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Changes in artefact assemblages during the last 8 000 years at Walyunga, Western Australia

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Abstract

Excavations at Walyunga, a large open site near Perth, Western Australia, produced an artefact sequence and datable charcoal, indicating recurrent occupation of the site through most of the Holocene period. Marked changes between assemblages from lower and upper levels occurred about 4 600 years ago. "Backed blade" and "flat adze" tools were found only in the upper levels. The presence of bryozoan chert artefacts in the lower levels only, supports a recent hypothesis by Glover (1975), that the chert sources lay exposed off the west coast until submerged by rising sea levels. The sequence and dates now indicate that sources are close to the present sea level.

Introduction

The excavations at Walyunga were designed to produce "backed" tools from stratified assemblages in a datable deposit. Tools of this type (backed blades and geometric microliths) were recovered from dated contexts in three earlier excavations in Western Australia, at Puntutjarpa in the Western Desert (Gould 1968), at Frieze Cave 90 km east of Perth (Hallam 1972) and at Northcliffe near the south coast (Dortch 1975). Such tools occurred in small quantities in surface samples from about 20% of artefact sites recorded near Perth by Hallam (1972).

Walyunga was selected for detailed investigation since it is one of the few large sites near Perth having numerous artefacts, including backed tools, exposed over a wide area (Butler 1958, Akerman 1969, Turner 1969). The site lies within Walyunga National Park near the west bank of the Swan River valley in the Darling Range about 38 km northeast of Perth. Artefacts occur over an area about 200 x 200 m on the eroding surface of a sand dune resting on the lower slopes of a granite hill. On the western side of the dune an old fence is partly covered by sand. Since the fence is European the sand must have accumulated there to a depth of more than a metre in less than 150 years. Contours of the dune (Fig. 1) indicated movement of sand from east to west, and it seemed possible that a similar but slower movement may have occurred in the prehistoric period. This was supported by excavations which revealed a deep stratified deposit containing charcoal and numerous artefacts. Backed tools were confined to the upper levels, and several other changes occurred through the sequence.

Excavations

With student assistance I excavated two trenches (C18 and B6), each 1 m², near the crest of the dune (Fig. 1). The trenches were 25 m apart and contained similar artefact sequences. Trench B6 reached 140 cm below surface yielding 690 artefacts spread through all levels.

The main trench (C18) was excavated in spits of 5 cm depth or less, to a level 190 cm below surface, yielding artefacts in every spit except the last two (180-190 cm). Two holes drilled below 190 cm reached hard base (probably granite) at 5.1 m below surface. Sand from the bores contained no artefacts nor charcoal. The trench yielded 2 874 flaked artefacts, 302 non-flaked items and 1 071 g lateritic gravel (Table 1).

Within several spits artefacts were concentrated in narrow bands about 2 cm thick, possibly indicating conditions of temporary standstill or erosion. These were not accompanied by distinctive soil changes except near 16 cm, where the upper loose orange sand changed abruptly to dark brown firm soil. This may be the buried humic zone of an old soil covered by sand wind blown from deflating areas of the dune. Numerous stone artefacts and iron fragments lay at the interface, indicating that the dune crest was once subjected to erosion, like other parts of the site at present. This erosion, and the rapid sand build-up at the fence, may be related to disturbance of local environment by European activities.

Artefacts occurred above 16 cm, either as a result of European activities or of Aboriginal usage of the site after European occupation.

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Table 1

Analysis of excavated material from trench C18, Walyunga

Depth (cm)	Primary flake						Secondarily worked										Non-flaked								Distribution of some types of material			Radiocarbon dates bp (Libby years)
	Spit No.	Chip 0–1 cm	Chip 1–1½ cm	Flake	Blade	Flaked piece	Utilized non-formal	Trimming flake	Steep scraper	Scraper	Adze misc.	Adze flat	Backed tool	Fabricator	Other formal tools	Total flaked artefacts	Fragment & nodule	Lump	Abraded lump	Ochre granule	Hammer	Pebble	Iron and glass	Lateritic gravel (grams)	Bryozoan chert	Silcrete	Mylonite	
0– 8	1	3	3	6		1	3	1	..					1		18	1		2	1			4				4	
8– 15	2	32	17	8		2	13	3	1	4	2	1		4		87	1						2	10			11	
15– 20	3	407	103	35	2	3	25	2		9	2	3	1	9	2	602	8	1		11			26	215	1		22	
20– 25	4	161	47	26		1	5	2	1	4	1		1	2	1	253	3	1		7			3	30			21	**1 330 + 100 bp SUA 632
25– 27	5	7	6	5		1	2			2		1				24	1		..	1				5			7	
27– 30	6	39	15	6		1	2						1			64	2			3				19			5	
30– 35	7	20	9	6	1	...		1		2	1		..			40	3			3				14			3	
35– 37	8	31	8	3		1			1	1	..	1	1			47	2	1		3	1			17			3	
37– 40	9	20	4	5		1	1	1				4				36	1			3		1		34			8	
40– 45	10	11	6	3						1	1	...	1			23				6				8			3	
45– 50	11	28	6	4			1		1				1			41	1			3				22			8	
50– 55	12	23	1			1	1				1					27				4				21			4	
55– 60	13	45	1	2	.	..	1									49				2				25			5	
60– 65	14	25	5	3			4						2			39			1	2				19			6	**3 220 + 100 bp SUA 508
65– 70	15	31		4	1			1						....		37	1			1				22			2	
70– 75	16	42	1	7			1			1	1	1				54	2		1	18				31			3	
75– 80	17	18	10	13	.	1	2			1						45	1			10				24	3	1		**4 560 + 150 bp SUA 633
80– 85	18	30	11	3			4		3	1				1		53	1			9				35	1			
85– 90	19	29	7	4			4	1		1				1		47	4			7				27	4	2		**6 135 + 160 bp SUA 509
90– 95	20	35	11	9		1	9		1	2				1		69	1			5				52		1	4	
95–100	21	45	7	6		1	4							.	1	64	3	2		3		1		42	4		2	
100–105	22	34	7	3		1	4	1		1		.	.	...		51	2			1				40	1		5	
105–110	23	34	6	5		1	2		2	2						52		1	1	6				31	2	1		
110–115	24	27	6	5	1		2	1	1	1						44	3			2				35			1	
115–120	25	35	9	6			3	1		1						55	2			8				29	2	1		
120–125	26	36	6	6			3	1		1						53	2			5				21	3		1	
125–130	27	86	10	13		3	9	1								122	2							45	4	4		
130–135	28	77	9	4		1	3	1						1		96	5	1		12				32	2	2	1	
135–140	29	64	10	8			8			1						91	1			11				26	4	1	2	
140–145	30	56	11	13		1	4	1		1						87	2			4				18	3	1	2	
145–150	31	79	14	2		4	5	2	1	2					1	110	5			3				20	4		2	
150–155	32	69	7	6	1	2	5			1					1	92	3	2						12	2	2		**8 000 + 260 bp SUA 510
155–160	33	60	18	7		1	4	1				..	....	1		92	1		...	6				20	1	3	3	
160–165	34	73	9	8		4	2			1						97		1	1	2		3		17		3		
165–170	35	62	7	9		2	4			..				....	..	84	1			14	....	1		13	3	3	1	
170–175	36	15		1		...	3					...		.		19				3				16	1		..	
175–180	37	10	..	..						....	....					10								19				
180–185	38	0	...											...		0				..		..	.	4				
185–190	39	0														0						....		1				
Totals		1 899	407	254	6	35	143	22	12	41	9	11	8	21	6	2 874	65	10	6	179	1	6	35	1 071	45	25	139	

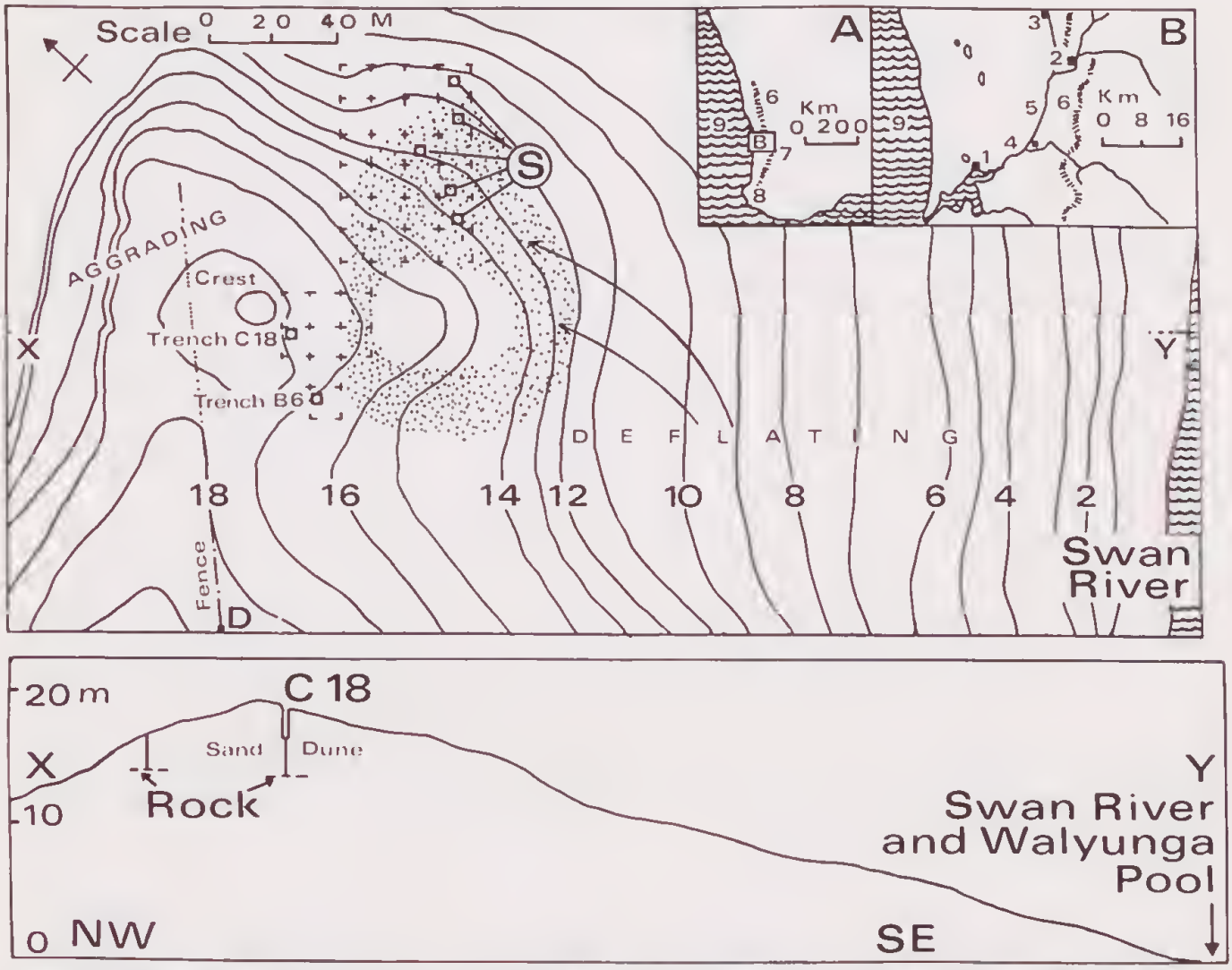

Figure 1.—Contour map and profile of Walyunga site, Walyunga National Park, Western Australia. Map reference SH50-14 4064 0743. Contour lines at 1m intervals above river level. Stippling indicates the area of high surface density of artefacts. Crosses indicate the area set out with 10x10 m squares for sampling. S — Positions of surface samples. C18 — Main excavated trench. B6 — Second excavated trench. D — Site datum. Dune profile; vertical scale = 5x horizontal scale. Inset A — South West of Western Australia. Inset B — Perth — Walyunga district. Key to numerals on inset maps A and B: 1 Perth, 2 Walyunga, 3 Bullsbrook, 4 Guildford, 5 Swan River, 6 Darling Range, 7 Frieze Cave, 8 Devil's Lair, 9 Indian Ocean.

