VOL. 112, PARTS 1 & 2
31 MAY, 1988

Transactions of the
Royal Society of South Australia
Incorporated

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ROYAL SOCIETY
OF SOUTH AUSTRALIA

INCORPORATED

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REASSESSMENT OF THE TAXONOMIC STATUS OF THE SEA TURTLE GENUS *NATATOR* MCCULLOCH, 1908, WITH A REDESCRIPTION OF THE GENUS AND SPECIES

BY COLIN J. LIMPUS, EMMA GYURIS† & JEFFERY D. MILLER‡*

Summary

The taxonomic status of the flatback turtle *Chelonia depressa* is reconsidered in terms of electrophoretic and osteological data. While both kinds of data show greatest affinity with *Lepidochelys*, the similarity, in each case, is comparable to that between *Caretta* and *Eretmochelys*. *C. depressa* is dissimilar from *Chelonia mydas*. Because of its distinctiveness, the genus *Natator* is resurrected to accommodate the species *depressa*.

KEY WORDS: Taxonomy, *Natator*, *Chelonia depressa*, osteology, electrophoresis.

REASSESSMENT OF THE TAXONOMIC STATUS OF THE SEA TURTLE GENUS *NATATOR* McCULLOCH, 1908, WITH A REDESCRIPTION OF THE GENUS AND SPECIES

By Colin J. Limpus[*], Emma Gyuris[†] & Jeffrey D. Miller[‡]

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Limpus, C. J., Gyuris, E. & Miller, J. D. (1988) Reassessment of the taxanomic status of the sea turtle genus *Natator* McCulloch, 1908, with a redescription of the genus and species. *Trans. R. Soc. S. Aust.* **112**(1), 1–9, 31 May 1988.

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Key Words: Taxonomy, *Natator*, *Chelonia depressa*, osteology, electrophoresis.

Introduction

The taxonomic relationship of sea turtles (Cheloniidae and Dermochelyidae) has been examined using serological and serum electrophoretic methods (Frair 1979, 1982). Zangerl (1980) proposed a phylogeny for the Cheloniidae based on fossil and extant skeletal material. The Australian endemic sea turtle, *Chelonia depressa*, was not included in these studies. The earliest account of the species was supplied by Stokes (1846) when visiting Delambre Island (what we now know to be a large *C. depressa* rookery in Western Australia) on 27 August 1840: "A few turtles were taken, of a different kind from any we had seen before and apparently a cross between the Hawk's Bill and the Green Turtle. . ." The species was described by Garman in 1880 and its taxonomic status has been reviewed on several occasions. Boulenger (1889) placed *C. depressa* in synonomy with *C. mydas* while Baur (1890) considered *depressa* warranted separate generic ranking. McCulloch (1908) erected a new genus and species (*Natator tesselarus*) for an immature specimen which Fry (1913) showed was identical with *depressa*; Fry retained *depressa* and *mydas* as separate species within *Chelonia*. Barbour (1914) showed Garman's 1880 type series to be a composite of *mydas* and *depressa*. Loveridge (1934) thought it "more probable that the type of *depressa* is an aberrent individual which should be referred to the synonomy of *mydas*". As noted by Cogger & Lindner (1969), many workers outside Australia listed *depressa* as conspecific with *Chelonia mydas*. Within Australia, *depressa* was usually recognised as not part of *Chelonia mydas* (Glauert, 1928), although a correct identification was not always made (e.g. *Chelonia japonica*, Worrell 1963; photo of "young loggerhead turtles", Ellis 1937). Williams *et al.* (1967) suggested that *Chelonia depressa* was morphologically so distinct from other *Chelonia* populations that it may be regarded tentatively as a species. The same study, like those before it, suffered from having a small series of preserved museum specimens available for examination. Cogger & Lindner (1969) and Bustard & Limpus (1969), reporting on sympatric nesting by *C. depressa* and *C. mydas*, established *C. depressa* as distinct. Cogger *et al.* (1983) clarified the designation of a lectotype.

The present study examines the relationships of *Chelonia depressa* to four pantropical species of cheloniid turtles which occur in Australia (*Caretta caretta*, *Chelonia mydas*, *Eretmochelys imbricata* and *Lepidochelys olivacea*) using enzyme electrophoresis and skull osteology. The results of these analyses, supplemented by examination of general morphological and behavioural characters, lead to the re-establishment of the genus *Natator* and confirmation of the species *depressa*.

Materials and Methods

Electrophoresis: Muscle tissues for analysis were collected from eastern Australian turtles as follows. Hatchlings were frozen at −20°C in a domestic freezer for return to the laboratory where samples of the pectoral muscle were removed for analysis. Muscle biopsies from the triceps brachii and brachialis inferior muscles of large turtles were taken at their point of capture using "Tru-cut" (Travenol Laboratories) biopsy needles (Gyuris & Limpus 1986). Hatchling *Chelonia depressa* (n = 10) were collected at Mon Repos (24°48′S,

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TABLE 1. *Enzymes examined.*

Protein (EC number)	Abbreviation	Buffer system*	Voltage	Time (min)	Stain reference
Creatine kinase (EC 2.7.3.2)	CK	v	250	120	Richardson 1983
Fumerase (EC 4.2.1.2)	Fum	i	250	40	Richardson *et al.* 1980
Glucose phosphate isomerase (EC 5.3.1.9)	GPI	v	300	90	Richardson *et al.* 1980
Glycerol-3-phosphate dehydrogenase (EC 1.1.1.8)	G-3-PDH	i	250	60	Richardson *et al.* 1980
Lactate dehydrogenase (EC 1.1.1.27)	LDH	vi	250	40	Richardson *et al.* 1980
Malate dehydrogenase (EC 1.1.1.37)	MDH-1	iv	250	60	Richardson *et al.* 1980
Malate dehydrogenase	MDH-2	iv	250	60	Richardson *et al.* 1980
Phosphoglucomutase (EC 2.7.5.1)	PGM	i	250	60	Richardson *et al.* 1980
Phosphoglycerokinase (EC 2.7.2.3)	PGK	iii	250	120	Richardson 1983
Pyruvate kinase (EC 2.7.1.40)	PK	ii	250	60	Richardson 1983

* Buffer systems: i 0.05 M Tris-citrate, pH 7.1; ii 0.05 M Tris-maleate, pH 8.0; iii 0.05 M Tris-citrate, pH 6.8 (+ 1 mM EDTA); iv 0.05 M Tris-citrate, pH 7.0; v 0.05 M Tris-maleate, pH 8.2; vi 0.1 M Tris-maleate, pH 6.5.

152°27'E). Adult and hatchling *C. mydas* (n = 206) were collected at Heron Island (23°26'S, 151°55'E) and adjacent reefs. Adult and hatchling *Caretta caretta* (n = 506) were collected at Mon Repos and adjacent mainland beaches and from Heron Island and adjacent reefs and islands. Immature *E. imbricata* (n = 16) were captured on the coral reefs adjacent to Heron Island. *L. olivacea* (n = 2) were captured at inshore feeding grounds off Cairns (16°55'S, 145°47'E) and Townsville (19°17'S, 146°20'E). All specimens were frozen immediately following collection, transported and stored at −20°C. Approximately 10–30 mg subsamples of the muscle samples were placed in a perspex multi-well tray and 75–100 microlitres of homogenising solution (0.2 mM Cleland's reagent in distilled water) was added to each specimen. Tissues were macerated by grinding within each well. Homogenates were centrifuged in capillary tubes (microhaematocrit tubes, Clay-Adams). Clear supernatants were obtained after breaking away those sections of the capillary tubes containing fibrous material at one end and lipid layer at the other. Individual supernatants were stored in wells of microtiter trays maintained at 0–4°C. All electrophoresis was completed within 48 hr of thawing of the muscle tissues.

Zone electrophoresis was run using cellulose acetate gel supporting medium ("cellogel", Chematron). Constant voltage was delivered to electrophoretic tanks (Shandon Southern) via Pharmacia EPS 500/400 power supplies. Paper wicks of 0.33 mm thickness (Whatman Chromatography paper) were used to ensure an even buffer front. Gels were pretreated prior to sample application according to manufacturer's recommendations. Samples were loaded onto the gels using a draftsman's ink pen. Enzymes studied are listed together with their optimum running conditions and staining methods in Table 1. Enzyme nomenclature used throughout is that recommended by the Commission on Biochemical Nomenclature (1972). Where several isozymes were detected, they were numbered in order of decreasing electrophoretic mobility. Initially a subsample of approximately 60 specimens was screened for allozyme variation in both *Chelonia mydas* and *Caretta caretta*. Only loci that were found to be polymorphic were then screened in every specimen of the species. All *depressa, E. imbricata* and *L. olivacea* were examined for 19, 15 and 12 enzymic systems respectively. Nei's genetic distances (D) and their corresponding standard errors were calculated (Nei 1978). A dendrogram was constructed using the

TABLE 2. *Comparison of selected osteological characters of the skulls of the members of the Cheloniidae.*

Species (sample size)	*Chelonia mydas* (26)	*Natator depressa* (8)	*Lepidochelys olivacea* (3)	*Eretmochelys imbricata* (10)	*Caretta caretta* (13)
external pterygoid process	nil	large horizontal	large horizontal	vertical	vertical
pterygoid muscle groove	large distinct	slight	slight	nil	nil
pterygoid extends posteriorly beyond the opening of the foramen posterius canalis carotici interni	yes	no	no	no	no
maxillary lingual ridge	present	present	nil	present	nil
prefrontal and postorbital do not meet (frontal forms part of the orbit)	yes	no	no	yes	no
fenestra ovalis divided by a septum, or nearly so	no	yes	no	no	yes
development of tuberculae basioccipital	low	prominant	low	medium	low
number of channels of posterior of squamosal	2	1	2	2	1
shape of posterior margin of basisphenoid	shelf	vertical wall	vertical wall	vertical wall	vertical wall
Vagus X enclosed or partly enclosed by exoccipital	no	yes	no	no	no
Vomer contacts premaxillary	yes	yes	yes	yes	no
descending process of the prefrontal connects with the palatine	yes	no	no	no	no
pterygoid meets jugal	yes	yes	no	no	no

unweighed pair-group arithmetic average cluster analysis (UPGMA) method (Ferguson, 1980).

