faunas of Shark Bay are given in Tables 1 and 2. The extents of the original ranges of the terrestrial species in south-western Australia and the arid zone are also indicated, based upon Strahan (1983), Baynes (1984, 1987a) and a substantial body of unpublished data from cave surface mammal remains collected in 1985 and 1986.

Faure Island has not been included as a separate entity, even though one skull of *Bettongia penicillata* (W.A. Museum M9544) has been found there. The Island appears to have been part of Peron Peninsula in the geologically very

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Table 1: Terrestrial mammals recorded from the islands and peninsulas of Shark Bay **BI** = Bernier Island; **DI** = Dorre Island; **DHI** = Dirk Hartog Island; **EL** = Edel Land peninsula; **PP** = Peron Peninsula; **ME** = mainland to the east. \checkmark = recorded and still present: (\checkmark) = recorded but locally extinct; [(\checkmark)] = recorded but totally extinct except for island populations; [[\checkmark]] = recorded but totally extinct; .. = not recorded. X = extensive original range or x = restricted original range in south-west (**SW**) and/or arid zone (**AZ**).

	SW	EL	DHI	DI	BI	PP	ME	AZ
Kultarr								
Antechinomys laniger	x						(~)	х
Mulgara	1000						× /	152
Dasycercus cristicauda	x	(~)	(~)			(~)	(~)	х
Western Quoll								
Dasyurus geoffroii	X	(~)	(~)			(~)	(~)	X
Dibbler								
Parantechinus apicalis	X	(~)	(~)	**				••
Red-tailed Phascogale								
Phascogale calura	X	(~)	100	440		(√)	(√)	X
[Dunnart with no common name]								
Sminthopsis dolichura	X	\checkmark	~		32	~	~	Х
Stripe-faced Dunnart								
Sminthopsis macroura	1.00	14	1.1				(~)	X
Pig-footed Bandicoot								
Chaeropus ecaudatus	x						[[]]	X
Golden Bandicoot								
Isoodon auratus	1						(~)	X
Southern Brown Bandicoot								
Isoodon obesulus	X	(~)	100					
Western Barred Bandicoot								
Perameles bougainville	X	[(√)]	[(~)]	~	~	[(~)]	[(√)]	x
Bilby	1							
Macrotis lagotis	X					34	(~)	X
Burrowing Bettong								
Bettongia lesueur	X		[(√)]	~	\checkmark		[(✔)]	х
Brush-tailed Bettong								
Bettongia penicillata	X		(~)	**		(~)		х
Rufous Hare-wallaby								
Lagorchestes hirsutus	x		••	~	~	(~)		X
Banded Hare-wallaby								
Lagostrophus fasciatus	X	1.00	[(?)]	~	~	[(~)]		••
Common Wallaroo	1000							
Macropus robustus		~				~	~	X
Red Kangaroo								
Macropus rufus		30				**	~	X
Crescent Nailtail Wallaby								
Onychogalea lunata	X	144		÷*.		[[~]]	122	X

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Table 1 (continued)

	SW	EL	DHI	DI	BI	PP	ME	AZ
Black Flying fox								
Pteropus alecto							~	X
Little Red Flying-fox	1.0							
Pteropus scapulatus		~						X
[Eptesicus with no common name]								
Eptesicus finalysoni		~	~		~			х
Lesser Long-eared Bat								
Nyctophilus geoffroyi	X	\checkmark	~	\checkmark	~		144	X
Greater Long-eared Bat								
Nyctophilus timoriensis	X					~		X
White-striped Mastiff-bat								
Nyctinomus australis	X			20		~		X
Lesser Stick-nest Rat								
Leporillus apicalis	x	[[]]				[[~]]	[[~]]	х
Greater Stick-nest Rat								
Leporillus conditor	x	$[(\checkmark)]$	[(~)]			[(~)]	[(✓)]	X
Spinifex Hopping-mouse								
Notomys alexis	x	(~)				\checkmark	~	X
Long-tailed Hopping-mouse	1 A A							
Notomys longicaudatus	x		**	100			[[~]]	Х
Ash-grey Mouse								
Pseudomys albocinereus	X	~	~	~	~	••		5
Desert Mouse								
Pseudomys desertor		(~)		**	(~)	**		X
Shark Bay Mouse/Alice Springs Mouse								
Pseudomys fieldi	x	$[(\checkmark)]$	[(~)]		~	[(~)]	[(~)]	Х
Sandy Inland Mouse								
Pseudomys hermannsburgensis	x	~	~			~	~	X
Western Chestnut Mouse								
Pseudomys nanus	X	(√)	••	900:	••		(~)	X
Heath Rat								
Pseudomys shortridgei	X	(~)	(~)	**				
Pale field-rat								
Rattus tunneyi	x	\checkmark	10		242	(~)	(~)	X
House Mouse								
Mus musculus	X	~	~	2.1	3	~	~	х
Rabbit								
Oryctolagus cuniculus	X	\checkmark			**	~	~	X
Dingo								
Canis familiaris	X				100		~	X
Fox								
Canis (Vulpes) vulpes	X	~	890			~	~	X
Cat								
Felis catus	X	~	~			~	~	X
Total No. native species		21	14	5	7	18	23	