The latter is indicated by the presence of worked glass artefacts at other parts of the site (Akerman 1969). The material may represent a post-contact phase of the sequence.

Five samples of charcoal from trench C18 were analysed by R. Gillespie and R. B. Temple at Sydney University Radiocarbon Laboratory. I use their values based on the Libby half-life of 5 568 y, in this paper (Table 1, Fig. 2). These dates indicate occupation starting early in the Holocene and continuing at intervals until European settlement.

Petrology

The commonest material was quartz, used for more than 80% of artefacts in all levels. Small quantities of quartzite, dolerite, granite and ochre occurred through the deposit, more frequently in lower than upper levels. Lateritic gravel (total 1 071 g) was retained on the 3 mm screen, in quantities approximately proportional to the number of artefacts in each spit except for higher values in spits 16 and 18.

Bryozoan chert

Artefacts made of fossiliferous chert comprised about 3% of artefacts throughout the lower levels up to the level 75 to 80 cm below surface (spit 17, dated 4 560 ± 150 bp) (Fig. 2). Above 75 cm only one example occurred, within 16 cm of the surface, probably carried from an eroded part of the site.

Glover (1975) found artefacts of this chert, containing distinctive bryozoan fossils of Middle-Late Eocene age, at many prehistoric sites on the Swan Coastal Plain, yet none of the chert nor any rock of that age is known to outcrop at the present land surface in this area. Strata of that age are known from only one location

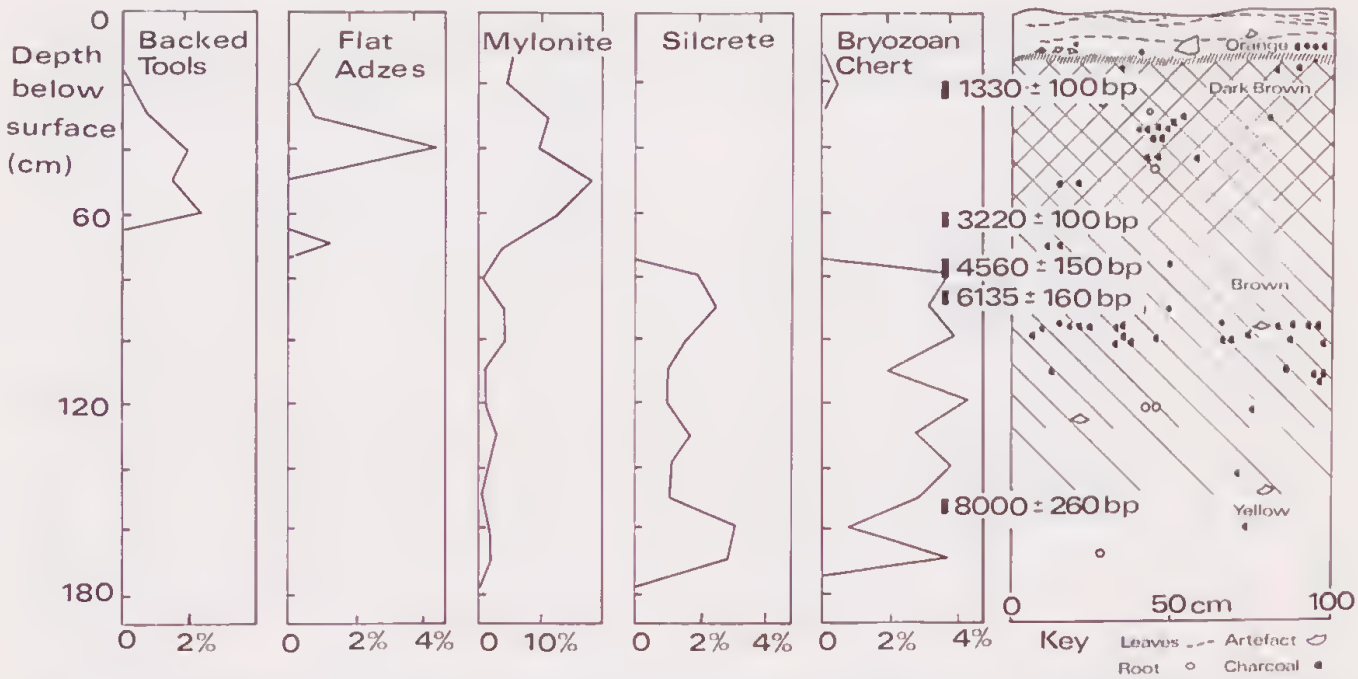

Figure 2. — Trench section, and changes of technology, trench C18 at Walyunga. The diagram shows the north-west wall in cross section with soil colour changes, the unconformity at 16 cm below surface, and positions of levels dated by charcoal samples listed in Table 1. Graphs show changes with time in percentages of some tool types and materials, calculated out of flaked items in each 10 cm interval.

in the Perth Basin, in an offshore well drilled about 60 km west of Mandurah (Glover 1975, p. 83). Glover pointed out " . . . that the sites with the highest proportion of these chert artefacts are invariably near the western coast" Chert artefacts of late Pleistocene age were excavated at Devil's Lair (Dortch and Merrilees 1973), and at Minim Cove near Perth (Clarke and Dortch 1977). Since sea level then was much lower than at present, Glover (1975, p. 84) proposed that the chert ". . . probably came from an off-shore source in the west . . . there is a probable pattern of west-east transportation . . . of fossiliferous cryptocrystalline chert from sites now submerged". If so then the source was cut off by rising sea level at some time before the present level was attained.

Thom and Chappell (1975) consider that the sea first reached its present level around the Australian coast about 6 000 years ago. Churchill (1959) suggested the date was around 5 000 years ago. The latest bryozoan chert in spit 17 of the Walyunga trench C18 may be contemporary with the charcoal sample (SUA 633) from that level, but it could have been deposited earlier if there was intervening erosion. This is not easily resolved since the change of depth with time is small at this level in the trench (Fig. 2). The evidence from this trench indicates that the chert continued to be available until about 4 560 ± 150 bp. In the second trench (B6) situated 25 m south of the main trench, charcoal from the level at 65-70 cm containing the latest bryozoan chert was dated 4 700 ± 215 bp (SUA 644). The combination of this with SUA 633 gives a satisfactorily tight bracket for cessation of chert use.

The presence of bryozoan chert artefacts through the lower levels of the Walyunga excavations, their sudden disappearance, and absence from the upper levels (with one exception mentioned above) support Glover's hypothesis that the source was cut off by rising sea level. The date indicated for disappearance of chert from the Walyunga sequence is close to but a little later than the date suggested at which the sea first reached its present level. The exact dates of these events and of changes in the local coastline are not yet known. The chert source may lie near present sea level, possibly quite close to the present coastline, or it may be buried under coastal deposits. The small quantities of this chert at Walyunga reflect the distance of the site—30 km—from the coast.

Silcrete

Silcrete artefacts occurred almost in parallel with bryozoan chert in the Walyunga sequence, indicating they might be closely related in usage. Possibly their sources were close together, submerged near the coast or under coastal deposits, or they may have been linked by trade or other cultural interaction that ceased when the chert disappeared. Silcrete artefacts occur in small quantities at some surface sites around Perth, but a source for the Perth and Walyunga material has not been established.

Mylonite

About 4% of artefacts in the Walyunga excavation were made of greenish "chert" containing thin veins of quartz. Glover (1976)

identified this material as mylonite and located outcrops on a granite hill adjacent to the Walyunga site.

Although a possible source is so close it occurred only sparsely in the lower levels of the excavation (1.7% of artefacts), but in significantly higher quantities (average 8%) in levels above 75 cm. A similar situation existed in the second trench. Possibly mylonite was a partial substitute after bryozoan chert and silcrete dropped out of the sequence, although these materials differ in petrology and to some extent in flaking properties (Glover 1975, 1976).

The change in usage of materials may be related to development of different tool types, depending on specific physical properties of the stone. Thus mylonite was used for 9 out of the 11 flat adzes and for only 3 other tools, all in the upper levels of the trench, where most of the 75 formal tools were made of quartz. Similar proportions exist in surface samples in which mylonite is 10% of all artefacts and 80% of flat adzes. This indicates preferential selection of mylonite for flat adze tools at this site.

Relationships involving trade between groups of people in the district (cf. Berndt and Berndt 1968, p. 111) may have been affected by the change in material usage, since in the early phase bryozoan chert was probably transported from west to east across the Swan Coastal Plain (Glover 1975, p. 84) while mylonite would have to be transported in the opposite direction to sites such as North Lake and Mongers Lake. Since the mylonite source was not covered by rising seas the material became more important in the second half of the Holocene, and may perhaps serve to indicate an age range of some assemblages.

Typology

Formal tool types—general.

Of the 2 874 flaked artefacts, 273 were secondarily worked or utilized, and of these 108 were recognizable formal tools. The proportions of formal tools were significantly higher in the upper than in the lower levels of the trench, 5.2% above 75 cm, as against 2.4% below 75 cm. The main differences between assemblages of upper and lower levels are summarised in Table 3. Artefacts were classified using current Australian typology (e.g. Mulvaney 1975).

Scrapers were fairly evenly distributed through the trench, indicating continuity of usage, but steep edge scrapers, all less than 4.3 cm long were less common in upper levels (larger items occur on the surface of the site).

Adze flakes occurred only above 75 cm. All are small non-tula forms (see "flat adzes" below).

Fabricators or "scalar cores" occur in significant numbers only near the top of the trench, but are present in small quantities in lower levels. This accords with early dates for fabricators from Green Gully (Wright 1970), Kow Swamp (Wright 1975), and Devil's Lair (Dortch

Table 2

A. Parameters of 'fabricators' excavated at Walyunga (N = 21)

	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Length :width	Thickness :width
Mean	2·04	19·7	13·1	7·6	1·58	0·61
Standard deviation	1·06	4·89	3·69	1·75	0·53	0·18
Minimum	0·34	11·0	8·8	1·75	0·97	0·31
Maximum	4·72	28·4	19·2	11·0	2·93	0·90
Coefficient of variation	53%	25%	28%	23%	33%	30%

B. Parameters of flat adzes excavated at Walyunga (N = 11)

	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Length :width	Thickness :width	Edge angle
Mean	0·86	18·4	9·9	4·3	2·2	0·47	56°
Standard deviation	0·58	3·4	3·1	0·94	1·1	0·16	13°
Minimum	0·32	13·3	4·4	2·7	1·2	0·3	31°
Maximum	2·21	23·5	16·0	5·9	4·8	0·9	86°
Coefficient of variation	67%	19%	32%	22%	50%	35%	20%

C. Parameters of 'backed' tools excavated at Walyunga (N = 13) (Includes 5 items from trench B6)

	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Length :width	Thickness :width
Mean	0·337	13·2	7·6	2·9	1·76	0·38
Standard deviation	0·397	4·1	2·0	0·88	0·37	0·077
Minimum	0·05	7·9	4·0	1·5	1·23	0·27
Maximum	1·55	24·6	12·0	5·1	2·71	0·50
Coefficient of variation	116%	29%	26%	30%	21%	20%

Table 3

Summary of differences between assemblages of upper and lower levels. Percentages expressed out of all flaked artefacts in each layer.