Skull Osteology: Skulls of each species of turtle were examined for a suite of morphological characters (Table 2). Terminology and definitions follow Gaffney (1979). Skeletal material examined included specimens gathered during field studies by the Queensland National Parks and Wildlife Service (QNPWS) and specimens held in the collections of the Queensland Museum, Brisbane (QM), Australian Museum, Sydney (AM) and Museum of Comparative Zoology, Harvard (MCZ) as follows: AM R28486, female, Port Essington, 27 March 1967. QM J3848, Queensland, collected pre 1923; J4058, Mackay, collected pre April 1924. QNPWS: X28144, unsexed adult, Cape Hillsborough, 1982; X33703, adult female, Facing Island, January 1970; X33704, adult female, Peak Island, December 1981. Two unnumbered hatchlings from Mon Repos, January 1982. MCZ4473 (Lectotype), "Northern Australia". A detailed description of the osteology of *depressa* is in preparation (J. Hendrickson pers. comm.).

Supplementary Information: Photographs of the specimens of Garman's (1880) type series in the Museum of Comparative Zoology (MCZ), Boston, were examined. Information and data on the general biology, behaviour and external morphology of adults and their eggs and hatchlings were extracted

TABLE 3. *Similarity matrix of Nei's genetic identity values.*

	Natator depressa	*Lepidochelys olivacea*	*Caretta caretta*	*Eretmochelys imbricata*
Chelonia mydas	0.52 (0.38)	0.70 (0.40)	1.01 (0.43)	0.70 (0.40)
Natator depressa		0.22 (0.35)	0.56 (0.38)	0.36 (0.37)
Lepidochelys olivacea			0.76 (0.40)	0.51 (0.38)
Caretta caretta				0.40 (0.36)

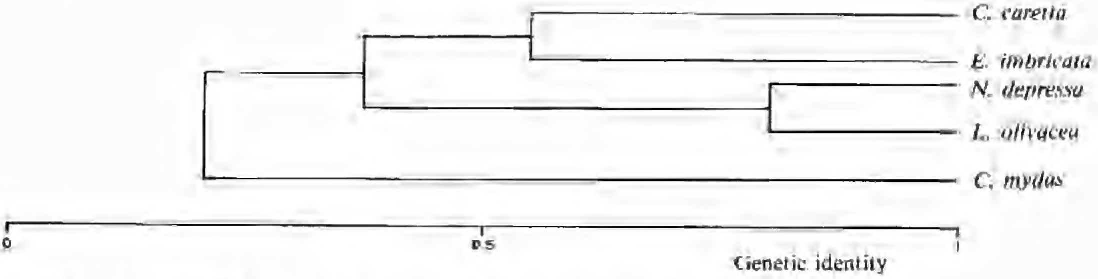

Fig. 1. Dendrogram of cheloniid turtle relationships based on electrophoretic data (Table 3).

from the literature: Coburg Peninsula and other areas of the Northern Territory (Fry 1913; Cogger & Lindner 1969); Crab Island (Limpus *et al.* 1983); south east Queensland (Limpus 1971, Limpus *et al.* 1981).

Results

Electrophoresis

A survey of 27 presumptive loci, coding for protein products in *Chelonia mydas* and *Caretta caretta* revealed low levels of genetic variation (Gyuris & Limpus 1988). Paucity of electrophoretic variation also characterised *depressa* and *E. imbricata*. Ten loci could be used without ambiguity from the five species of sea turtles examined (Table 1) and the results are summarised in Table 3 and Fig. 1. The greatest similarity was found between *depressa* and *L. olivacea*. Similarity between *depressa* and *Chelonia mydas* was less than that between *Caretta caretta* and *E. imbricata*.

Skull osteology

Gaffney (1979) provides an annotated review of the primary literature concerning the skulls of marine turtles and presents illustrations of all recognised cheloniid species except *depressa*. Hay (1908), Kesteven (1911), and Carr (1952) provide additional illustrations. Fry (1913) described some aspects of the cranial osteology of *depressa* based on observations of a single immature skull and provided a comparison of specific features of the skulls of *depressa* and *mydas* based on 1 and 7 specimens respectively. Those notes are re-presented with new information in Table 4. The description and illustration of the pterygoid of *depressa* given by Fry (1913, Fig. 49F) are incorrect because the external pterygoid processes were omitted. The correct position and shape of the external pterygoid process are illustrated in Fig. 2A. The external pterygoid process projects laterally from the pterygoid and terminates with a slight twist with an upward inflection and is characteristic of all *depressa* skulls examined. The skull from which Fry prepared his description (Fry 1913) (specimen No. 7) cannot be located for re-examination (H. G. Cogger pers. comm.). The reason for the omission cannot be determined. The details of the descriptions of the skulls given by Fry indicate that if the process had been present he would have described it. The type specimen for *N. tessellatus* (AM R4158) also cannot be located for re-examination (H. G. Cogger pers. comm.). Attempts to observe the pterygoid bones of the lectotype of *depressa* (MCZ 4473) using X-rays were unsuccessful. This was because the head of this specimen had been filled with plaster of paris when originally mounted.

The skulls of *depressa* and *Lepidochelys olivacea* and *L. kempii* have very similar pterygoid bones which differ markedly from those of *Chelonia mydas* (Fig. 2B) and the remaining cheloniid turtles. A comparison of selected osteological characters of the skulls of members of the Cheloniidae (Table 2) shows *depressa* differs from *Chelonia mydas* in many characters. Of the 13 characters considered, *depressa* and *mydas* differed by ten features; whereas, *depressa* and *L. olivacea* differed by six. *depressa* differed from *C. caretta* and *E. imbricata* by seven and eight features respectively.

TABLE 4. *Detailed comparison of selected osteological characters of the skulls of* Chelonia mydas *and* Natator depressa.

Chelonia mydas	*Natator depressa*
Frontal forms part of orbit	Frontal not forming part of orbit
Prefrontal and post orbital do not meet	Prefrontal and post orbital meet
Opening of foramen posterius canalis carotici interni within pterygoid; not contiguous with other bones	Opening of foramen posterius canalis carotici interni not within pterygoid; contiguous with exoccipital and basioccipital
Exoccipital not separating fenestra ovalis with a septum	Exoccipital separates fenestra ovalis with septum to form (or nearly form) tube
Processus pterygoideus externus wide and only bulges into fossa temporalis inferior without distinct dorsal inflection	Processus pterygoideus externus narrow extending into fossa temporalis inferior with distinct terminal dorsal inflection
Basioccipital with low rounded tuberculae; basioccipital protruding on either side of wide trough	Basioccipital with prominent tuberculae; basioccipital forming vertical walls of narrow trough
Foramen nervi hypoglossi situated in recess of exoccipital	Foramen nervi hypoglossi situated on flat area of exoccipital
Posterior of squamosal with two steep walled channels	Posterior of squamosal with single wide channel
Interorbital space, at outer angle of frontal, one-third of greatest width of skull	Interorbital space, at outer angle of frontal, two-thirds of greatest width of skull
Parieto-squamosal suture always quite distinct, to 3.8 cm in length in adults	Parieto-squamosal suture extremely small
Fronto-parietal suture strongly arched	Fronto-parietal suture transverse
Length of fronto-parietal suture two-thirds to three-quarters greatest width of frontals	Length of fronto-parietal suture equals greatest width of frontals
Pterygoids deeply constricted on each side by oblique pterygo-mandibular sulcus	Pterygoids not constricted by deep pterygomandibular sulcus on each side
Basisphenoidal ridge angled posteriorly to form shelf	Basisphenoidal ridge presents vertical wall at posterior face

Based on these characters, the skull of *depressa* is least similar to *mydas* and most similar to *L. olivacea*. Based on skull characteristics, *depressa* and *mydas* should not be considered congeneric.

Supplementary information

depressa is a carnivorous turtle that feeds principally on benthic animals in soft bottomed communities. It also eats jellyfish. Its carnivory contrasts with the herbivory of the green turtle. *depressa* feeds more on soft-bodied prey (soft-corals, sea-pens) rather than on prey with thick exoskeletons as is eaten by *Lepidochelys* and *Caretta*.

depressa at all sizes except hatchlings and early post hatchlings has a smooth low domed carapace which is distinctly reflexed dorsally at the lateral margins (Bustard & Limpus 1969; Limpus 1971). In cross section the carapace is bow-shaped; in other cheloniid species the carapace is much higher domed and not reflexed on the lateral margin. Hatchling and early post-hatchling *depressa* are not as high domed as the hatchlings of other species but do not have the dorsally reflexed marginal rim. Relative to this characteristic, within the Cheloniidae, *Lepidochelys* with its wide flat marginal rim to the carapace shows the greatest similarity to *depressa*.