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recent past. *B. penicillata* originally occurred on Peron Peninsula, and it is quite possible that the specimen predates island formation rather than representing an island population. No other native mammal species has been recorded from Faure Island.

Ride and Tyndale-Biscoe (1962) noted that *Mus musculus* was recorded from Bernier Island by Shortridge, although they did not find any at the time of their visit in 1959. The absence of this species from the surface remains in the site on Bernier Island is consistent with a 20th century introduction.

The short list of marine mammals recorded from Shark Bay (Table 2) is probably incomplete. The most commonly observed are the Bottle-nose Dolphins (*Tursiops truncatus*), which have become well known as a result of their interactions with humans at the Monkey Mia beach (Connor and Smolker 1985). The Humpback Whales (*Megaptera novaeangliae*) were exploited intermittently between 1912 and 1963 by shore-based hunting operations from Point Cloates and Carnarvon (Chittleborough 1965). The record of *Orcinus orca* derives from the reports of Anderson and Prince (1985). The Dugong is the subject of ongoing research (Prince *et al.* 1981, and Anderson 1986).

Table 2 Marine mammals recorded in Shark
--

Cetacea

Unidentified Beaked Whale, (Ziphiidae indet.) Pygmy Sperm Whale (Kogia breviceps) Unidentified Pilot Whale (Globicephala sp.) Killer Whale (Orcinus orca) Bottle-nose Dolphin (Tursiops truncatus) Humpback Whale (Megaptera novaeangliae)

Sirenia

Dugong (Dugong dugon)

Systematics of the Shark Bay Mouse

For much of this century the Shark Bay Mouse was thought to be restricted to Shark Bay. However, recognition of its remains in cave deposits all along the west coast south of Shark Bay (Archer and Baynes 1973, Baynes 1982), not only showed a much wider original distribution but also raised questions on its specific status.

In 1910, Oldfield Thomas described *Pseudomys praeconis* on the basis of a specimen from Peron Peninsula, and also referred to the same species a skull collected on Bernier Island by G.C. Shortridge in 1906 (Thomas 1910). Shortridge (1936) himself listed the skull under "*Mus gouldi*", although he seems to have been a little confused because he mentioned "...original type-specimen (from the Peron Peninsula, Shark's Bay)...". (The lectotype of *Pseudomys gouldii* originated in New South Wales.) This suggests that Oldfield Thomas originally

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identified the Shark Bay specimens as *P. gouldii*, and that in naming *P. praeconis* as a separate species Thomas was splitting his former concept of *P. gouldii*. Mahoney (1969) identified as *P. gouldii* some mice collected in 1843 from the Victoria Plains near New Norcia. Specimens from this area which I examined in the British Museum (Natural History) showed that these fell within my definition of *P. praeconis*. Pursuing the investigation led me to suggest (Baynes 1980) that *Pseudomys fieldi* (Waite, 1896), long known from only a single specimen from near Alice Springs, in the Northern Territory, was closely related to or conspecific with *P. praeconis*, and that both were related to *P. gouldii* from New South Wales.

Later work extended the original distribution of *P. praeconis* inland into the arid zone (Baynes 1984). Material collected in 1985 and 1986 has now shown that the original distribution of *P. praeconis* extended across the upper Gascoyne, northern goldfields and Gibson Desert (unpublished data). With the recent discovery of remains of *P. fieldi* at Uluru (Baynes 1987b), it seems very likely that "*P. praeconis*" and *P. fieldi* were continuous and were one and the same species. Specimens show no significant morphological differences between east and west (unpublished observations), or between Alice Springs and the Nullarbor (Baynes 1987a). For these reasons the scientific name used here for the Shark Bay Mouse is *Pseudomys fieldi*.

Discussion

Before discussing patterns in the distribution of the species it is necessary to consider how well the recorded assemblages represent the original faunas.