Levels	Trench C 18		Trench B 6	
	Below 75 cm	Above 75 cm	Below 60 cm	Above 60 cm
Percentages of materials—				
Bryozoan chert	3%	0·1%	5·9%	0·3%
Silcrete	1·5%	nil	0·4%	nil
Mylonite	1·8%	8·5%	2·9%	9·4%
Percentages of secondarily worked/utilized items	8·9%	10·05%	8·1%	12·5%
Percentages of formal tools	2·4%	5·0%	3·6%	5·1%
Range of types of formal tools	4 types	7 types	3 types	6 types
Percentages of some formal tool types—				
Steep scraper	0·56%	0·28%	0·4%	0·3%
Fabricator	0·35%	1·1%	1·1%	0·6%
Adze, miscellaneous	nil	0·63%	nil	0·6%
Flat adze	nil	0·76%	nil	0·3%
Backed tool	nil	0·56%	nil	2·0%
Flake dimensions (except chips)—				
Mean width	17 mm	15 mm	Insufficient data	
Mean thickness	6 mm	5 mm	Insufficient data	
Total flaked artefacts	1 441	1 433	272	351

and Merrilees 1973); and more numerous occurrences later (Wright 1970, p. 90). Fabricator dimensions are listed in Table 2, where length is taken as the maximum distance between bipolar altered edges, and width as the maximum measurement normal to length.

One item from spit 4, a slab of quartz 7.6 cm long, trimmed bifacially at one end to a sharp sinuous edge is perhaps a chopping tool or Kodja. No edge-ground items were excavated although a few occurred in surface collections (Butler 1958, Ride 1958, Akerman 1969). Four large broken pebbles (one used as an anvil) were found near the bottom of the trench. One small oval pebble with use marks at each end was probably a hammer-stone. Six pieces from various levels had one face uneven but partly smoothed, evidently rubbed on some other object. Four of these were small slabs of granite 6 to 10 cm long and about 2 cm thick.

Flat adzes

This tool type occurred in levels above 75 cm in the trench at Walyunga. Akerman (1969, p. 15) illustrated examples from a surface collection at Walyunga and described them as concave or biconcave adzes or slugs.

"Flat adze" is the term suggested by Gould and Quilter (1972) for a type of small implement collected by Gould at two sites about 450 km northeast of Perth, and from surface collections from South Bullsbrook and Walyunga, held at the Western Australian Museum. Three qualitative attributes apply to flat adzes: (1) "Steep unifacial retouch along the working edge (or edges)"; (2) "Small, terminated flakes appearing along the bulbar face of the adze flake, directly behind the working edge", (Gould and Quilter 1972, p. 3); (3) "Successive use and resharpenings, however, caused the working edges of these tools to become deeply concave" (p.5). The tools were "extremely small" (p. 11). Mean thickness was 5.4 mm, and mean edge angle 46.5°. The items in Gould and Quilter's scale drawings have maximum dimensions averaging 27 mm. Their term "width" is ambiguous.

A set of 51 flat adzes from surface collections at Walyunga by Butler (1958) and others, now held at the Western Australian Museum, had mean dimensions similar to Gould and Quilter's except edge angle (65° in the Walyunga set). Mean length was 26 mm, mean width 12.8 mm and mean thickness 5.6 mm. The excavated specimens are smaller (Table 2), perhaps due to a more systematic recovery process. These items were worked on one or sometimes both lateral margins (Fig. 3). Some of the original bulb of percussion usually remained, showing that it was small, while the bulb:platform angle was less than 110°. The last two attributes are similar to those of backed tools from this district and quite unlike those of small or large tula adzes. In measuring these tools length was taken as the greatest dimension of the tool. This was in most cases in the direction of the blow of percussion that produced the flake, and parallel to the worked edge(s). Width was the maximum measurement at right angles to length in the plane of the bulbar face. Thickness was the maximum measurement normal to the bulbar face.

The age of flat adzes was previously unknown. In the Walyunga sequence they appeared first between 4 560 and 3 220 bp, then persisted throughout upper levels with backed tools. The flat adze thus belongs within Mulvaney's "Inventive Phase" as suggested by Gould and Quilter (1972, p. 11).

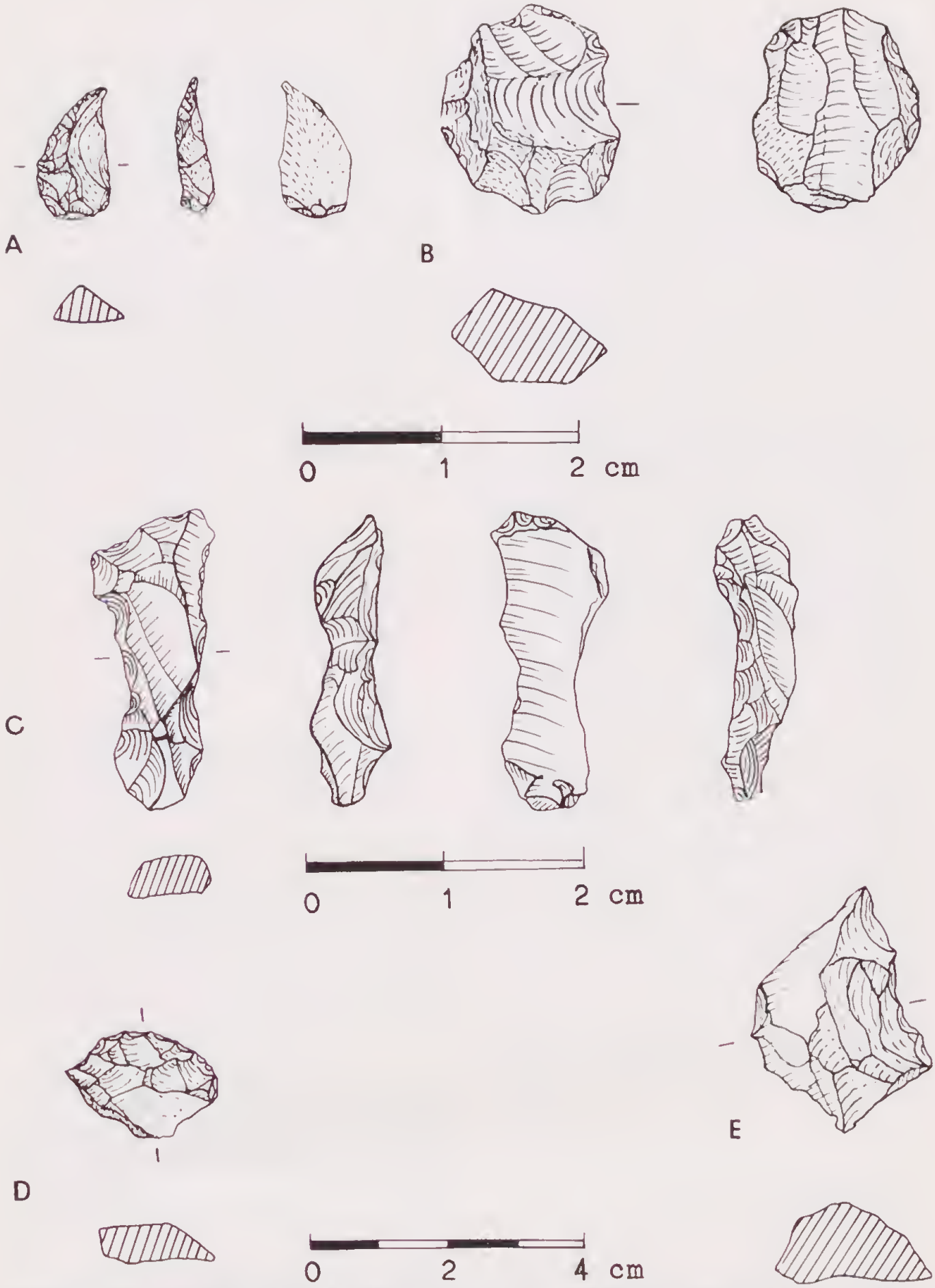

Figure 3. — Five tools from Walyunga excavation, trench C18. A. — Backed tool, quartz, depth 33 cm, Cat. No. P6/23. B. — Microscraper, quartz, depth 34 cm, Cat. No. P7/9. C. — Flat adze, mylonite, depth 39 cm, Cat. No. P9/1. D. — Knife, quartz, depth 148 cm, Cat. No. P31/23. E. — Scraper, quartz, depth 154 cm, Cat. No. P32/7.

Backed tools

Backed tools occurred only in the upper levels of the Walyunga excavation; the earliest in spit 14, depth 60 to 65 cm, dated 3 220 ± 100 bp (SUA 508), and the latest in spit 3, 16 cm below surface and 4 cm above the level dated 1 330 ± 100 bp (SUA 632). This latest backed tool may be anything up to about 1 300 years old, since the material in spit 3 is probably the residue from disturbance and erosion affecting part of the deposit that accumulated after 1 300 bp.

The interval between spits 14 and 19 (3 220 to 6 135 bp) contained only 275 artefacts including chips. The absence of backed tools from such a small sample is not conclusive proof that they were absent throughout the site in that interval.

The time range of backed tools found at Walyunga is slightly earlier than the range 3 090 bp to "modern" at Frieze Cave, located 80 km to the east (Hallam 1972, p. 16). Backed tools dated earlier than these are reported by Dortch (1975) from excavation at a site near Northcliffe 300 km south of Perth. Charcoal 3 to 7 cm above the uppermost backed tool at Northcliffe was dated 3 080 ± 75 bp (ANU 1131), while the sample from a spit 10 cm thick and 1 to 3 cm below the lowest backed tool was dated 6 780 ± 120 bp (SUA 379). This industry could be considerably older than the backed tool component at Walyunga.

Most of the backed tools excavated at Walyunga seem to be made from flakes rather than blades. They are trimmed in a curve along all or part of one lateral margin, usually to a squat asymmetric shape (Fig. 3). All from the trench sample were made of quartz except one of mylonite, and most are very small (mean dimensions listed in Table 2). These figures agree with the samples from systematic surface collection, but not with those from early casual collections which contain 30% mylonite items and are much larger (mean length 23 mm).

Backed tools in the Walyunga excavations occurred over about the same time span as flat adzes. Both types were components of the tool kit in the upper levels, and neither occurred before 4 560 bp.

Flakes

Most of the 260 primary flakes were less than 3 cm long, and their mean length (measured in the direction of percussion) was 1.8 cm (excluding chips less than 1.5 cm long). For comparison the mean length of secondarily worked flakes was 1.9 cm, while for 35 mylonite flakes and tools it was 1.7 cm. However some of the mean values changed over time (Fig. 4). Mass, width and thickness of primary flakes decreased in mean values from bottom to top levels of the trench, while length and length:width ratio showed a temporary increase around 3 000 bp (depth 90 to 45 cm), possibly related to changes in stone-working techniques or the introduction of new tool types.