The integument of the carapace of *depressa* with a CCL greater than approximately 16 cm is a soft, thinly keratinised skin rather than a series of hard, keratinised scutes. To the touch, it is very similar to the carapacial skin of *Dermochelys coriacea*. Following death and decomposition, there are no large keratinised scutes which can be peeled from the carapace, as occurs with the other cheloniids. Because of the reduced epidermal keratinisation of the carapace, the scutes which are so prominent on

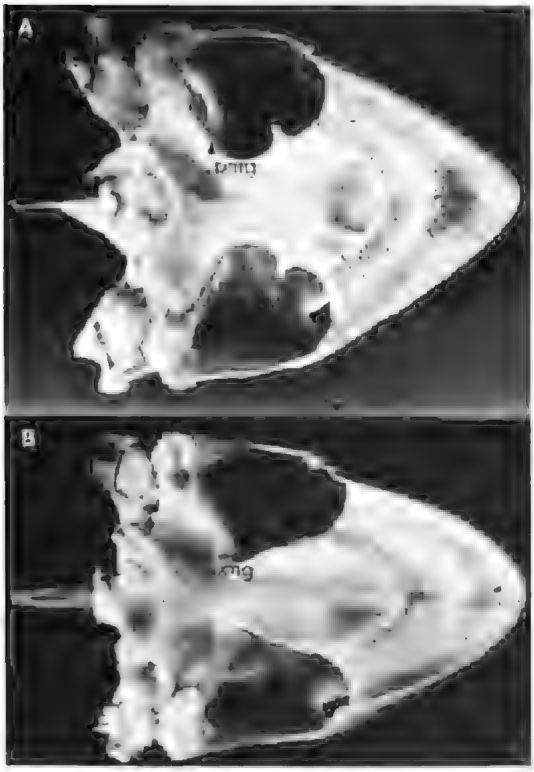

Fig. 2. Ventral view of sea turtle skulls. epp = external pterygoid process, pmg = pterygoid muscle groove. A. *Natator depressa*, adult female (QNPWS X33704). Note the prominent external pterygoid process and poorly developed pterygoid muscle groove. B. *Chelonia mydas*. Note the absence of the external pterygoid process and the well developed pterygoid muscle groove.

the hatchlings are difficult to delineate in the adult. The scutes of the hatchlings are usually strongly pitted and form areolae-like structures as each scute area increases during growth. The areolae are shed to produce the smooth skin like surface of the carapace (CCL between 10 and 16 cm). Within the Cheloniidae, post hatchling *Lepidochelys* also have limited keratinization of carapacial scutes.

Only hatchling *depressa* and *C. mydas* are white ventrally, although the ventral surface of some hatchlings of the other species of Cheloniidae can be light coloured (yellowish instead of brown). In contrast the adults of all species of the family are light coloured (white, cream, or yellow) ventrally. Only in *depressa* and *C. mydas* does a distinct white band outline the margin of the carapace and the flippers. Dorsally *depressa* hatchlings are the most distinctively coloured of all the sea turtles (Limpus 1971).

The gait of hatchling *depressa* on the beach is the typical alternating gait used by all hatchling Cheloniidae. Adult *depressa* move by pushing with all four flippers together in a manner similar to that of *C. mydas* and *D. coriacea* (Limpus 1971). The short front flippers of *depressa* result in a track with less of the front flipper print remaining outside the hind flipper prints than occurs with *C. mydas*.

During egg laying, *depressa* leaves one hind flipper within and pressed against the wall of the egg chamber while the other hind flipper is placed flat on the sand surface to partly cover the opening of the egg chamber (Bustard *et al.* 1975). This posture resembles that of *C. mydas* and *D. coriacea*. In contrast *Caretta*, *Eretmochelys* and *Lepidochelys* have both hind flippers removed from the egg chamber and flat on the sand behind the egg chamber while laying.

The eggs of *depressa* are characteristic and distinctive from those of other species of Cheloniidae. The mean egg diameter measures greater than 4.65 cm and the mean clutch count is approximately 50 (Cogger & Lindner 1969; Limpus, 1971; Limpus *et al.* 1983). The eggs of *depressa* are large and of similar size to those of *D. coriacea* but clutches can be distinguished from the latter because *D. coriacea* clutches always include large numbers of small irregular shaped yolkless eggs (Limpus *et al.* 1984), while yolkless eggs rarely occur in *depressa* clutches and then only in small numbers (Limpus 1971; Limpus *et al.* 1983). Hirth (1980) provides a summary of clutch data from non-Australian populations of other species.

The specimen illustrated by Deraniyagala (1971) as a possible *depressa* from Ceylon in no way resembles any *depressa* we have ever seen and its identification is not supported. The Garman (1880) specimen of *depressa* from East Indies has been shown to be a hatchling *Chelonia mydas* from Penang, Malaysia (Barbour 1914). The only record of *depressa* from beyond the Australian Continental shelf is based on photographs of a stuffed immature specimen from off the north coast of Java (photographs made in 1984 by G. Usher were examined by CJL). The species has been recorded breeding only in Australia where it has a wide nesting distribution. Major breeding aggregations can be found at Peak Island, Wild Duck Island and Avoid Island in central eastern Queensland; Deliverace Island and adjacent islands or north western Torres Strait; Crab Island and the Sir Edward Pellew Islands in the Gulf of Carpentaria; Wessel Islands, Greenhill Island and Field Island in the Northern Territory and Delambre Island on the north west shelf of Western Australia. There are numerous other less important nesting locations.

Discussion

Interpretation of the present electrophoretic study is limited because of the small number of loci used

(Nei 1978). However even with that constraint the data still provide useful information. Friar (1982), in reviewing all the available biochemical data based on serum electrophoresis (band-counting method), immuneoelectrophoresis and serology, constructed a tentative dendrogram suggesting possible sea turtle relationships. The present study corroborates Friar's model and extends it by examining the taxonomic status of *depressa*. On the basis of the electrophoretic data it would appear inconsistent to continue viewing *depressa* and *mydas* as congeneric.

Most taxonomic revisions of *depressa* have been based on examination of a small number of museum specimens. Several unusual characters of the species, especially the thinly keratinised scutes and the upwardly reflexed lateral marginal rim of the carapace, have in the past led to the idea that the lectotype of *depressa* (Fig. 3) was possibly an aberrent specimen (Loveridge 1934; Williams *et al.* 1967). This specimen is not aberrent but is a good representative of the adult *depressa* which can be seen on any of its numerous rookeries in tropical Australia. If there is anything unusual about the lectotype, it is in terms of the way the flippers have been prepared for display.

Baur (1890) commented that clarification of the generic status of the flatback turtle had to wait "until the skull of this species is known. . ." This has been rectified. Both the electrophoretic and osteological characteristics of *depressa* provide a clear separation of it from *Chelonia* at the generic level.

Past studies have noted similarities between *depressa* and *Lepidochelys* (Baur 1890; Williams *et al.* 1967). The first *depressa* skulls registered in the collection of the Queensland Museum were assigned to *Caretta caretta* after being identified as *Caretta remivaga* (= *Lepidochelys olivacea*; QM J3848) and *Colpochelys kempii* (= *L. kempii*; QM J4058) respectively. The present study has identified many common characters shared by *depressa* and *Lepidochelys*. However this similarity is comparable to the degree of similarity that exists between *Caretta* and *Eretmochelys* and between *Caretta* and *Lepidochelys*. Given the common acceptance of the generic discreteness of these latter genera, *depressa* must also be recognised at the generic level.

These data warrant resurrecting the genus *Natator* to accommodate the species *depressa*.

Genus *Natator* McCulloch

Natator McCulloch, 1908, pp. 126–8.

Type species: *N. depressa* (Garman, 1880).

Diagnosis: Because of the confused history of the nomenclature, the genus *Natator* is redefined based on the original descriptions by McCulloch (1908) and Garman (1880), revisions by Fry (1913) and Williams *et al.* (1967) and descriptions of the morphology from the *N. depressa* nesting populations at Coburg Peninsula (Cogger & Lindner 1969), Mon Repos (Limpus 1971) and Crab Island (Limpus *et al.* 1983) and our more recent unpublished observations.

Body broad, depressed, subelliptical, broadest near or behind the middle. In larger specimens, carapace flattened over the second to the fourth vertebral scutes and with lateral marginal rim reflexed upwards. Head and carapace covered with non-imbricate keratinised scutes, each with distinct symmetrical areolae in the young. Areolae shed before carapace length of approximately 16 cm. In adults, carapace scutes thinly keratinised, indistinct with waxy feel. Usual scute pattern as follows. Carapace: nuchal shield undivided; five vertebrals; four pairs of costals; twelve pairs of marginals. Plastron: thirteen scutes, in two series of six each, preceded by small but well developed triangular intergular. Inframarginals: four on each bridge, no

Fig. 3. *Natator depressa* lectotype (MCZ 4473). A. Head showing distinct preoccular scute (po). B. Whole mount showing flattened carapace with reflexed lateral marginal rim and indistinct scutes. Ruler = 1 m.

inframarginal pores. Head: one pair large prefrontals; one pair preoculars lying between prefrontals and upper jaw sheath; frontal in contact with prefrontals and pair of large supraoculars; parietal shield very large; post-parietal in odd numbered series symmetrically arranged behind post parietal (if even numbered array occurs, usually assymmetrically arranged); three post-oculars lying posterior and postero-ventral to each eye, lowest large. Colour: Hatchlings, in life gray dorsally with each scute outlined in black; ventrally white; posterior margin of carapace and flippers outlined in white; iris blue. Adults, in life dorsally olive-gray; ventrally white; iris brown. Limbs: paddle-shaped (= flippers), each with two claws in young (more distal claw becoming less obvious in larger turtles); distal half of forelimb with single rows of enlarged scales extending along phalanges separated by areas of smaller irregular scales or wrinkled skin. Head larger and broader than that of *C. mydas*, broad posteriorly, convex on occiput, flattened between and compressed in front of eyes. Upper jaw not serrated, outline nearly straight, with notch at symphysis almost obliterated, vertically grooved on inner face. Lower jaw serrated (not obvious in hatchlings), bearing sharp recurved prominence on the symphysis. Single choanal spine at each internal naris.