Examination of Table 1 shows that a number of species are not recorded from the original faunas of areas where they would be expected to have occurred. Thus, Lagostrophus fasiatus and Bettongia lesueur have not yet been recorded from Edel Land, even though both were originally widespread in south-western Australia and were on all or most of the major islands, and *Lagostrophus* is recorded from Peron Peninsula. Both species were probably members of the original fauna of Edel Land: the current lack of records reflecting the fact that the deposits which have so far been found on this peninsula are mainly owl pellet accumulations. The same may apply to Lagorchestes hirsutus, but it was less widespread in the south-west and may represent an arid zone element at Shark Bay. Sminthopsis dolichura, Lagorchestes hirsutus, Onychogalea lunata and *Pseudomys desertor* have not yet been recorded from surface deposits on the eastern, mainland, side of Shark Bay. There is a modern specimen of S. dolichura from the area, and the species occurred in the arid zone nearby (Kitchener et al. 1984). The two wallables were widespread in the arid zone. In the case of L. hirsutus and Pseudomys desertor absence may be true and reflect lack of suitable habitat.

The species richness of the recorded bat fauna is relatively low. This probably reflects the absence of trees in the region, but may be a partly false picture

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resulting from the lack of biological survey in the area. The *Pteropus scapulatus* record probably represents a vagrant individual. The colony of *Pteropus alecto* around Carnarvon is probably dependent upon fruit from the plantations and street trees, and so may be regarded as commensal.

These considerations suggest that there are species still to be added to the original faunas of all areas except the smaller islands. Knowledge of the faunas appears sufficient to permit the general patterns to be elucidated, but the data are probably still not robust enough to investigate parameters as subtle as possible peninsula effects.

Island and peninsula effects

As expected, the figures of original total native mammal species (Table 1) show that the islands have smaller faunas than the peninsulas and eastern mainland. The original figures for the islands are close to the theoretical saturation figures for islands of those sizes (Kitchener *et al.* 1980). The faunas of the peninsulas would also be expected to be smaller than that of the adjacent mainland (the peninsula effect) but this is not clear from the figures.

Which macropods originally occurred on Dirk Hartog Island?

All authors of papers on the mammals of Dirk Hartog Island in the 20th century have assumed that Lagostrophus fasciatus occurred on the island, and some have also included *Lagorchestes hirsutus* in the fauna (see Burbidge and George 1978). I can find no evidence that *Lagorchestes hirsutus* originally occurred on the Island and I consider that there are good grounds for doubting that *Lagostrophus* fasciatus originally occurred there either. Péron, who with Lesueur named L. fasicatus, stated that it occurred in large numbers on Bernier, Dorre and Dirk Hartog Islands (Ride and Tyndale-Biscoe 1962); yet the party from the Geographe, in which Péron sailed, only visited Bernier and Dorre Islands (see Horner 1987). During Baudin's expedition it was a party from the *Naturaliste*, under the command of Hamelin, that visited Dirk Hartog Island. The Naturaliste zoologist Levillain was less than enthusiastic about Dirk Hartog Island and appears to have made only a poor collection of natural history specimens (Horner 1987). The source locality of the original material of L. fasciatus was Bernier Island (Calaby and Richardson 1988). During Freycinet's second visit to Shark Bay, in the Uranie, Quoy and Gaimard visited Dirk Hartog Island, and found skulls of the animal they named Hypsiprymnus (= Bettongia) lesueur along with debris of birds, reptiles and fish beneath an Osprey's nest (see Ride and Tyndale-Biscoe 1962). A bird of prey capable of taking a B. lesueur would be able to catch young L. fasciatus or L. hirsutus fresh out of the pouch. If either had been present on the Island it would be surprising if their remains were not included in the Osprey midden, and if so were not collected and remarked upon by Quoy and Gaimard. F.M. Rayner also collected skulls of B. lesueur on Dirk Hartog Island, during the Herald expedition in 1858 (see Thomas 1888, p.114), but Mammals

apparently found skulls of neither *L. fasciatus* nor *L. hirsutus*. No remains of either species have been found in cave deposits or sand dune blowouts on Dirk Hartog Island, which have yielded several more *B. lesueur* specimens and remains of 10 other species (see Burbidge and George 1978).

It may have been a little premature to attempt to re-introduce, or more probably introduce, *Lagostrophus fasciatus* to Dirk Hartog Island (see Burbidge and George 1978). It is to be hoped that skeletal remains from the introduced animals will not confuse future attempts to establish whether *L. fasciatus* was originally present on the Island.