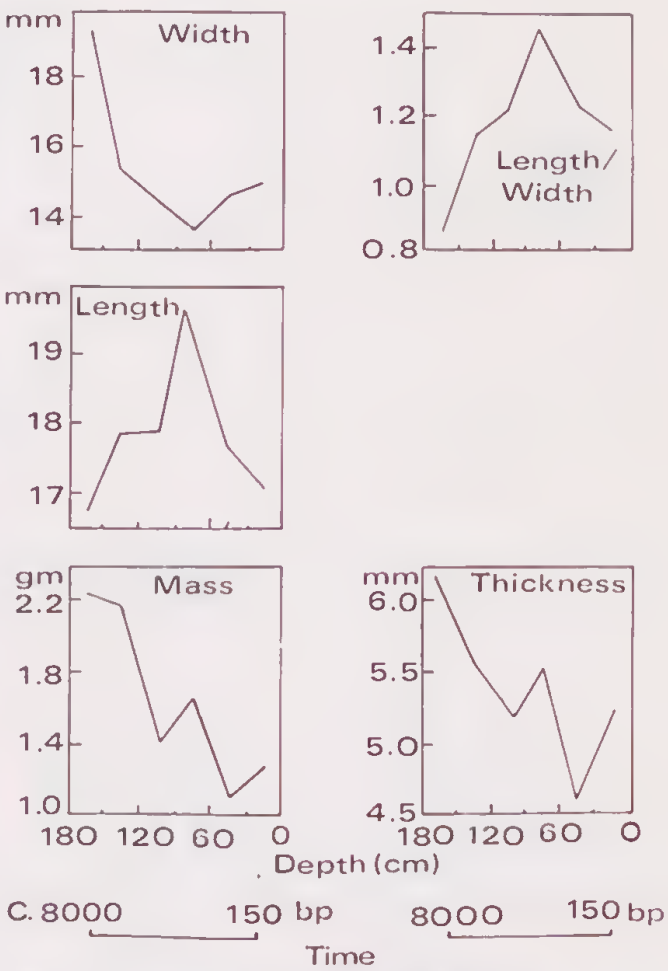

Figure 4. — Variations in flake sizes with time (N = 232). The graphs show variations with time in mean values of main dimensions of unaltered flakes from Walyunga trench C18. Flakes were grouped from successive 30 cm depth intervals. Items of dolerite, and chips less than 15 mm long were excluded.

About 24 "long" flakes have length:width ratios over 2.0, but only 6 are blades with parallel straight lateral margins and arrisses. These 6 items, less than 3 cm long and 1 cm wide, from lower as well as upper levels, may have been produced from scalar cores, as no prismatic or pyramidal cores occur. Some flaked pieces are probably cores though not of standard shapes, and occasionally they show narrow flake scars.

Rate of accumulation

The overall result of sand movement near the dune crest was aggradation, but the rate of accumulation indicated by depths of dated levels was not uniform. The rate was slower between spits 19 to 14 (about 10 cm per 1 000 years) than below (about 30 cm per 1 000 years) or above (about 20 cm per 1 000 years). The differences must be due to variations in rates of deposition and/or erosion.

Intermittent erosion is possibly indicated by concentrations of artefacts in two narrow "bands" within spits 18 and 16, but quantities

are small (14 artefacts near 81 cm, and 15 artefacts near 73 cm below surface), they were not accompanied by soil unconformities, and thus do not indicate prolonged or severe erosion.

The alternative to increased erosion is a reduced rate of addition of sand onto the dune crest, which may be related to reduced human activity (fewer fires, less disturbance of the surface, more vegetation, less bare sand and lower sand mobility).

The degree of activity and occupation at the trench location in different periods may be indicated approximately by relative artefact frequencies (quantities per square metre per 1 000 years). The frequencies were about 470 per 1 000 years in the lower levels (spits 32 to 20), about 90 per 1 000 years in spits 19 to 14, and 400 per 1 000 years in upper levels. This indicates discontinuous or reduced occupation during the period around 6 000 to 3 000 bp. (Fig. 5).

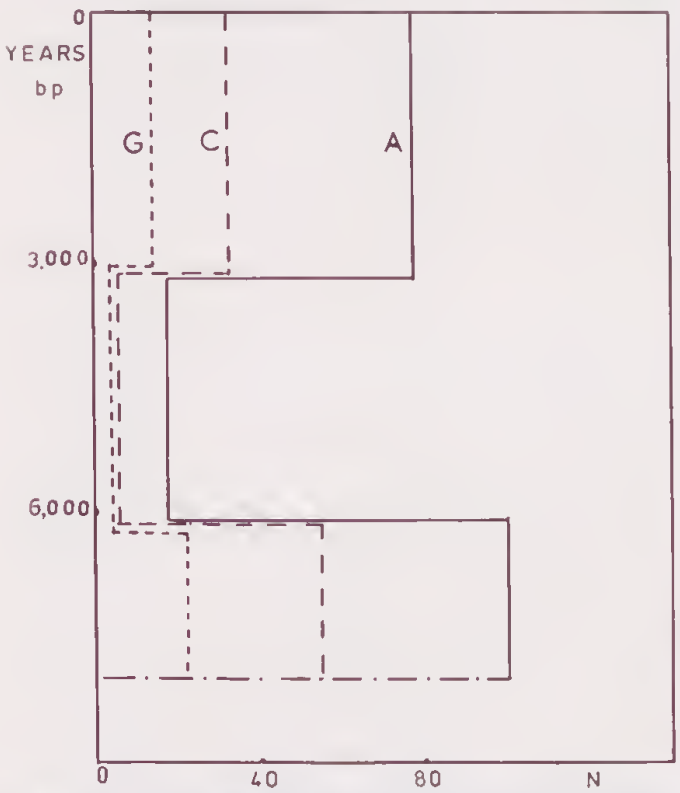

Figure 5. — Changes in artefact frequencies. Quantities per 1000 years in three dated intervals. Trench C18. A. — All flaked items except chips (N). C. — Chips, length less than 15 mm (N ÷ 10). G. — Lateritic gravel (grams).

Charcoal fragments occurred in most spits, occasionally concentrated in small areas but usually spread through the sand, probably windblown from fireplaces or bushfires in areas nearby. Charcoal was scarce in spits 16, 17 and 18, (depth 70 to 85 cm) compared with spits above and below, again indicating diminished occupation in this interval.

The evidence of dates in relation to stratigraphy, artefact density and charcoal density indicates a probable reduction of human activity in the immediate area of the trench from about 6 000 to 3 000 bp. This reduction may apply more widely over the site or represent only a shift in focus of usage. Nevertheless it does coincide with the period of marked changes in artefact technology.

Pollen studies by Churchill (1968) indicated a mid-Holocene dry climate for this region. Also Kendrick (1977) deduced from the presence of marine shells, a reduction in the flow of fresh water in the Swan and Helena Rivers and a relatively dry climate in the mid-Holocene. Thus some of the changes in human usage of the Walyunga site may be related to climatic changes.

Summary

Changes in technology (Table 3) appear as modifications in a continuing tradition rather than a succession of different traditions. The main changes are the disappearance of bryozoan chert and silcrete, a fivefold increase in mylonite usage, a decrease in frequency of steep scrapers, the introduction of backed tools and flat adzes, and a late increase in fabricators.

This dated sequence supports Glover's (1975) hypothesis that the source of bryozoan chert remained available until covered by rising sea levels. Various changes which took place about 4 600 years ago at Walyunga conform with similar changes which occurred in other parts of Australia after about 6 000 bp. "Backed" tools and "flat adzes" were absent from the lower levels and were present through the upper levels from at least 3 200 years ago.

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Henioehus diphreutes Jordan, a valid speeies of butterflyfish (Chaetodontidae) from the Indo-West Paeifie

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Abstract

The wide-ranging Indo-Paeifie butterflyfish *H. aeuminatus*, as presently reeognised eemprises two speeies. The true *acuminatus* oeeurs from the eoast of East Afriea aeross the Indo-West Paeifie to the islands of Oeeania and is eharaeterised by 11 dorsal spines. *H. diphreutes* is distinguished by the presenee of 12 dorsal spines and also differs from *H. aeuminatus* in morphology, eoloration, eeology, and behaviour. It has an apparent reliet distribution whieh ineludes the Hawaiian Islands, Japan, New South Wales, Western Australia, Maldive Islands, South Afriea, and the Red Sea.

Introduction

The butterflyfish genus *Heniochus* eontains seven speeies whieh are primarily eonfined to the reefs of the tropieal Indo-West Paeifie region. Perhaps the best known speeies is the Bannerfish, *H. acuminatus*, deseribed by Linnaeus (1758) from Indian Seas and subsequently reported by various authors from widespread loealities in the Indian and Paeifie Oeeans. Most reeent authors, ineluding Klausewitz (1969) who revised the genus, are in agreement with regards to the use of the name *acuminatus* for this speeies. *H. macrolepidotus*, also deseribed by Linnaeus was frequently reeognised as a distinet elosely related speeies during the 19th eentury, but is now generally regarded as a junior synonym of *acuminatus*. Another speeies whieh has been plaeed in the synonymy of *acuminatus* by Fowler and Bean (1929) and Weber and de Beaufort (1936) is *H. diphreutes* Jordan (1903) deseribed from Japan. However, Klausewitz failed to mention it either as a synonym or valid entity.

The senior author made several field trips to Eniwetok Atoll, Marshall Islands while residing in Hawaii between 1967 and 1971. During this period individuals of *Heniochus acuminatus* were frequently observed while SCUBA diving at both Hawaii and Eniwetok. Speeimens from the two loealities appeared to be morphologieally similar, although a detailed eomparison was not made at the time. However, there was a very noticeable differenee between the two populations with regards to eeology and behaviour. The Hawaiian fish eharaeteristieally oeeurs over roeky areas in aggregations whieh may inelude more than 100 individuals. Furthermore, they swim well above the bottom and apparently forage on plankton. Members of the Eniwetok population, on the eontrary, were nearly always sighted alone or in pairs and oeeurred near the bottom in the vieinity of coral reefs.

Klausewitz (1969) eommented that *H. aeuminatus* is often falsely assumed to be a reef inhabitant, but pointed out that it prefers shallow eoastal waters, in bays, lagoons, estuaries, and along roeky eoasts. His observations were largely, if not entirely, based on the population eeeurring at Eilat, northern Red Sea. He further noted that most speeimens of *H. "acuminatus"* from the Indo-Paeifie had 11 dorsal spines while those from the Gulf of Aqaba, Red Sea had 12. He also reeorded a differenee in the number of soft dorsal rays and maximum length between individuals from these two areas. He eoneluded that the Red Sea population might be deserving of sub-speeific status. The present study, however, indieates that these populations are distinet.