The skull of *Natator* has the following characteristics (Table 3, 4). Frontal not forming part of orbit; prefrontal and post orbital meet. Processus pterygoideus externus narrow extending into fossa temporalis inferior with distinct terminal inflection. Pterygoids not constricted by deep pterygomandibular sulcus on each side. Pterygoid not extending posteriorly beyond opening of foramen posterius canalis carotici interni. Fenestra ovalis divided by septum (or nearly divided). Tuberculae basioccipital prominant. Fenestra for vagus X enclosed or partly enclosed by exoccipital. Descending process of prefrontal not connecting with palatine; pterygoid meets jugal.

Natator depressa (Garman) New Comb.

Chelonia depressa: Garman, 1880, Bull. Mus. Comp. Zool. 6, p. 124 (in part); Baur 1890, Amer. Nat. 24, p. 487; Fry 1913, Rec. Aust. Mus. 10, p. 159; Cogger & Lindner 1969, Aust. Zool. 15, p. 154; Bustard & Limpus 1969, Herpetologica, 25, p. 29; Cogger *et al.* 1983, Zoological Catalogue of Australia. Vol. 1. Amphibia and Reptiles, p. 69.

Chelonia japonica: Worrell, 1963, Reptiles of Australia, p. 10.

Chelonia mydas: Boulenger, 1889, Catalogue of the Chelonians, Rhynchocephalians and Crocodiles in the British Museum (Natural History), p. 182; Loveridge 1934, Bull. Mus. Comp. Zool. 77, p. 261.

Natator tessellatus: McCulloch, 1908, Rec. Aust. Mus. 7, p. 126.

Lectotype: MCZ 4473 from northern Australia (possibly purchased in Torres Strait, Barbour 1914) (Cogger *et al.* 1983). Adult sized, probably a female.

Diagnosis: As for the genus.

Geographical distribution: Feeding grounds occur within the warm temperate and tropical waters of the Australian continental shelf, including southern New Guinea waters and along the north coast of Java. Only known to breed in Australia.

Acknowledgments

This study was conducted within the Queensland Turtle Research Project of the Queensland National Parks and Wildlife Service. It was funded in part by a Marine Science and Technology Grant from the Australian Department of Science. Logistic support was provided to E.G. by the Alfred Hospital, Melbourne. Dr Perran Ross provided photographs of the Garman 1880 type series. J. P. Rosado provided radiographs of the head of the lectotype. Dr J. Stoddart aided the analysis of the electrophoretic data. Dr E. Gaffney, Dr P. Baverstock and J. Covacevich gave constructive criticism of early drafts of the manuscript.

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FLINDERS/MOUNT LOFTY RANGES, SOUTH AUSTRALIA THEIR UPLIFT, EROSION, AND RELATIONSHIP TO CRUSTAL STRUCTURE

BY P. WELLMAN & S. A. GREENHALGH†*

Summary

The Flinders/Mount Lofty Ranges are low, elongate highlands. The amount of denudation, the present earthquake activity, and the age of the sediments in the region, are consistent with uplift starting in the Palaeocene or earlier, with uplift and erosion continuing to the present. Seismic, gravity and heat flow observations are consistent with the crustal load of the ranges being supported in regional isostatic compensation by a relatively strong lithosphere, the ranges not having a crustal root, and denudation not being followed by a similar amount of isostatic rebound. The axis of the ranges is coincident with an elongate gravity anomaly high, that may be due to high density in the underlying basement. The ranges probably represent reactivation of the crustal structure causing this gravity anomaly.

KEY WORDS: Flinders Ranges, Mt Lofty Ranges, geomorphology, gravity anomalies, magnetic anomalies, seismic, Adelaide Orogen.

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KEY WORDS: Flinders Ranges, Mt Lofty Ranges, geomorphology, gravity anomalies, magnetic anomalies, seismic, Adelaide Orogen.

Introduction

The Flinders/Mt Lofty Ranges (Fig. 1) have a roughly north-south trend, are 40-100 km wide, 600 km long, and have a mean axis height of 0.2 to 0.6 km. Both these ranges and the Eastern Highlands are relatively elongate. They differ from the broad areas of high altitude in western Australia, central Australia, and in the Kimberley area of northwest Australia. These broad uplifts conform to the pattern for other continents (Wyatt 1986).

The Flinders/Mt Lofty Ranges were uplifted to their present altitude after the Palaeozoic. This paper reviews the information on the timing and amount of uplift, the rate of Cainozoic denudation, their isostatic support, and the underlying crustal structure. An understanding of the history and structure of these ranges is useful in understanding the associated earthquake activity, which has caused considerable property damage.

Timing of the uplift

Geological constraints

Formation of the Mt Lofty-Flinders Ranges was by uplift of a land surface of low relief developed on Adelaide Orogen rocks of Late Proterozoic and Cambrian age. There are differences of opinion on the timing of the uplift, with some writers advocating most uplift in the late Cainozoic. Webb (1957) considered that the Mt Lofty and Flinders Ranges were uplifted by "broad regional upwarping and doming, associated with strong faulting", the tectonic activity continuing through the Tertiary, but culminating in the Late Pliocene to Early Pleistocene times. Firman (1969) thought that the modern landscape of the Mt Lofty and Flinders Ranges was late Cainozoic. The movements were by block faulting and tilting commencing "in the late Miocene, and continued through the Pliocene into the Quaternary", and he linked the later movements with the Kosciusko Orogeny. Twidale (1976) believed that the uplift of the Mt Lofty Ranges was either Late Mesozoic or earliest Tertiary. Williams & Goode (1978) accepted that the Mt Lofty Ranges were uplifted in the Late Cainozoic, and thought that the Murray River crossed these ranges in the Eocene or Miocene (cf. Gostin & Jenkins 1980; Harris *et al.* 1980). Veevers (1984) argued that the inception of the highlands was in the Cambrian, with high ground since the Carboniferous. He reviewed the Cainozoic sedimentological evidence, and concluded that the highlands were uplifted in the Palaeocene, the Eocene, and later.

There is very little firm evidence to constrain the time of the uplift. At the northern end of the Flinders Ranges (A of Fig. 1) remnants of Early Cretaceous sediments occur on ridge tops, so uplift in the north must have been subsequent to this time. At the northern end of the Mt Lofty Ranges, Alley (1973) showed that uplift and dissection of the ranges was prior to disposition of the Snowton Sands of Miocene age. In the southern Mt Lofty Ranges (F of Fig. 1) there are two elongate valleys containing uplifted early Miocene (Batesfordian Stage) limestones. The top of the limestone in the Hindmarsh Tiers Basin is 210 m, and in the Myponga Basin it is 238 m (Furness *et al.* 1981), while the tops of the surrounding hills are about 400 m altitude. A limestone of similar age in the Murray River gorge 50 km to the east (G of Fig.

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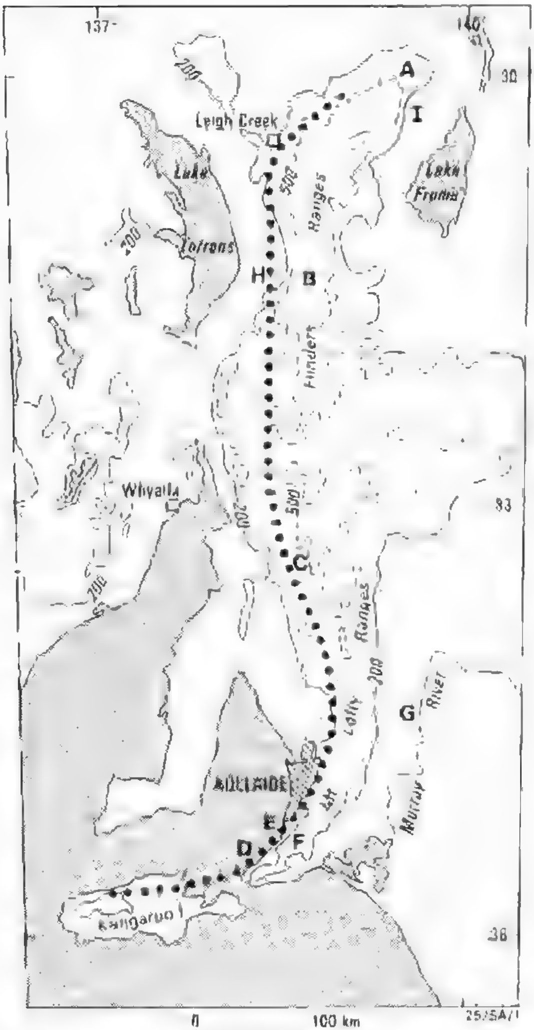

Fig. 1. Relief. Contours at 200 m (continuous), 500 and 1000 m (dashed). Letters are referred to in the text. Dotted line is along the western margin of the higher part of the Flinders/Mt Lofty Ranges, and along a gravity gradient of Fig. 2.