Patterns of mammal distribution

As Table 3 shows, at least half of the non-volant native land mammals recorded from the Shark Bay area are wider-ranging species for which the Bay does not represent a geographic limit. For several arid zone species Shark Bay is a point on the western limit of their ranges. For only five south-western species is it their northern range limit.

 Table 3: Numbers of non-volant native terrestrial mammal species following various biogeographic patterns across Shark Bay: SW to SB = south-western species for which Shark Bay marks the northern range limit; WIDE = species widespread in both the south-west and arid zone; AZ to SB = arid zone species for which Shark Bay marks the south-west limit.

	SW to SR	WIDE	A7 to SR
Number of species	5	15	8
Percent	17.9	53.5	28.6

Species pairs

Three or four out of these five south-western species at their northern limits are members of pairs of ecological vicar species in which both members are recorded in the original mammal fauna of Shark Bay (Table 4). In most cases the members of the pairs are closely related and have very similar morphology, particularly in size and form of teeth. *Lagorchestes* is included as the arid zone vicar of *Lagostrophus* with less certainty (indicated by parantheses) because the two species are less closely related and are rather less similar morphologically than the members of the other pairs.

 Table 4: The south-western mammal species which reach their northern range limit at Shark Bay, and the ecological vicar species which replaces each across Shark Bay and in the arid zone.

South-western	Arid zone vicars	Sympatric?
Parantechinus apicalis	77	
Isoodon obesulus	Isoodon auratus	No
Lagostrophus fasciatus	(Lagorchestes hirsutus)	Yes
Pseudomys albocinereus	P. hermannsburgensis	Yes
Pseudomys shortridgei	Pseudomys desertor	Yes

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The direct, vicarious, replacement of *Pseudomys shortridgei* in the arid zone is probably *P. desertor*. In south-western Australia, *Pseudomys shortridgei* forms a mutually exclusive pair with *P. nanus*. *P. shortridgei* is restricted to the heaths of the Swan Coastal Plain and southern Yilgarn Block, and *P. nanus* is restricted to different habitats on the more northerly Yilgarn Block. This pattern continues into the Shark Bay area. On Edel Land, and Dirk Hartog Island its geomorphological continuation, *P. shortridgei* appears to have been restricted to the western coastal edge and absent from the eastern coasts, where, at least at the southern limit of the peninsula, it was replaced by *P. nanus* (Baynes and Smith in prep.). *P. nanus* is also a member of the mainland fauna, but has not been recorded from Peron Peninsula.

It would be very interesting to investigate the fine details of the sympatry of the members of species pairs which are recorded from the same areas. Ecological separation by primary habitat would be expected. For example, *Pseudomys albocinereus* and *P. hermannsburgensis* are the small mice of the sand substrate habitats of respectively the south-west and the arid zone. *P. albocinereus* is adapted to the reliable winter rainfall of the south-west, whereas *P. hermannsburgensis* is adapted to the very variable but occasionally heavy rain experienced in the arid zone. Their distributions intermingle on the western side of Shark Bay. It seems likely that *P. hermannsburgensis* would be found to occur on the red sand dunes, whereas *P. albocinereus* is probably restricted to the white sands bearing south-western plant species. Both species still occur on Dirk Hartog Island where they are stated by Burbidge and George (1978) to occur in the same habitat.

Zoogeography

Shortridge (1910, p. 819) made three crucial points about the faunas of the islands off the coasts of Western Australia. Following a discussion of the extent and causes of post-European extinction of much of the native mammal fauna, he stated that "... the abundance of native mammals on the small islands off the coast, ... is very marked, and forms a key to the original distribution of many of them." "Insular forms of South-Western mammals extend as far north as the Shark Bay Islands in the West;" and "The mammals on the islands off Shark Bay correspond with the originally widely spread "sand-plain fauna" of the South-West."

Ride and Tyndale-Biscoe (1962) reviewed the then known mainland records of the species recorded from Bernier and Dorre Islands and concluded that: "The distributions of the various species thus indicate that the island fauna is not a South-western fauna which is, as a result of being "stranded" on an island, out of place in relation to its latitudinal position along the Western Australian coast."

The new information on the mammal faunas of Shark Bay presented in this paper supports Shortridge's generalizations. The idea of a "stranded" fauna Mammals

appears to be reading a meaning into Shortridge's words which is not justified. All seven of the mammal species recorded from Bernier and Dorre Islands were indeed members of the original faunas of the Shark Bay peninsulas and/or mainland. Four of these, Perameles bougainville, Lagorchestes hirsutus, Lagostrophus fasciatus and Pseudomys albocinereus originally occurred in the sand plains of south-western Australia; and four (the remaining three plus Lagorchestes hirsutus again) were originally widespread in the arid zone, at least two in sandy habitats. One of the arid zone group (Pseudomys desertor) was unknown to Shortridge. The exact compositions of the island faunas are probably best explained in terms of the theory of island biogeography (Kitchener et al. 1980). However, all three major islands are principally composed of sand substrate habitats and so it is not surprising that their original faunas are largely composed of sandy habitat species of both south-western and arid zone affinities. Four of the five south-western species which reach their northern limits at Shark Bay (Table 4), are recorded from one or more of the islands. The four constitute all of the sand plain species in that group.