Between 1971 and 1973 the senior author eolleeted fishes and made underwater observations at the Caroline Islands, Great Barrier Reef of Australia, New Guinea, New Britain, Solomon Islands, New Hebrides, New Caledonia, and the Fiji Islands. *H. acuminatus* was ebserved at all these loealities and the behaviour and eeology in eaeh plaee was similar to that of the Eniwetok population. During 1973 the junior author eolleeted two very similar speeies of *Heniochus* from Sydney, Australia whieh when

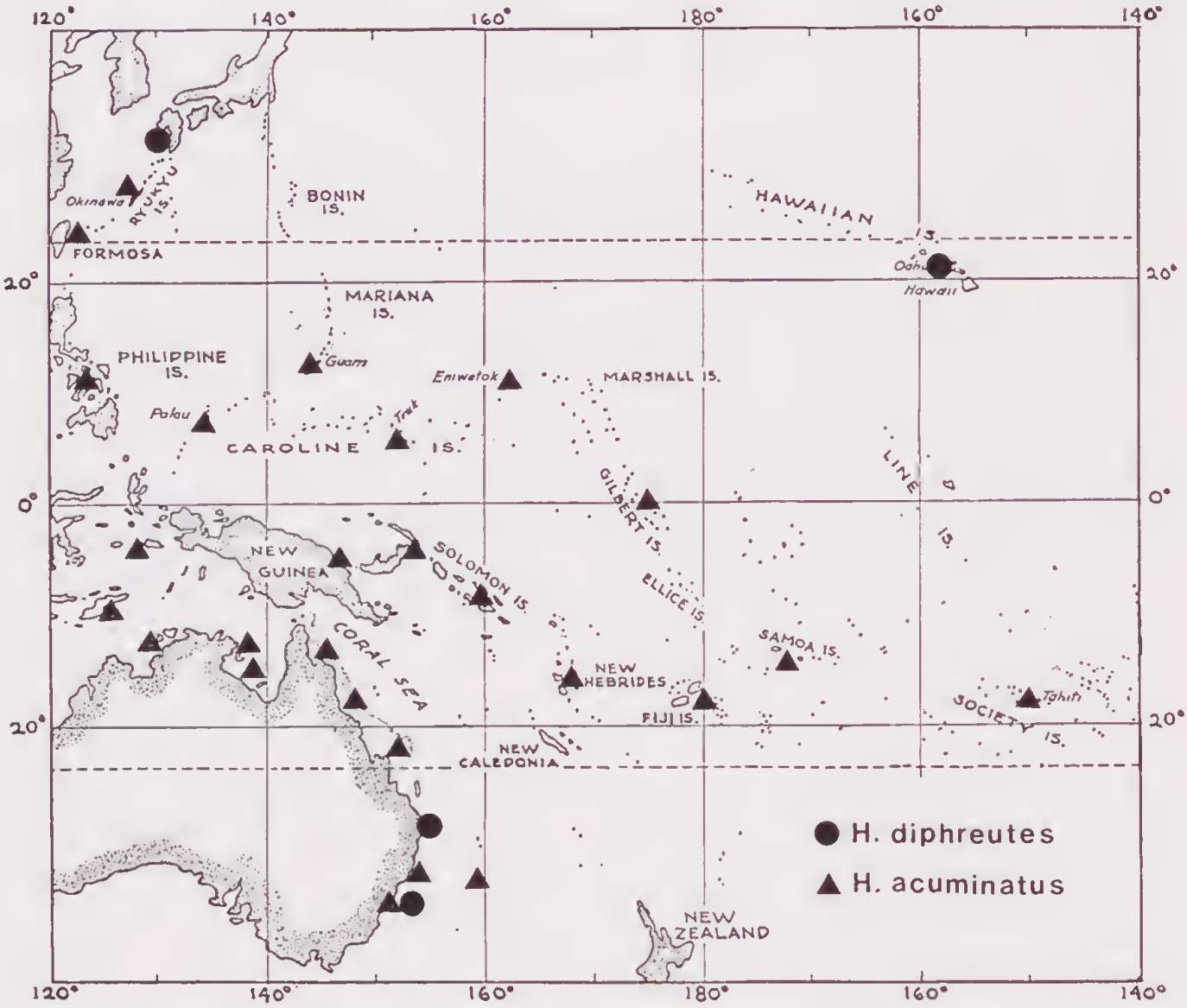

Figure 1. — Pacific Ocean distribution of *Heniochus acuminatus* and *H. diphreutes*.

first presented to the senior author for identification were believed to be only morphological variants of *H. acuminatus*. An adequate sample of both forms was eventually procured and a detailed comparison of this material supplemented by additional underwater observations reveals that they are indeed distinct. A subsequent literature search indicates that one of these is the widespread *H. acuminatus* and the other is *H. diphreutes* which perhaps has a relict distribution including Hawaii, Japan, New South Wales, Western Australia, Maldive Islands, South Africa, and the Red Sea. The two species are compared and a brief diagnosis for each is presented below. Selected fin ray counts are presented in Table 1 and the distributions are summarised in Figs. 1 and 2. The latter were compiled from Fowler and Bean (1929), Weber and de Beaufort (1936), Klausewitz (1969), personal observations, and examination of museum specimens.

The following abbreviations are used in the subsequent text: AMS—Australian Museum, Sydney; BPBM—Bernice P. Bishop Museum, Honolulu; CAS—California Academy of Sciences, San Francisco; JLBS—J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa; QM—Queensland Museum, Brisbane; SMF—Natur-Museum Senckenberg, Frankfurt; SU—Stanford University, California (specimens now deposited at CAS); WAM—Western Australian Museum, Perth.

Heniochus acuminatus (Linnaeus)

(Figs. 3 and 4; Table 1)

Chaetodon acuminatus Linnaeus, 1758: 272 (type locality, Indies).

Chaetodon macrolepidotus Linnaeus, 1758: 274 (type locality, Indies).

Chaetodon bifasciatus Shaw, 1803: 342 (type locality, Indian Seas).

Chaetodon mycteryzans Gray, 1854: 76 (no locality given).

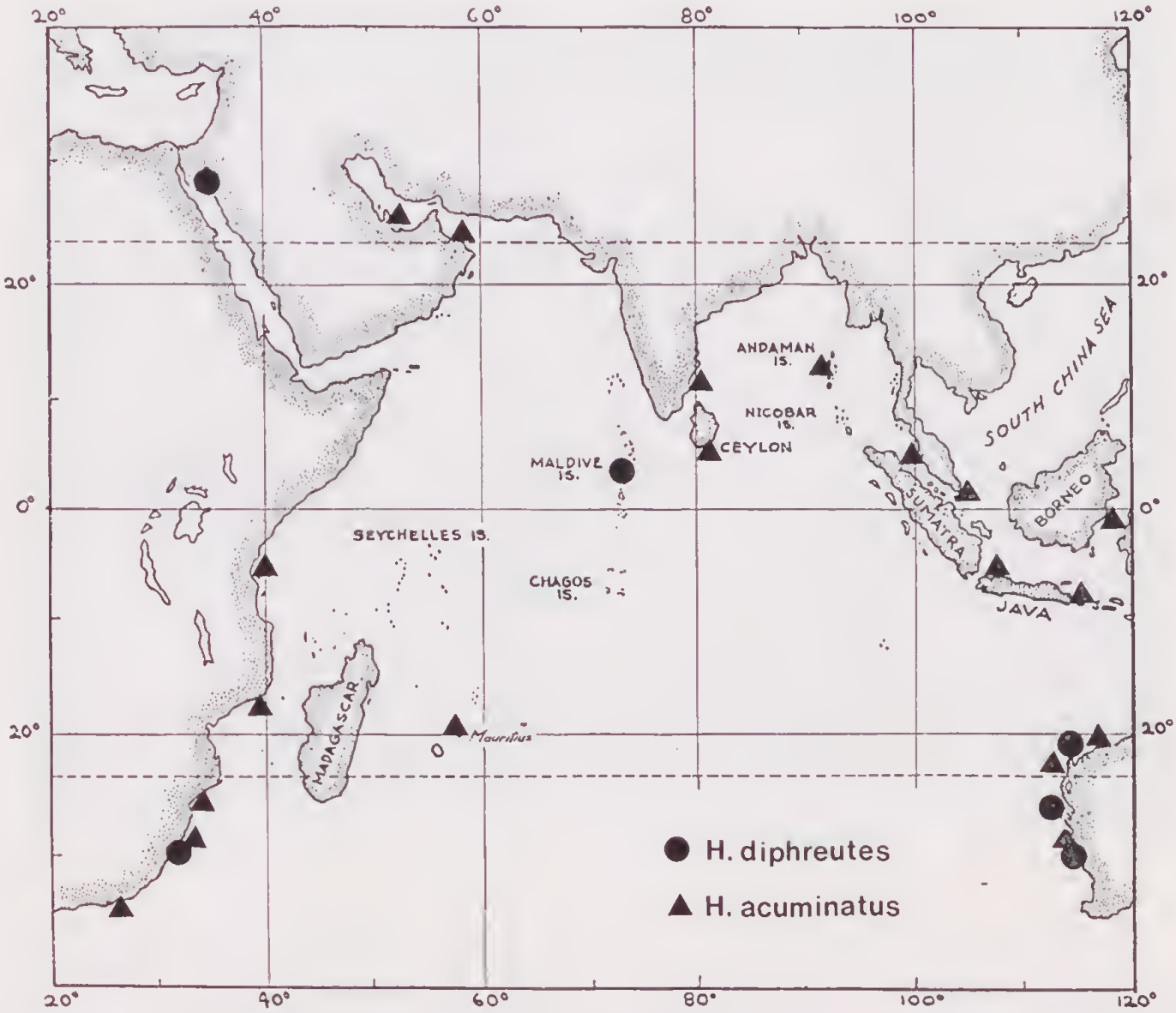

Figure 2. — Indian Ocean distribution of *Heniochus acuminatus* and *H. diphreutes*.

Material examined: 111 specimens, 22.8-196.0 mm SL.

Australia-New South Wales: AMS IA.177, 113.3 mm SL (no locality); AMS IB.2929, 26.5 mm SL (Newcastle); AMS IB.5707, 2 specimens, 24.0-44.8 mm SL (Lord Howe Island); AMS IB.5742, 75.4 mm SL (Sydney Harbour); AMS IB.5744-5745, 2 specimens, 33.2-53.5 mm SL (Sydney Harbour); AMS IB.8104, 47.1 mm SL (Port Hacking); AMS IB.8208, 66.7 mm SL (Woolongong); AMS I.15575-001, 52.5 mm SL (Woolongong); AMS I.15778-003, 44.0 mm SL (Port Macquarie); AMS unregistered, 112.0 mm SL (Lord Howe Island); WAM P25632-001, 2 specimens, 22.8-35.7 mm SL (Lakes Entrance); WAM P25633-001, 4 specimens, 25.9-41.5 mm SL (Sydney); WAM P25634-001, 2 specimens, 40.3-43.4 mm SL (Sydney); WAM P25635-001, 58.0 mm SL (Sydney); WAM P25636-001, 2 specimens, 35.0-36.0 mm SL (Sydney Harbour); WAM P25637-001, 2 specimens, 29.2-54.5 mm SL (Sydney Harbour); WAM P25638-001, 123.6 mm SL (Sydney). Queensland: AMS IA.1750-1752, 3 specimens, 54.7-57.3 mm SL (Port Denison); AMS I.15557-197, 65.0 mm SL (Gulf of Carpentaria); QM I.1777-1778, 2 specimens, 79.0-92.0 mm SL (Moreton Bay); QM I.3467, 166.0 mm SL (Moreton Bay); WAM P24688, 34.3 mm SL (Lizard Island); WAM P24701, 38.5 mm SL (Lizard Island); WAM P24714, 3 specimens, 30.0-33.0 mm SL (Lizard Island). Western Australia: WAM P4432, 52.0 mm SL (Exmouth Gulf); WAM P4438, 5 specimens, 77.0-152.0 mm SL (Dampier Archipelago); WAM P4453, 81.5 mm SL (Exmouth Gulf); WAM P4763, 196.0 mm SL (Wedge Island); WAM P5329, 71.5 mm SL (Exmouth Gulf); WAM P6101, 55.6 mm SL (Exmouth Gulf); WAM P8347, 56.2 mm SL (Point Quobba); WAM P24068, 149.5 mm SL (Dampier Archipelago); WAM P25113-006, 124.6 mm SL (Dampier Archipelago); WAM unregistered, 2 specimens, 53.0-57.2 mm SL (North West Cape).

East Africa: SMF 8241, 47.0 mm SL; SMF 11557, 5 specimens, 75.0-91.0 mm SL (Dar es Salam).