1) has a top at about 40 m altitude. Both limestones are mainly worn, coarse shells deposited in very shallow water. Hence the post-Early Miocene uplift relative to the Murray Basin was about 200 m, and this uplift is approximately one half of the total uplift. On some of the margins of the highlands (D, H, I of Fig. 1) there is faulting of inferred Quaternary age, and thick fluviatile deposits, both consistent with considerable Quaternary uplift. In these areas the margins of the highlands are fault line scarps that are relatively continuous and steep, so they are thought to have been reactivated in the Late Cainozoic. In contrast some areas within the highlands (e.g. B of Fig. 1) have wide "U" shaped valleys with narrow residual hills that must have started eroding prior to the late Cainozoic.

Other evidence is more subjective. Callen (1983) has shown that at the northern end of the Flinders Ranges two silcretes were developed, a mid Cainozoic silcrete formed between Early Eocene and Early Miocene that is now largely eroded away, and an extensively outcropping silcrete of mid Miocene to early Pleistocene age. These silcretes are interpreted by Callen to be warped and faulted. This is consistent with some late Cainozoic uplift. In the Mt Lofty Ranges, evidence for substantial relief on the land surface in the early Cainozoic is of three kinds. Firstly, lateritic and silcrete surfaces of possible Eocene or Palaeocene age have developed on a similar drainage system to the present in the Broughton River area (C of Fig. 1) (Gostin & Jenkins 1980; c.f. Milnes *et al.* 1985). Secondly, gravelly fluviatile deposits, of middle Palaeocene or older age, occur in the western Murray Basin, and are thought to be derived from rejuvenation of the highlands (Twidale *et al.* 1978). Thirdly, in the Willunga Embayment (E of Fig. 1), south of Adelaide, there is a considerable thickness of coarse sands of Eocene age (Lindsay 1986), that may be due to local erosion at that time.

In summary, at the northern end of the Flinders Ranges the uplift was after the Early Cretaceous, with some uplift continuing in the late Cainozoic. In the middle and southern Mt Lofty Ranges, about one half the uplift was prior to the mid Cainozoic, and uplift continued. The initial uplift of the ranges is likely to have been in the Palaeocene or earlier.

Denudation

The Late Cretaceous/Cainozoic denudation rate has not been determined for the Flinders/Mt Lofty Ranges. However a denudation rate can be estimated from those found elsewhere in Australia. In the Eastern Highlands in New South Wales and Queensland (which has a similar altitude and local relief to the Flinders/Mt Lofty Ranges) average Cainozoic denudation rates have been determined by numerous authors using dated Cainozoic volcanics for time control (Wellman 1987) to lie between 0.5 and 5 m.Ma^{-1}, with a mean of about 3 m.Ma^{-1} (1 m.Ma^{-1} = 1 mm/1000 years = 1 Bubnoff unit). For the shield of southwest Australia, Van de Graaf (1981) infers a denudation rate of 1.5-2 m.Ma^{-1} for the humid late Cretaceous and Early Tertiary, and about 0.2 m.Ma^{-1} during the dry period since the Miocene. A study by G. E. Wilford (pers. comm.) gives the mean Cainozoic denudation rate in Australia for areas of relatively low relief. For eight areas covering over one half of Australia, but not including the Eastern Highlands, the estimates range from 0.5 to 2.3 $m.Ma^{-1}$ with a mean of 1.3 $m.Ma^{-1}$. All these estimates are consistent with the Flinders/Mt Lofty Ranges having a mean Cainozoic denudation rate in the range 1-4 $m.Ma^{-1}$, with a most probably value near 3 $m.Ma^{-1}$.

With these low average erosion rates there would be a long lag time between uplift and subsequent erosion. Hence, in contrast to models such as Jones & Veevers (1982) where a pulse of uplift is followed within a few million years by a pulse of erosion, it seems likely that uplift is followed by slow erosion over long periods — of the order of 50-100 Ma.

An estimate of the minimum total denudation of the Flinders and Mt Lofty Ranges can be determined by assuming that before uplift there was a surface of low relief, and that this surface is now at or above the level of the present summits. With this assumption the minimum volume eroded is the volume between an envelope over the summit levels and the present land surface. On the PARACHILNA 1:250 000 sheet area of the central Flinders Ranges (B of Fig. 1), the local relief averages about 500 m, with only narrow elongate hills above nearly flat valley floors, so denudation below the summits is about 500 m. In this area hard rocks form hills. Other rocks form the flat bottomed valleys, giving an area of "mature" landscape. In the Mt Lofty Ranges the local relief is 200 to 500 m, with only 50% of the rock removed between local stream base and summit level, so denudation below the summits is about 200 m.

Using the most likely denudation rate of 3 $m.Ma^{-1}$, these total denudations give a calculated time period for erosion of 170 Ma for the Flinders Ranges and 70 Ma for the Mt Lofty Ranges. These periods of erosion would first start when there was some local relief, and would not be very dependent on the uplift history. They are consistent with uplift and erosion starting prior to the Cainozoic, with erosion continuing since then.

Isostatic compensation of topography

Gravity anomalies

In the Flinders/Mt Lofty Ranges area, Wellman (1979) showed that the best Airy/Heiskanen isostatic model (after correction for sediment) had compensation near infinite depth, and for this model the $0.5 \times 0.5°$ area anomalies had a larger scatter than those of the relatively weak crust of the southeastern highlands of Australia. Both these observations are here interpreted as indicating a relatively strong crust, with regional rather than local isostatic compensation of topography.

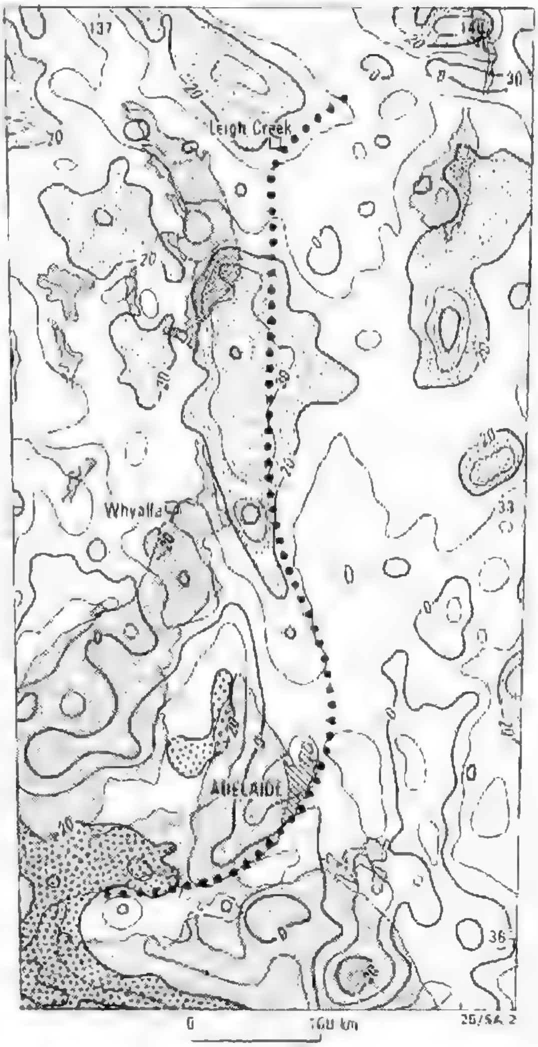

Fig. 2. Gravity anomaly map — Bouguer anomalies on land, free air anomalies at sea. Contour interval 50 $\mu m.s^{-2}$; density used in the Bouguer anomaly reduction is 2.67 $t.m^{-3}$ (after BMR, 1976b).

Bouguer gravity anomalies within the Flinders/Mt Lofty Ranges are generally more positive than over the adjacent lowland, in particular the higher parts of the highlands (east of the dotted line of Fig. 1) corresponding with a relative gravity high (east of the dotted line of Fig. 2). This is consistent with the ranges not having a significant isostatically compensating crustal root (or other compensating body) directly underlying them, but being isostatically compensated by deep bodies over a broader region, the load being spread regionally by a relatively strong lithosphere.

The regional compensation of topography has implications for isostatic rebound subsequent to denudation of the ranges. In areas elsewhere, of weak crust and local isostatic compensation of topography, any denudation of, say, a 1×1° area results in isostatic rebound of this 1×1° area. The average altitude after denudation is only slightly less than before denudation, and erosion does not therefore significantly reduce the average altitude of a mountain range. However the effect is different if regional isostatic compensation is assumed, such as is inferred for the Flinders/Mt Lofty Ranges. Denudation restricted to the range will cause uplift of the whole area of compensation, and because the total volume of uplift is slightly less than the volume of denudation, any denudation will result in only minimal rebound of the highlands. In a model of constant rate of uplift and a constant smaller rate of denudation, there would be an increase with time in both the average altitude of the crest of the ranges and its local relief. With a model where most of the uplift occurs early, and where the denudation rate is constant, then after uplift there would be a significant decrease in the average altitude of the ranges, and an increase in local relief.

Seismic studies of the crust

The variation of the mean velocity of the upper crust in the area has been studied by Greenhalgh & Tapley (1988) using local earthquakes and a tomographic technique. The study shows variations in the P-wave velocity are from 5.9 to 6.5 km.s^{-1} (Fig. 3). Much of the Flinders/Mt Lofty Ranges are underlain by relatively high velocity crust, and much of the area immediately west of the ranges is underlain by relatively low velocity crust.