Conclusions

The change from south-western to arid zone mammal fauna across Shark Bay is not as dramatic as the floristic change between the South-west and Eremean Botanical Provinces. Although the Bay marks the northern limit of south-western elements in the mammal fauna, not many south-western species' original range limits reached as far north along the coast as Shark Bay.

For mammals, Shark Bay is thus just one point on the South-west Province/ arid zone boundary, but it is an important one for the understanding of mammal zoogcography because the original fauna is relatively well known, and there is a sharp climatic gradient across the Bay. Bernier and Dorre Islands preserve their original faunas, and the geology of the region is suitable for the formation of many small coastal caves which contain remains of the original mammal fauna. In this respect it is comparable with the eastern end of the South-west Botanic Province, where the caves of the southern Nullarbor and adjacent regions provide a good record of the original occurrence of south-western elements at that limit of the Province (Baynes 1987a). As can be seen in Table 5, all the south-western mammals which originally reached their northern limits at Shark Bay, reached their eastern limit in western Australia at the Bight. The Bight fauna includes a further four species. Tarsipes rostratus has not been detected at Shark Bay, but might have originally occurred there also: it is more difficult to detect in cave surface remains than the other species because its tooth-bearing structures are vanishingly small and fragile, and its identification depends upon postcranial elements. The other three additional species reaching their limits at the Bight generally had a more southerly distribution within the south-west (none has been recorded from north of 29°S latitude). The original ranges of

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most south-western mammals appear to have been limited by rainfall, but at least one of the three (*Pseudomys occidentalis*) appears to have been limited by temperature — probably summer maxima.

Because both Shark Bay and the western Bight lie across the boundary, and there is an intermingling of south-western and arid zone elements, the levels of mammal species richness, at an assemblage level, are exceptionally high in both areas (Morton and Baynes 1985, Baynes 1987a).

The original mammal faunas of the Shark Bay islands relate directly to those of the peninsulas and mainland, and are not "stranded" examples of a fauna from higher latitudes.

 Table 5: The south-western mammal species which reach the northern limit of the South-west

 Botanic Province at Shark Bay, compared with those that reach the eastern limit of the

 Province on the Great Australian Bight.

Shark Bay	Bight	
Parantechinus apicalis	Parantechinus apicalis	
Isoodon obesulus	Isoodon obesulus	
	Tarsipes rostratus	
	Potorous platyops	
Lagostrophus fasciatus	Lagostrophus fasciatus	
Pseudomys albocinereus	Pseudomys albocinereus	
	Pseudomys occidentalis	
Pseudomys shortridgei	Pseudomys shortridgei	
, .	Rattus fuscipes	

Future work

As the discussions above show, more data are badly needed in several categories: particularly the original mammal faunas of Edel Land and the mainland to the east, which are inadequately known; the original mammal fauna of the mainland to the south, which is not known at all; and on the vexed question of the original occurrence of *Lagostrophus fasciatus* on Dirk Hartog Island.

Skeletal remains from the surfaces of cave deposits represent the only possible source of many of the data required. Most of such material is accumulated by predators. Owls, particularly the Barn Owl *Tyto alba*, produce large accumulations of remains which can provide a rich source of information on most or all of the small mammals which occur in an area. Remains of medium to largesized mammals are accumulated mainly by mammalian predators, whose lairs tend to contain remains of far fewer individuals. The discovery of one or two large owl pellet accumulations in critical localities will provide many of the missing data on small mammals, but the question about original presence of species of wallabies in various faunas will require substantially more timeconsuming searches. Especially large samples are needed convincingly to demonstrate absence from a fauna (see Baynes 1987a). Any *Lagostrophus fasciatus* Mammals

remains found on Dirk Hartog Island will need to be radiocarbon dated to distinguish original from introduced material.

A survey of the present day mammal fauna of Shark Bay is clearly needed; and indeed a survey of the Carnarvon Basin is high on the list of priorities of the biological survey group at the Western Australian Wildlife Research Centre (N.L. McKenzie pers. comm.).

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