Fiji Islands: AMS I.7465, 82.9 mm SL (Suva).

India: AMS I.54, 120.6 mm SL (Madras); SMF 6773, 4 specimens, 75.0-141.0 mm SL (Madras).

Indonesia: SMF 3965, 62.0 mm SL (Jakarta); SMF 8242, 2 specimens, 91.0-114.0 mm SL (Celebes).

Madagascar: SMF 10379, 6 specimens, 94.0-148.0 mm SL.

Mauritius: SMF 1705, 2 specimens, 81.0-140.0 mm SL.

Figure 3. — *Heniochus acuminatus*, 151 mm SL, Bahrain, Persian Gulf (J. Randall photo).

Persian Gulf: BPBM unregistered, 6 specimens, 60.0-151.0 mm SL (Bahrain); SMF 9803, 5 specimens, 83.0-108.0 mm SL; SMF 11974, 3 specimens, 91.0-93.0 mm SL (Kuwait).

Philippine Islands: AMS I.10575, 79.0 mm SL (Cebu); SMF 9262, 4 specimens, 64.0-78.0 mm SL.

Sri Lanka: SMF 4267, 6 specimens, 54.0-61.0 mm SL; SMF 8243, 3 specimens, 64.0-73.0 mm SL; SMF 9117, 3 specimens, 85.0-115.0 mm SL; SMF 9120, 89.0 mm SL; SMF 10748, 2 specimens, 62.0-84.0 mm SL; SMF 12208, 74.0 mm SL.

Diagnosis: Dorsal rays usually XI (rarely XII), 24 to 27; anal rays III, 17 to 19; pectoral rays 15 to 18; tubed lateral-line scales 47 to 54.

The following proportions are based on 10 specimens, 53.0-196.0 mm SL; depth of body 1.2 to 1.4, head length 2.6 to 3.1, both in standard length; snout length 2.7 to 3.3, eye diameter 2.5 to 3.6, interorbital width 2.9 to 3.8, caudal peduncle depth 2.7 to 3.7, pectoral fin length 1.0 to 1.2, pelvic fin length 0.9 to 1.1, anal fin length 1.0 to 1.3 all in head length.

Colour in alcohol: ground colour of head and body yellowish-white or tan; dorsal portion of snout blackish; lower lip and chin frequently with black smudges; a blackish bar connecting orbits across interorbital region; body with two oblique black bars, the first encompassing anterlormost dorsal spines and posterior part of nape extending to abdomen, becoming gradually broader ventrally, the lowermost width extending approximately from pelvic base to anus; the second bar extending from distal part of 6th-8th dorsal spines to ventral half of anal fin, more oblique in position than first bar and of more uniform width; dorsal fin greyish-white to yellowish except where interrupted by dark bars; caudal fin yellowish; anal fin yellowish-tan on anterior half, black posteriorly (continuation of second body bar), anal spines and anterior edge of soft anal also black; pelvic fins black; pectoral fin yellowish with black base and axil.

Colour in life: similar to preserved coloration except filamentous extension of fourth dorsal spine and ground colour of body generally whitish, and region posterior to second body bar largely yellow grading to translucent on distal edge of soft dorsal and caudal fins.

Remarks: This species generally occurs solitarily or in pairs, usually in coral reef areas. However, at certain subtropical or warm temperate localities it may be encountered over rocky substratum. The young are frequently seen around caves and crevices. We have observed the species at depths ranging from about 2 to 30 m, but it is most often encountered between 5 and 15 m.

Figure 4. — Juvenile specimens of closely related *Heniochus* collected at Sydney, Australia: left — *H. acuminatus*, 58 mm SL; right — *H. diphreutes*, 51.8 mm SL.

Nomenclature: Linnaeus (1758), in his brief description of this species, gave a dorsal ray count of "3/28" (i.e., three spines and 25 soft rays or 28 total elements). This must certainly represent an error as the description is apparently based on the specimen illustrated by him in 1754 (Linnaeus 1754, plate 33, fig. 3). The illustration clearly shows at least 11 dorsal spines and the characteristic snout shape of *acuminatus* (see discussion of comparative morphology under *H. diphreutes*). Furthermore, B. Broberg of the Naturhistoriska Riksmuseet in Stockholm (the depository of many Linnaean types) has confirmed the existence of the type specimen in their collection. He stated that the specimen "is in good condition and agrees very well with the figure in Museum Adolphi Friderici (Linnaeus 1754) and still retains much of the original pattern of coloration. Dorsal spines of the specimen are 11 and the pectoral rays are 16 on one and 17 on the other side. Standard length is 67.3 mm and the three anal spines appear dark".

Comparisons: H. acuminatus differs from *H. diphreutes* by having 11 (rarely 12) dorsal spines instead of 12 (rarely 13), a longer snout, a longer anal fin, and a shorter pelvic fin. There are also differences in coloration, behaviour, ecology, and postlarval size. These are summarised in the comparisons section for *H. diphreutes*. Less than 1% of the specimens examined possessed an abnormal count of 12 spines, and these were from widely scattered localities. Identification was facilitated in these cases primarily on the basis of snout shape and the length of the pelvic and anal fins.

Distribution: (see maps, Figs. 1 and 2) *H. acuminatus* appears to be widespread in the tropical Indo-West Pacific from the coast of East Africa to the islands of southeastern Polynesia. However, some of the published records (such as those from Hawaii and the Red Sea) are no doubt attributable to *H. diphreutes*. The senior author has observed it at the Society Islands, Marshall Islands, Fiji Islands, New Hebrides, Solomon Islands, New Britain, New Guinea, Palau Islands Ryukyu Islands, Philippine Islands, Indonesia, eastern Australia (Great Barrier Reef and Sydney), Lord Howe Island, Western Australia, Sri Lanka, Persian Gulf, and Gulf of Oman. It appears to be largely allopatric with *H. diphreutes*, but the two species occur together at certain localities such as Exmouth Gulf, Western Australia;

Figure 5. — *Heniochus diphreutes*, 100 mm SL, Oahu, Hawaiian Islands (J. Randall photo).

Sydney, New South Wales; and the Durban area of South Africa (based on specimens examined for us by M. M. Smith).

Heniochus diphreutes Jordan

(Figs. 4 and 5; Table 1)

Heniochus diphreutes Jordan, 1903: 694 (type locality, Wakamoura, Japan).

Material examined: 23 specimens, 36.0-134.0 mm SL.

Australia—New South Wales: AMS IB.5743, 46.0 mm SL (no locality); WAM P25640-001, 3 specimens, 48.8-52.0 mm SL (Sydney); WAM P25641-001, 2 specimens, 67.8-74.3 mm SL (Port Stephens); WAM P25642-001, 6 specimens, 38.8-47.5 mm SL (Sydney); WAM P25643-001, 2 specimens, 47.5-55.0 mm SL (Sydney Harbour); Western Australia: WAM P5912, 36.0 mm SL (30°37′S, 115° 04′E); WAM P15448, 40.0 mm SL (Shark Bay); WAM P25095-039, 2 specimens, 62.3-67.5 mm SL (Exmouth Gulf); WAM unregistered, 65.0 mm SL (Exmouth Gulf).

Hawaiian Islands: AMS IA.186, 110.5 mm SL (Honolulu).

Japan: SU 7247, 41.3 mm SL, holotype (Nagasaki).

Maldive Islands: SMF 8712, 134.0 mm SL (Ari Atoll).

Diagnosis: Dorsal rays usually XII (rarely XIII), 23 to 25; anal rays III, 17 to 19; pectoral rays 16 to 18; tubed lateral-line scales 46 to 54.

The following proportions are based on eight specimens, 52.0-110.5 mm SL: depth of body 1.2 to 1.5, head length 2.4 to 3.0, both in standard length; snout length 3.0 to 3.7, eye diameter 2.6 to 3.1, interorbital width 3.3 to 3.6, caudal peduncle depth 2.7 to 3.4, pectoral fin length 1.0 to 1.2, pelvic fin length 0.7 to 0.9, anal fin length 1.3 to 1.5, all in head length.

Colour in alcohol and life: the coloration is nearly identical to *H. acuminatus* except the anal spines, at least in juvenile specimens under about 60 mm SL, are usually whitish or only slightly dusky. In addition, young specimens

when alive usually have a white area on the back between the second black bar and the soft dorsal fin.

Nomenclature: H. diphreutes Jordan is the oldest name for the 12-spined *"acuminatus"*. We have examined the type, a specimen (SU 7247) 41.3 mm SL, collected at Nagasaki, Japan by D. S. Jordan and J. O. Snyder during the summer of 1900. We recorded the following counts and measurements (expressed in percent of the standard length) from this specimen: dorsal rays XII, 24; anal rays III, 18; pectoral rays 18; tubed lateral-line scales 48; depth of body 62.0 (1.6 in SL); width of body 12.6; head length 36.8 (2.7 in SL); snout length 10.2 (3.6 in head); eye diameter 13.6 (2.7 in head); interorbital width 10.4 (3.6 in head); caudal peduncle length 4.8; snout to dorsal origin 49.9; snout to anal origin 74.1; snout to pelvic origin 44.3; pelvic fin length 49.4 (0.7 in head); pelvic spine length 28.6; pectoral fin length 32.4 (1.1 in head); dorsal fin base 73.8; anal fin base 25.2; length of first dorsal spine 13.3, of fourth dorsal spine (including filamentous portion) 107.5, of last dorsal spine 13.8, of longest soft dorsal ray 22.8 (1.5 in head), of first anal spine 11.1, of second anal spine 21.1, of third anal spine 19.4, of longest soft anal ray 24.7, and of caudal fin 27.4.

Ecology: This species usually occurs in aggregations which may include up to more than 100 individuals. They swim high above the substratum in search of planktonic food, usually above rocky outcrops or some other form of shelter which are frequently located in sandy areas. The depth range extends from about 3 to at least 183 m (Strasburg, *et al.*, 1968).

Distribution: (see maps, Figs. 1 and 2) *H. diphreutes* is here reported from the Hawaiian Islands, southern Japan, New South Wales, Western Australia, Maldive Islands, South Africa (Durban area), and the Red Sea. If the above mentioned areas represent the total distribution it would appear that *H. diphreutes* is a relict species, perhaps being once widespread throughout the Indo-West Pacific. It is interesting to note that the existing distribution records are mainly peripheral to the distribution of *H. acuminatus*, for the most part lying barely within the tropics or in warm temperate seas. Perhaps the widespread ancestral population of *diphreutes* became largely extinct because of its lack of ability to successfully compete for food and shelter on the coral reefs of the tropical Indo-West Pacific. It now survives in sandy habitats relatively low in species diversity, largely outside of the tropics. Indeed, it is the only member of the genus not generally associated with coral reefs.

Comparisons: H. diphreutes is readily separable from *H. acuminatus* on the basis of dorsal spine count (12 as opposed to 11 for *acuminatus*), and the modal number of soft dorsal and pectoral rays (see Table 1). In addition, the snout of *diphreutes* is generally less protruding (see Figs. 3-5) and this species has a longer pelvic fin and shorter anal fin than *acuminatus*. We have compared 20 specimens, 36.0-74.3 mm SL ($\bar{x}$ = 50.8 mm SL) of *H. diphreutes* with 41 specimens, 22.8-92.0 mm SL ($\bar{x}$ = 50.7 mm SL) of *H. acuminatus*. The average pelvic fin length of *diphreutes* was 46.8% of the standard length compared with 37.2% for *acuminatus*. The average anal fin height (i.e. length of tallest soft anal ray) of *diphreutes* was 21.5% of the standard length and 32.2% for *acuminatus*. Unfortunately we were unable to obtain a sufficient number of large (in excess of 100 mm SL) *H. diphreutes* for comparisons. However, on the basis of two specimens of *diphreutes*, 110.5 and 134.0 mm SL, and many large specimens of *acuminatus*, it appears that fin length differences are not diagnostic among the adults. The snout shape and number of dorsal spines remain the best means for separating larger individuals.