Crustal thickness variations in South Australia were derived by a time-term analysis of local earthquake Pn travel time (Singh 1985)[1]. The mapped time-term values range from 1.4 to 5.1 seconds (Fig. 4). A low time-term corresponds to a relative crustal velocity high and/or a relatively thin crust. Conversely, a high time-term implies low crustal velocity and/or thick crust. There is a close association between the tomographic velocity map of Fig. 3, and the time-term map of Fig. 4. The major part of the observed time-term variation is accounted for by known lateral variation in crustal velocity. The remaining time-term variation can be explained by a crustal thickness variation of ± 5 km.

The Flinders/Mt Lofty Ranges are characterized by a time term of 2.5 to 3 seconds. Using the measured average velocity of 6.3 km.s^{-1}, this gives a crustal thickness of 26 to 28 km. The area at the head of Spencer Gulf, west of the highlands, has a crustal velocity of 5.9 km.s^{-1}, and a time term of 3-3.5 s, so it has a similar calculated crustal thickness of 26 to 30 km.

Crustal thicknesses were also obtained by Shackleford & Sutton (1981), who recorded an east-west refraction profile across the northern Mt Lofty Ranges using quarry sources at Iron Baron on Eyre

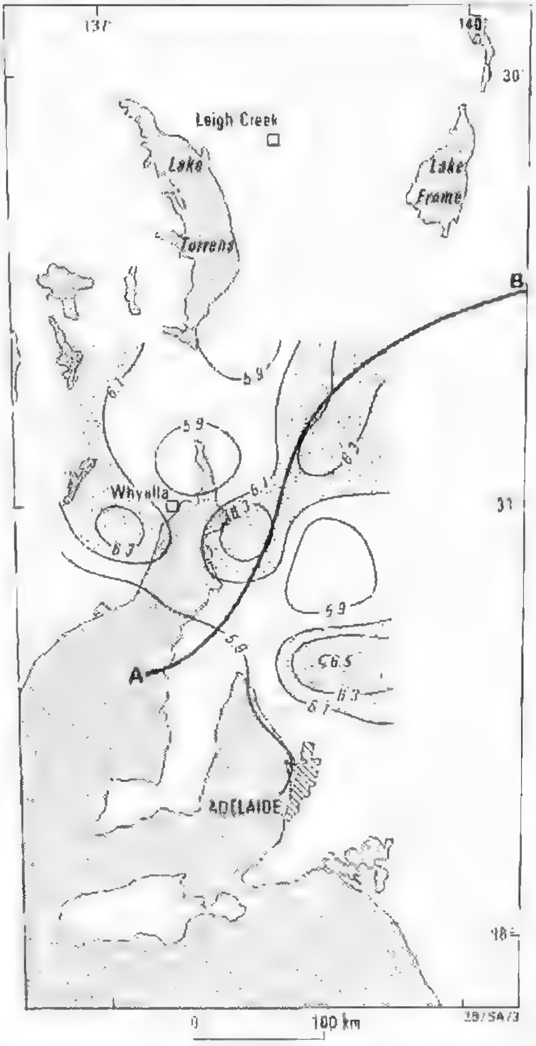

Fig. 3. Lateral seismic P-wave velocity in the upper crust, obtained from tomographic analysis of local earthquake data. Contour interval 0.2 m.s^{-1} (after Tapley 1984[3]). Line A-B is the position of the elongate electrical conductor (from Chamalaun 1986).

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[1] Singh, R. (1985) Seismicity and crustal structure of South Australia. M.Sc. Thesis, Flinders University, Adelaide (unpubl).

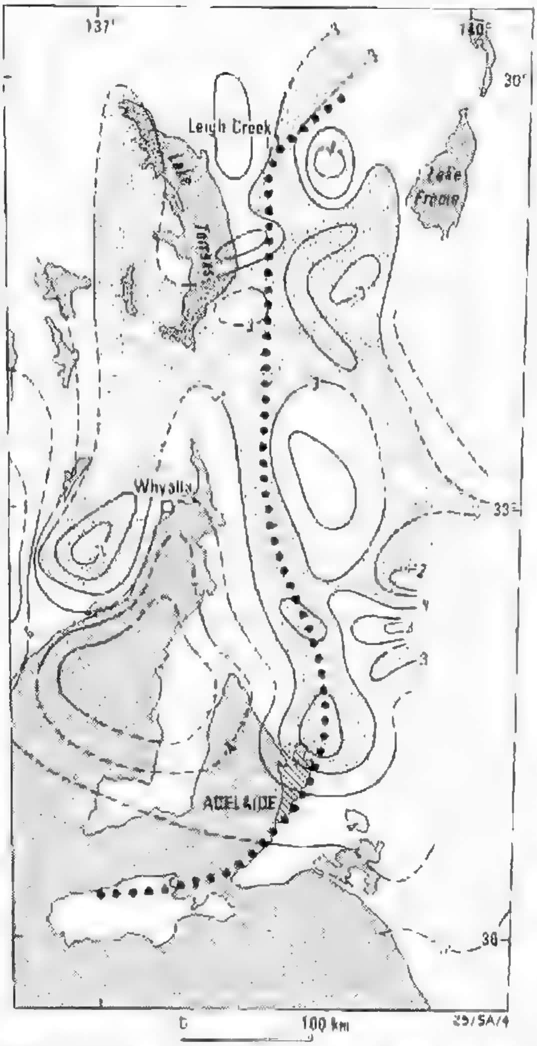

Fig. 4. Seismic travel-time delays, obtained from time-term analysis of earthquake Pn data. Contour interval 0.5 s (after Singh 1985[1]).

Peninsula. These profile data were reinterpreted by Tapley (1984)[2] using an iterative ray tracing technique. The inferred crustal thicknesses were fairly uniform; the crust underneath the Adelaide Orogen, in the region of the northern Mt Lofty Ranges, not being appreciably thicker than that beneath the Murray Basin and Eyre Peninsula.

These earthquakes and explosion results are consistent with the ranges not having a significant crustal root, their mass being supported by regional isostatic compensation. In particular there is no evidence for a thick root of velocity about 7.5 km.s^{-1}, such as is found under the Eastern Highlands (Finlayson *et al.* 1979). However the ranges appear to have higher crustal velocity than the surrounding area.

A strong lithosphere implies a relatively cool lithosphere. Cull (1982) found a 3×3° average heat flow of 70-90 mW.m^{-2} for the area, which is only slightly higher than the world average of about 60 mW.m^{-2}, and consistent with a lithosphere of near average strength.

Another major geophysical anomaly is the elongate conductor mapped using geomagnetic deep sounding arrays (A-B of Fig. 3) (Chamalaun 1986). The depth and cause of this conductor is not clear. In particular it appears independent of the Flinders/Mt Lofty Range structures.

Earthquake activity

Earthquake activity in S. Aust. is predominantly in the topographically high area over 200 m altitude (Fig. 5). Much occurs in the Adelaide Orogen extending from Leigh Creek in the north to Kangaroo Island in the south (Greenhalgh *et al.* 1986). The greatest concentration of epicentres occurs in the Flinders Ranges adjacent to the northern end of Spencers Gulf; other concentrations occur in the Mt Lofty Ranges, in the relatively high land near Broken Hill, and along a low topographic high that extends northwest from the Flinders Ranges. Over 80% of the activity takes place within the upper crust at depths of less than 20 km.

Using earthquake data from 1969 to 1985 we have computed the average focal depth of ¼° latitude by 1/8° longitude areas covering S. Aust. There is no conspicuous concentration of deeper earthquakes beneath the Flinders/Mt Lofty Ranges. The only striking feature is the shallow nature of the seismicity in S. Aust.

Focal mechanisms have been obtained for six earthquakes occurring in the central Flinders Ranges (Greenhalgh *et al.* 1986). The predominant principal stress is northeast-southwest compression, with the major movements being strike-slip in type. The simplest model explaining the general correlation of earthquakes with relative topographic highs, is for a component of thrust faulting to cause a thickening of the crust, the faulting and uplift to have continued throughout the Cainozoic. As there seems to be an absence of crustal root, the crust has been thickened mainly by extension upward, not downwards.

Correlation of topography with Adelaide Orogen structure

Geology

The basement rocks in the area are, in the west the Gawler Block of Archean Early Proterozoic age

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[2] Tapley, D. (1984) Seismic investigation of crustal structure in South Australia. B.Sc. (Hons) Thesis, Flinders University, Adelaide (unpublished).

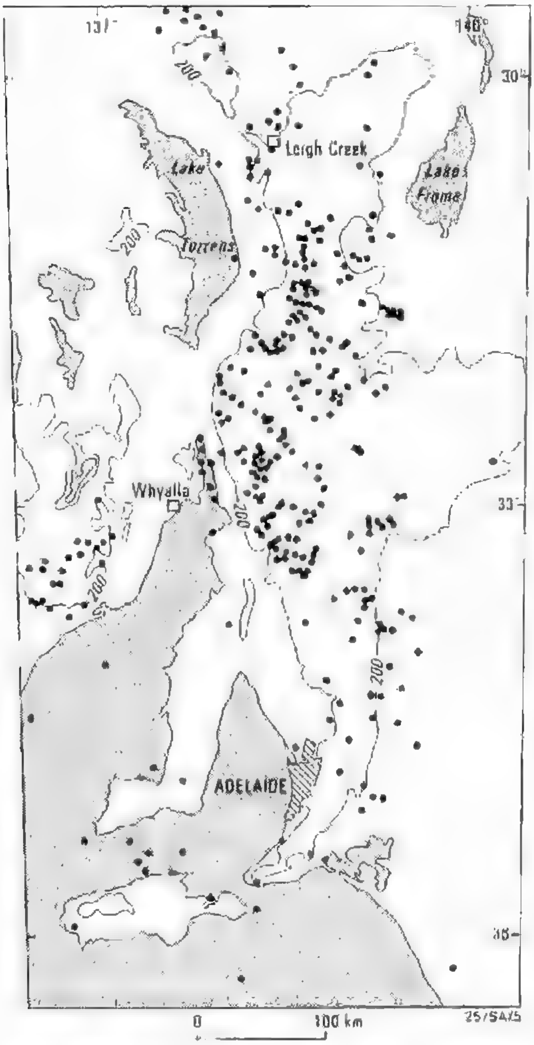

Fig. 5. Seismicity. Dots give epicentres of earthquakes of magnitude ML >=2. 200 m topographic contour shown.