Table 1

Comparison of certain counts for Heniochus acuminatus *and* H. diphreutes

Count	Frequency	
	H. acuminatus	*H. diphreutes*
Dorsal spines:		
11	98	
12	6	22
13		1
Soft dorsal rays:		
23		5
24	4	10
25	47	8
26	44	
27	3	
Soft anal rays:		
17	16	3
18	80	18
19	8	2
Pectoral rays:		
15	1	
16	3	2
17	63	19
18	37	2
Tubed lateral-line scales:		
46		2
47	1	1
48	4	3
49	7	2
50	17	3
51	23	4
52	11	5
53	17	2
54	6	1

The general colour patterns of the two species are very similar, but several differences were detected in fresh specimens (primarily juveniles) from the Sydney area. The anal spines of *diphreutes* were white or only slightly dusky and those of *acuminatus* were black. Furthermore there was a difference in the pepper-like dark pigmentation which is located in the yellow area of the upper back and adjacent basal portion of the dorsal fin (primarily the soft portion). In *diphreutes* the pigment is loosely scattered and the outer boundary of the pigmented area on the soft dorsal fin is more or less concave; the pigmentation of *acuminatus* is much heavier and the outer boundary is distinctly convex. In the small (less than about 50 mm SL) juveniles there is a difference in the coloration of that part of the back immediately adjacent to the posterior edge of the second dark body bar. In *diphreutes* there is a narrow white strip separating the second bar from the yellow dorsal fin, whereas the area is solid yellow in *acuminatus*.

The two species also differ in ecology and general diurnal behaviour. *H. diphreutes* is most often encountered swimming in mid-water aggregations in sandy areas with scattered shelter, while *H. acuminatus* is chiefly solitary or forms pairs and is found primarily in coral reef areas near the substratum. However, the juveniles of the latter species are sometimes found in small aggregations.

Finally, there is an apparent difference in the size of postlarval juveniles and adults. The smallest postlarvae of *H. diphreutes* which we have collected are in the 25-30 mm standard length range, whereas those of *H. acuminatus* are about 15 mm SL. Klausewitz (1969) noted that specimens of *acuminatus* reported from various parts of the Indo-West Pacific had a maximum total length ranging from 160-200 mm compared with a maximum of 122 mm in specimens (of *diphreutes*) from the Gulf of Aqaba, Red Sea. We detected a similar difference among the specimens examined during the present study. Our largest specimens measured 238 mm and 134 mm total length for *H. acuminatus* and *H. diphreutes* respectively.

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Cadmium levels in coastal and estuarine waters of Western Australia

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Abstract

The stable isotope dilution technique has been used to measure the cadmium concentration in 30 coastal and estuarine water samples from 16 locations around the Western Australian coast, from Albany in the south to Pardoo Station in the north. A base-line value of 0.013 ppb ($\mu g\ kg^{-1}$) cadmium for coastal sea water has been established, and this result compares favourably with overseas studies. It is pleasing to note the minimal levels of contamination caused by industry, and in most cases it seems that the nature of the environment controls the cadmium levels present.

Introduction

Cadmium was recognized many years ago as a highly toxic element. However it was not until comparatively recently that concern was expressed over the possible effects to human health of exposure over long periods to low concentrations of cadmium. This situation has developed because of the increasing technological use of cadmium (Cox 1974). Ingestion from food or water, and inhalation from the atmosphere are the major routes by which cadmium enters the body.

Cadmium is used by industry in electroplating, in pigments and chemicals, as a plastics stabiliser, in alloys and solder, in making batteries, photocells and in pesticides. Cadmium minerals are found in conjunction with zinc ores because of the geochemical similarity of the two elements, and hence a major source of cadmium in the environment is the zinc industry. Thus, in addition to zinc refining, there are a number of processes which involve cadmium including galvanizing iron and steel, making brass and other alloys and in the production of zinc oxide.

The World Health Organisation (WHO 1963), has declared that the maximum advisable concentration limit for cadmium in drinking waters is 10 ppb ($\mu g\ kg^{-1}$). Long term exposure to cadmium-contaminated food and water has been found to induce a bone disease in members of a small community in Japan, who live in the Jintsu region situated on a river heavily polluted by mining wastes (Singhal *et al.* 1975).

A variety of cadmium minerals exist in nature and these are soluble in excess aqueous salt solutions; many cadmium compounds are also soluble in fresh water (Cox 1974). Williams and David (1973) have shown that the cadmium content of phosphatic fertilisers and superphosphate used on Australian pastures ranges from 27 to 90 ppm ($mg\ kg^{-1}$). Thus cadmium can be transferred to natural waterways, and hence find its way to estuaries and the oceans.

Rosman and De Laeter (1976), have measured the concentration of cadmium in two river systems in Western Australia, and shown that the content is approximately one hundredth of the WHO recommended value. This data may therefore serve as a basis for comparison with cadmium concentrations in waterways in other parts of the world. De Laeter *et al.* (1976), examined the cadmium content of rural tank water and have shown that in most cases the concentration is less than 1 ppb.

There is considerable interest in the fate of heavy metals in estuarine and coastal environments, and several studies have been carried out to determine the effects of discharging effluents containing heavy metals into estuarine waters. It has usually been assumed that such effluents are rapidly dispersed in the open sea (Butterworth *et al.* 1972). In assessing the impact on the environment of effluent containing cadmium, it is necessary to know the concentration of cadmium that would have been present in the absence of waste material. However these background levels are poorly documented in the literature, and the present study was undertaken to provide a set of base-line values for coastal and estuarine waters around the Western Australian coast, similar to the base-line values determined by Rosman and De Laeter (1976) for river systems.

Experimental procedure

It is quite likely that much of the published work on environmental cadmium is inaccurate, particularly where the content is at the sub-ppb level. The present project has used the stable

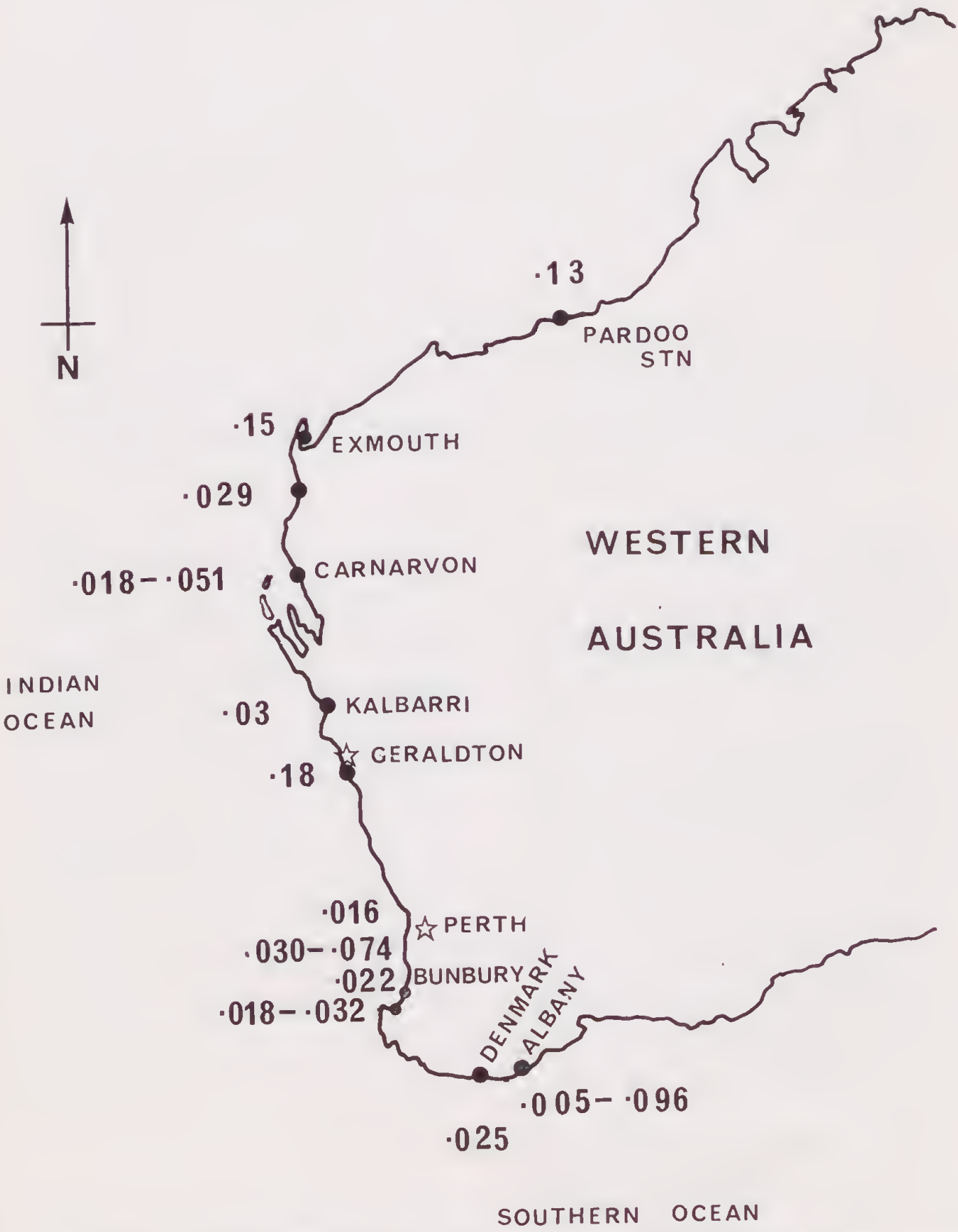

Figure 1.—Cadmium concentrations (in $\mu g\ kg^{-1}$) of seawater around the Western Australia coast.

isotope dilution technique to measure the cadmium content of ocean water along the coast of Western Australia. Because of its excellent sensitivity, high accuracy and precision, the isotope dilution technique is ideally suited to the analysis of cadmium in the environment. The sensitivity of this technique for cadmium in aqueous samples is 0.003 ppb, and the absolute accuracy is better than 10% at the sub-ppb level.

Water samples were collected in high density polyethylene containers, since it has been shown that polyethylene does not absorb cadmium from aqueous solutions and exhibits a low blank (Struempler 1973). The bottles were cleaned with high purity 6M HCl to remove any residual contamination. They were then washed thoroughly with quartz-distilled water, some of which was left in the bottle until the sample was collected. Before the sample was taken, the bottle was emptied, rinsed with sea water and filled with water taken near the surface. An unfiltered 200 g aliquot of each water sample was acidified and spiked with an accurately known weight of isotopically enriched ^{111}Cd tracer. After ensuring that the spike and sample were well mixed, the cadmium was chemically extracted by ion exchange. Full details of the chemical extraction procedure are given by Rosman and De Laeter (1977).

After the cadmium was extracted it was mounted in the source of a 30.5 cm radius, 90° magnetic sector field, solid source mass spectrometer. From the measured isotopic ratios the concentration of cadmium in each sample was determined. It was found necessary to make a blank correction of approximately 2 x 10^{-9} g for each sample. A blank was included with each batch of samples undergoing chemical processing.

Results and discussion

Water samples were collected from 16 locations around the Western Australian coast, from Albany in the south to Pardoo Station in the north (Fig. 1). Multiple sampling was carried out at 7 of these locations, making a total of 30 samples available for analysis. For almost every sample, duplicate analyses were made to provide an indication of the reproducibility of the procedure. Table 1 lists the location and cadmium concentrations of the 30 samples, together with an assessment of the error of each individual analysis. Figure 1 shows the location and average cadmium concentration of each of the major collection points around the coast. Samples 1-20 and sample 30 were collected in April 1976. The remaining samples were collected in July 1976.

South coast region

Five samples were collected near Albany in the Southern Ocean. The concentrations at Middleton Bay and Frenchmans Bay in King George Sound are approximately half the values in the Inner Harbour at the Wharf and at Pelican Point. This could be due to the presence of cadmium in drainage from the Albany townsite, or activities at the wharf. The fifth sample

Table 1

Cadmium content of coastal water (in $\mu g\ kg^{-1}$ by weight)

Sample Number	Locality	Individual analyses	Mean concentration
	Albany		
1	Middleton Bay	0·060 ± 0·005 0·060 ± 0·006	0·060
2	Wharf	0·092 ± 0·004 0·101 ± 0·006	0·096
3	Pelican Point .	0·08 ± 0·01	0·08
4	Frenchmans Bay	0·031 ± 0·005 0·027 ± 0·008	0·029
5	Oyster Harbour	0·006 ± 0·004 0·005 ± 0·004	0·005
	Denmark		
6	Southern Ocean	0·024 ± 0·011 0·026 ± 0·004	0·025
7	Denmark River	0·003 ± 0·004 0·007 ± 0·004	0·005
8	*Yallingup* (ocean) .	0·017 ± 0·004 0·019 ± 0·004	0·018
9	*Dunsborough* (ocean)	0·022 ± 0·011 0·031 ± 0·014	0·026
10	*Busselton* (ocean)	0·032 ± 0·102 0·032 ± 0·006	0·032
11	*Bunbury* (ocean)	0·024 ± 0·003 0·020 ± 0·004	0·022
	Australind		
12	Collie River mouth	0·027 ± 0·004 0·035 ± 0·005	0·031
13	Pipeline	0·43 ± 0·01 0·35 ± 0·02	0·39
14	North of pipeline ...	0·189 ± 0·006 0·195 ± 0·007	0·192
	Cockburn Sound		
15	South Fremantle Power Station	0 030 ± 0·004 0·031 ± 0·004	0·030
16	Owen Anchorage ..	0·079 ± 0·005 0·070 ± 0·004	0·074
17	Southern Flats .	0·058 ± 0·005 0·068 ± 0·011	0·063
	Fremantle		
18	Inner Harbour	0·043 ± 0·004 0·049 ± 0·005	0·046
	Cottesloe Beach		
19	A	0·013 ± 0·006 0·014 ± 0·004	0·016
20	B	0·019 ± 0·004 0·015 ± 0·004 0·019 ± 0 004	
	Greenough		
21	Mid-river	0·047 ± 0·005 0·043 ± 0·004	0·045
22	Ocean (opposite river mouth)	0·21 ± 0·01 0·15 ± 0·01	0·18
23	Bore water	0·118 ± 0·006 0·125 ± 0·007	0·121
24	Tank water	0·090 ± 0·006 0·095 ± 0·008	0·092
25	*Kalbarri* (ocean)	0·03 ± 0·01	0·03
	Carnarvon		
26	Pelican Point (ocean)	0·017 ± 0·004 0·019 ± 0·004	0·018
27	Babbage Island	0·06 ± 0·01 0·043 ± 0·008	0·051
28	*Coral Bay* (ocean)	0·032 ± 0·009 0·026 ± 0·008	0·029
29	*Exmouth Gulf* (ocean)	0·16 ± 0·01 0·14 ± 0·01	0·15
30	*Pardoo Station* (ocean)	0·129 ± 0·006 0·132 ± 0·007	0·130

was collected just south of the King River Bridge in Oyster Harbour. The concentration of 0.005 ppb is extremely low and probably reflects the fact that two rivers—the King and the Kalgan—flowing into this inlet probably have low cadmium levels. Rosman and De Laeter (1977) showed that the cadmium concentration of water in the Swan and Peel inlet river systems could be as low as 0.01 ppb. Two samples were also analysed at Denmark, a small town some 54 km west of Albany. One sample was taken from the ocean, the second from the Denmark River. The results were almost identical to the corresponding types of collection points at Albany.

Southwest coast region

The cadmium contents of ocean water at four collection sites along some 90 km of coastline from Yallingup to Bunbury in the Indian Ocean gave extremely low and consistant values from 0.018 to 0.032 ppb, which are similar to the cadmium values for the Southern Ocean samples.

The three Australind samples were collected in Leschenault Inlet, a large, tidal inlet with an opening to the ocean at the southern end, near the town of Bunbury. The Collie River enters the inlet approximately 2 km north of the outlet. A titanium-ilmenite refinery is located about 5 km from the channel on the landward side of the inlet. Effluent from the factory is carried across the inlet to the ocean by an elevated pipeline. The sample from the mouth of the Collie River gave a cadmium value of 0.031 ppb. This low value is probably due to the fresh water flowing down the river, together with the muddy nature of the river mouth which acts as a sink for the cadmium. The second sample was taken directly under the raised centre section of the pipeline. This section is continually leaking effluent, and the cadmium content of 0.39 ppb was the highest value found in any of the 30 samples analysed. The third sample was taken approximately 3 km to the north of the pipeline. The cadmium content of 0.192 ppb was still high, but approximately half the value of the pipeline sample. There are strong tides in the estuary which would disperse the cadmium from the effluent throughout the estuary, although the sediments in the inlet would undoubtedly act as a sink for cadmium as occurs in the Peel Inlet some 100 km to the north of the Leschenault Inlet (Rosman and De Laeter 1977).

Fremantle region

Three samples were taken from Cockburn Sound which has a complex system of tides, currents and wind effects. Industry along Cockburn Sound releases effluent at a number of places, and Meagher and Le Provost (1971) have measured zinc concentrations at the 50-1 000 ppm level in a number of locations in the Sound. The first sample was collected approximately 1 km offshore from the South Fremantle Power Station. The second sample was collected off Southern Flats approximately 1 km east of Careening Bay (Garden Island). The third was collected approximately 1 km offshore from Woodman Point at Owen Anchorage. All three samples gave reasonably low values—and all were significantly lower than the values measured in Leschenault Inlet.

The cadmium content of the water sample collected in Fremantle Harbour gave a value of 0.046 ppb which compares reasonably well with the value of 0.06 ppb collected at the Fremantle Traffic Bridge in April 1975 as reported by Rosman and De Laeter (1977). Two samples were collected off Cottesloe Beach, the first sample being analysed on three, and the second sample on two separate occasions. The results give a good indication of the reproducibility and precision of the isotope dilution technique for sea water samples.

The Cottesloe samples were analysed over a three month period, and the consistency of the results supports the conclusion of Shendrikar *et al.* (1975), that absorption of cadmium on high density polyethylene is minimal, even over an extended period of time.

North coastal region

Four samples were collected at Greenough, some 8 km south of Geraldton. The Greenough area is a flat, open expanse of agricultural land through which the Greenough River flows. Across the mouth of the river is a semi-permanent sand bar about 200 m wide. In periods of heavy rainfall the river floods over a considerable land area and breaks the sand bar. However, in seasons of low rainfall the additional water is lost by seepage without actually breaking the bar.

The cadmium concentration at a point in the river approximately 130 m upstream from the mouth was 0.045 ppb. In seawater directly opposite the river mouth, the concentration was 0.18 ppb. A sample of water taken from a bore 30 m deep 250 m north of the river mouth gave a value of 0.121 ppb. Another sample taken from a galvanized iron tank fed from the bore but diluted by fresh water, gave a value of 0.092 ppb. The sandy soil in the vicinity of the river mouth does not absorb cadmium to any extent, whereas the rich humic material in the river is a good absorber of cadmium (Rosman and De Laeter 1977). The cadmium concentrations at Greenough therefore seem to be the result of absorption and seepage mechanisms.

The concentration of cadmium in the sea water at Kalbarri at the mouth of the Murchison River, was 0.03 ppb. The Murchison River is open to the sea and drains a large agricultural area including a mineraliferous zone east of the National Park. The Carnarvon samples were collected in the ocean at Pelican Point and in the estuary of the Gascoyne River near Babbage Island. The cadmium concentrations of 0.018 and 0.051 ppb respectively are typical of coastal and estuarine waters in Western Australia.

Coral Bay, approximately 200 km north of Carnarvon, is a reef-locked bay which is not linked to any river system. A small settlement at the location is used by holiday makers. The cadmium concentration of 0.029 ppb is significantly less than the water sample taken in

Exmouth Gulf near the Exmouth townsite. The concentration here was 0.15 ppb and probably reflects the proximity of the town and the activities at the U.S. Naval Supply Depot which serves the North West Cape radio base.

The most northerly sample was collected off the coast at Pardoo Station, approximately 100 km northeast of Port Hedland. The cadmium concentration of 0.13 ppb was higher than expected at this very remote locality.

Conclusions

This study has shown that it is difficult to establish definite base-line levels for cadmium in coastal sea water, even for a relatively uninhabited area such as Western Australia. The concentration of cadmium is obviously influenced to a significant extent by industry, agriculture, estuaries and river systems. The nature of the sediment underlying the locality is also a significant factor governing the amount of cadmium in the marine environment. Remote localities which are not near rivers and have sandy sediments, show the lowest concentrations of cadmium. From these localities one can estimate a base-line concentration of 0.013 ppb cadmium for coastal sea water, and the higher values can therefore be compared to this base-line value. The highest cadmium concentration was found at Australind, and this is probably due to effluent from the ilmenite works nearby. On the other hand the cadmium values in Cockburn Sound are significantly lower, and show little evidence of industrial contamination. In fact sea water samples collected near Greenough, Exmouth and Pardoo Station show cadmium concentrations that are approximately twice as large as the highest reading found in the Cockburn Sound area.

Preston (1973) has given the results of a study of heavy metal concentrations in British coastal waters conducted in 1969-1970. Samples were collected in five coastal areas and gave cadmium concentrations from <0.01 to 0.11 ppb. Preston (1973) concludes that elevated concentrations of heavy metals are largely restricted to estuaries and the coastal margin, and are associated with drainage from industrial areas or the dumping of sewerage sludge and industrial wastes. These conclusions are also applicable to the Pacific, Gulf and Atlantic coasts of the United States (IDOE 1972).

This study has shown that the stable isotope dilution technique is an excellent method of measuring the concentrations of cadmium with reasonable accuracy at the levels typically found in sea water. The present study complements the overseas data for cadmium concentrations in coastal waters for the eastern seaboard of the Indian Ocean, and part of the Southern Ocean.

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Volume 61 1978

Part 1

Contents

	Page
Changes in artefact assemblages during the last 8 000 years at Walyunga, Western Australia. By R. H. Pearce	1
Henjochus diphreutes Jordan, a valid species of butterflyfish (Chaetodontidae) from the Indo-West Pacific. By Gerald R. Allen and Rudie H. Kuiter	11
Cadmium levels in coastal and estuarine waters of Western Australia. By P. D. Morris, K. J. R. Rosman and J. R. De Laeter	19
Membership of the Royal Society of Western Australia, March, 1978	25

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