(Fig. 6), and in the east the Willyama Block of Early Proterozoic age. Inliers of Early Proterozoic rock crop out at the northern end of the Flinders Ranges (B of Fig. 6), and the southern Mt Lofty Ranges (A of Fig. 6). Sediments and minor volcanics of Late Proterozoic-Cambrian age Adelaide Orogen are relatively thick between the two cratons. They are thin west of the Torrens Hinge Zone (Fig. 6) forming the Stuart Shelf sediments, and thin east of about 139°20'E on the Willyama Block. The thick sediments are thought to have been deposited following the formation of a lithospheric rift (von der Borch 1980). The inferred rift is complex with two triple junctions. Subsequent folding of the thick sediments of the Adelaide Orogen is, in the south mainly on north to east striking fold axes that parallel the curved northwestern margin of the Murray Basin, and in the north on east to southeast striking fold axes that parallel the margin of the Eromanga Basin.

The axis of the Flinders/Mt Lofty Ranges overlie the north-south part of this rift, and the relatively high land northwest of Leigh Creek (Fig. 1), and northwest of C in Fig. 1, overlie other arms of the rift. Hence all the present-day relatively high land directly overlies the inferred Late Proterozoic rifts, and so the high land is a reactivation of this older structure. The Adelaide Orogen structures are not

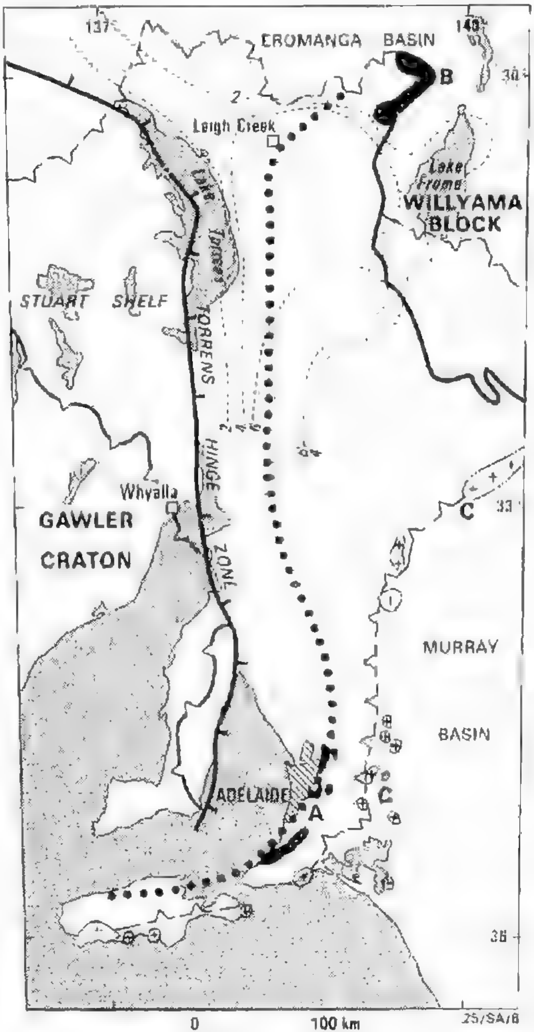

Fig. 6. Geological structure. Showing extent of cratons with thin cover (thick lines), inliers (A & B), and Cambrian-Ordovician granite (C) (after Preiss 1983). Dashed lines give depth to aeromagnetic basement (contour interval 2 km).

all north-south. For example folds in the north and central parts of the Range cross the Range at a large angle. Hence a simple reactivation of the Adelaide Orogen structures does not explain the linearity, and relatively high altitude, of the north-south trending Flinders/Mt Lofty Ranges.

Sediment thickness

Tucker & Brown (1973)[3] compiled depths to aeromagnetic basement north of 32°20'S. A contour map of these depths (Fig. 6) is roughly consistent with geological constraints — with the shallow depths over the cratonic areas to the west and east. It shows depths under the northern Mt Lofty Ranges of 4 to 6 km. Magnetic basement may be volcanics in the Callanna Group near the base of the Adelaidean sequence (e.g. in area A of Fig. 6), the top of the Early Proterozoic basement, or igneous bodies within the basement. Basement contours of Thompson (1970; GSA, 1976) were said to be "largely a compilation of aeromagnetic basement interpretation", but they appear to be mainly depths inferred from stratigraphic thickness (Tucker & Brown 1973)[3].

Geophysical model

Using maps of gravity anomaly (Fig. 2) and magnetic anomaly (Fig. 7), the Flinders/Mt Lofty Ranges region can be divided into strips of similar magnetic and density properties (Fig. 8).

In the west is strip 1 (Fig. 8), which is a gravity and magnetic high, corresponding roughly in position with the Torrens Hinge Zone (Fig. 6). Strip 2 is a gravity and magnetic low west of the Torrens Hinge Zone, that on geophysical (Fig. 6) and geological evidence has relatively thick sediments. The lower gravity anomaly in strip 2 is likely to be mainly due to the relatively-thick, low-density sediments underlying strip 2. the elongate local magnetic highs in strip 1 are thought to be due in part to an edge anomaly at the eastern margin of the Gawler Craton. East of this margin, thick relatively non-magnetic Adelaidean sediments overlie a Lower Proterozoic basement that, during the rifting, was thinned and possibly heated and demagnetized. However within strip 1, west of Adelaide and Leigh Creek, and sited mainly east of the Torrens Hinge Zone, are elongate, isolated magnetic highs that do not have the geometry of an edge anomaly. There are coincident local gravity highs. These anomalies are inferred to be due to elongate, relatively dense and magnetic igneous rocks, forming narrow bands. They are inferred from their location to be structurally related to the Torrens Hinge Zone, but displaced from it.

Area 4 of Fig. 8 is a gravity low and magnetic high due to the exposed and concealed Willyama Block. Strip 7 is a gravity low, and line of magnetic highs, corresponding to a line of Cambrian-Ordovician granitoids (C of Fig. 6), along the eastern margin of the Murray Basin.

The majority of the area of thick Adelaidean sediments is a relative magnetic low (strips 2, 3 & 6). Within this area is an elongate high in the gravity anomalies (strip 3). This high corresponds in position to the higher part of the Flinders/Mt Lofty

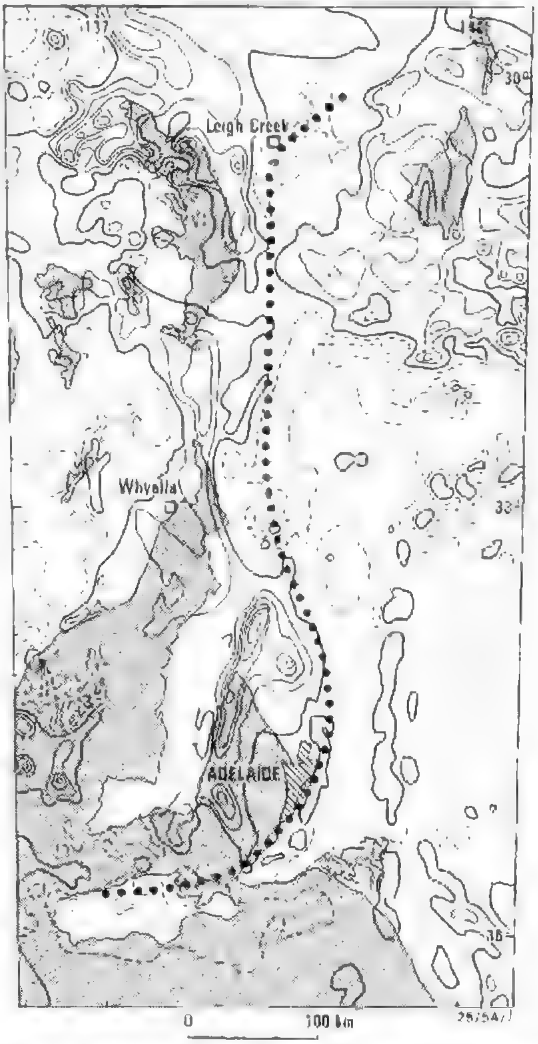

Fig. 7. Residuals of total magnetic intensity. Contour interval 250 nT, negative contours dashed (after BMR 1976a).

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[3] Tucker, D. H. & Brown, F. W. (1973) Reconnaissance helicopter gravity survey in the Flinders Ranges, South Australia, 1970. Bur. Min. Resour. Aust. Record 1973/12 (Unpubl.)

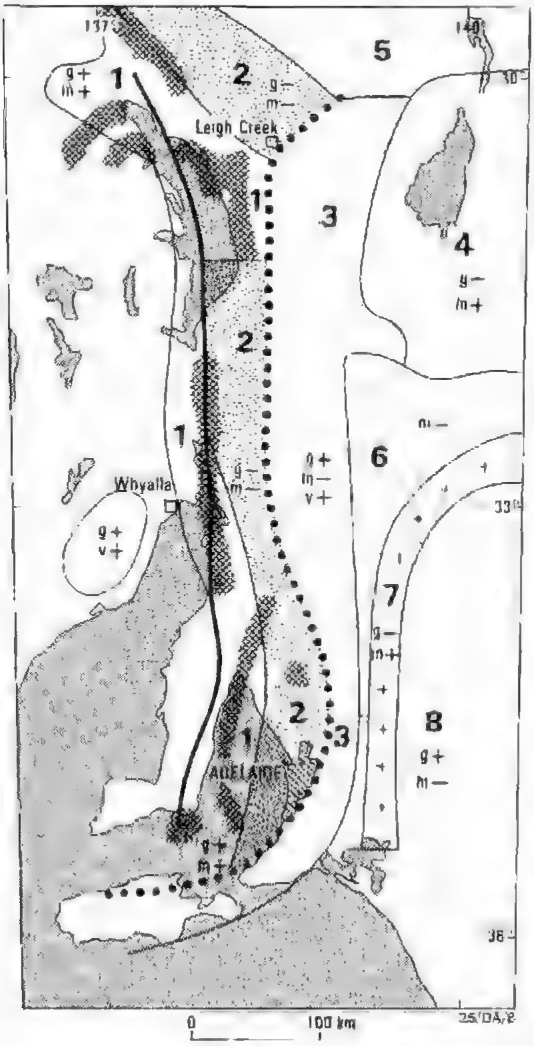

Fig. 8. Geophysical model of crustal strips. Gravity, magnetic and velocity residuals shown by g, m, v, +, – symbols. Narrow magnetic highs shown by hatched pattern. Thick line is the Torrens Hinge Zone.

Ranges, but the mass above sea level of these ranges does not cause the Bouguer gravity high. This is because the calculation of Bouguer anomalies removes the effects of masses above sea level, and the effect of any component of local isostatic compensation is to give a lower, not higher Bouguer anomaly. Tucker & Brown (1973) interpreted this gravity high in the north as due to either an increase in the density of the Adelaidean sediments, or an increase in the density of the basement. Von der Borch (1980) thought that the gravity high "may be due to axial dyke emplacement". Gunn (1984) thought that the gravity high "probably reflects the presence of thin oceanic-type crust". There is no good evidence that the high is due to thin Adelaidean sediments. The gravity high could be due to underlying sediments being relatively denser, however the western margin of the carbonate sedimentation is closer to the Torrens Hinge Zone (Fig. 5.11 of Preiss *et al.* 1981), and post depositional structures cross the boundary of strip 3. It seems most likely that the gravity high is due to an increase in the density of the underlying basement. With any interpretation, the similarity in geographic position of the relative gravity high and the ranges, suggest that the ranges have been formed geographically coincident with the pre-Mesozoic structural features forming the gravity high. The ranges are highly likely to be a reactivation of this structural feature.

Conclusion

Geological information is consistent with intermittent uplift starting in the Palaeocene or earlier, with some uplift in the Quaternary. The likely Cainozoic denudation rates of about 3 $m.Ma^{-1}$, and the known denudation of over 0.5 km in the Flinders Ranges and over 0.2 km in the Mt Lofty Ranges, are consistent with erosion occurring at least through most of the Cainozoic.

The gravity anomalies are interpreted as showing that the ranges have no significant crustal root; the ranges being on a part of a relatively strong lithosphere that supports them by regional isostatic compensation. This model is consistent with available seismic information showing no significant increases in crustal thickness under the ranges, and heat flow observations showing only slighty higher heat flow than average.

The present day earthquake activity is mainly restricted to the ranges, and it has compressive fault plane solutions. This faulting is thought to reflect continuing uplift. The associated crustal thickening is apparently not causing a significant crustal root.

The axis of the highlands corresponds with a gravity high that may be due to underlying high density basement. The highlands appear to be a reactivation of the structural feature causing this gravity high.

Acknowledgments

We are grateful to C. C. von der Borch and M. Idnurm for comments on aspects of this work, and to D. M. Boyd, V. A. Gostin and W. Preiss for referees' comments. The figures were drafted by John Convine of BMR. Published with the permission of the Director, Bureau of Mineral Resources.

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SETOBATES (ACARIDA: CRYPTOSTIGMATA: SCHELORIBATIDAE) FROM SOUTH AUSTRALIAN SOILS

BY DAVID C. LEE & GEORGE A. PAJAK*

Summary

Setobates Balogh, 1962 is rediagnosed and compared with other genera in the Scheloribatidae. Two species are described as new: *S. ultraforaminosus, S. coronopubes.* They are from soil and litter from the arid, semi-arid and mallee-heath sites, but not the other six South Australian sites in the Mediterranean type region. This is the first record of *Setobates* from Australia. Hysteronotal chaetotaxy is discussed. Five species are newly combined with *Setobates.*

KEY WORDS: Setobates ultraforaminosus sp. nov., *S. coronopubes* sp. nov., Acarida, chaetotaxy, soils, South Australia.

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Summary

Lee, D. C. & Pajak, G. A. (1988) *Setobates* (Acarida: Cryptostigmata: Scheloribatidae) from South Australian soils. *Trans. R. Soc. S. Aust.* **112**(1), 21-27, 31 May 1988.

Setobates Balogh, 1962 is rediagnosed and compared with other genera in the Scheloribatidae. Two species are described as new: *S. ultraforaminosus*, *S. coronopubes*. They are from soil and litter from the arid, semi-arid and mallee-heath sites, but not the other six South Australian sites in the Mediterranean-type region. This is the first record of *Setobates* from Australia. Hysteronotal chaetotaxy is discussed. Five species are newly combined with *Setobates*.

Key Words: *Setobates ultraforaminosus* sp. nov., *S. coronopubes* sp. nov., Acarida, chaetotaxy, soils, South Australia.

Introduction

This publication is part of an ongoing study of sarcoptiform mites in South Australian soils, sampled from nine florally diverse sites, and for which there is an introduction to the relevant work on the advanced oribate mites (Planofissurae) (Lee 1987). A paper on the family to which *Setobates* belongs, Scheloribatidae, and its nominotype, includes relevant further comments on methods (Lee & Pajak *in press*). Measurements are in microns (μm).

No new notational systems are introduced here, but the hysteronotal chaetotaxy is commented on to indicate how a commitment to certain homologies was reached, which in turn requires a new signature for one seta. The mites studied have been deposited in the South Australian Museum.

Hysteronotal Chaetotaxy

It is assumed that the primitive complement of hysteronotal setae amongst Cryptostigmata is 16 pairs (*6J*, *6Z*, *4S*) (Lee 1987) and that the general trend is towards loss of setal pairs (regressive synapomorphies) in the adults. On the other hand, primitive members of the Planofissurae, the Pherenotae, have fewer pairs (with *J4* absent except amongst Hermaniellidae) than some members of the advanced Poronotae (including *Setobates* with *J4* present), indicating that if the Pherenotae are a paraphyletic group that is ancestral to the remaining Planofissurae, then the relevant synapomorphies are not always regressive. The tritonymphs of the Poronotae and adults of the included *Constrictobates* (see Lee 1987, Fig. 3) have 15 pairs of hysteronotal setae, lacking *S2*, and this is assumed to be the primitive full complement for the Poronotae, although *Neotrichozetes* is hypertrichous with 35 pairs of hysteronotal setae. Amongst Oripodoidea most genera have ten pairs of hysteronotal setae and some as few as seven pairs, whilst *Setobates* has amongst the more extensive chaetotaxies with up to 14 pairs where the second absent pair is considered to be *J1*. After transformation, this is the only disagreement with previous homologies. The closely allied *Topobates* with 14 pairs, for example, being regarded as having present '*c1*' and '*c2*' and not '*c3*' (Grandjean 1958, Fig. 3A) or, transformed to the notation used here, *S1* is absent and *J1* is present. Deciding the hysteronotal setae that are lost in some members of *Setobates*, regarded here as including species with as few as 11 pairs, as well as from other genera such as the closely allied *Scheloribates*, is difficult. The setal chaetotaxy of tritonymphs is conservative and too drastically changed in many adults to be useful in establishing homologies, whilst the relative position of adult setae to other structures such as pores probably varies between taxa within the Oripodoidea. Here, the option of trying to maximise the similarity between taxa is taken so that position variations are regarded as translocations of setae. As a result, *Scheloribates* is regarded as having a hysteronotal chaetotaxy of *2J*, *6Z*, *2S*, requiring a modification of the initial interpretation of the 10-pair system (Lee 1987, Fig. 2), seta '*ti*' being *Z3* not *J3*, so that it is homologous to '*lm*' in the 15-pair system (Lee 1987, Fig. 1). This is as previously given by Balogh (1972, Fig. 5), and when the common ten pairs of hysteronotal setae of oripodoid species are treated as a reduced 15-pair system (*la* etc.) as for *Cryptozetes* (Norton & Palacios-Vargas 1987, Fig. 1A) rather than the 10-pair system (*ta* etc.) previously used (e.g. as for *Hemileius* by Grandjean 1953, Fig. 1A). Also, in this study, the chaetotaxy of *Anaplozetes* (see Lee & Pajak 1987, Fig. 1) should be changed, so that what was represented as *J3* should be regarded as

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*Z*3, the formula becoming 2*J*, 6*Z*, 2*S*, seta *Z*3 being transposed into the *J*3 position relative to the slit-like pore *hf*3.

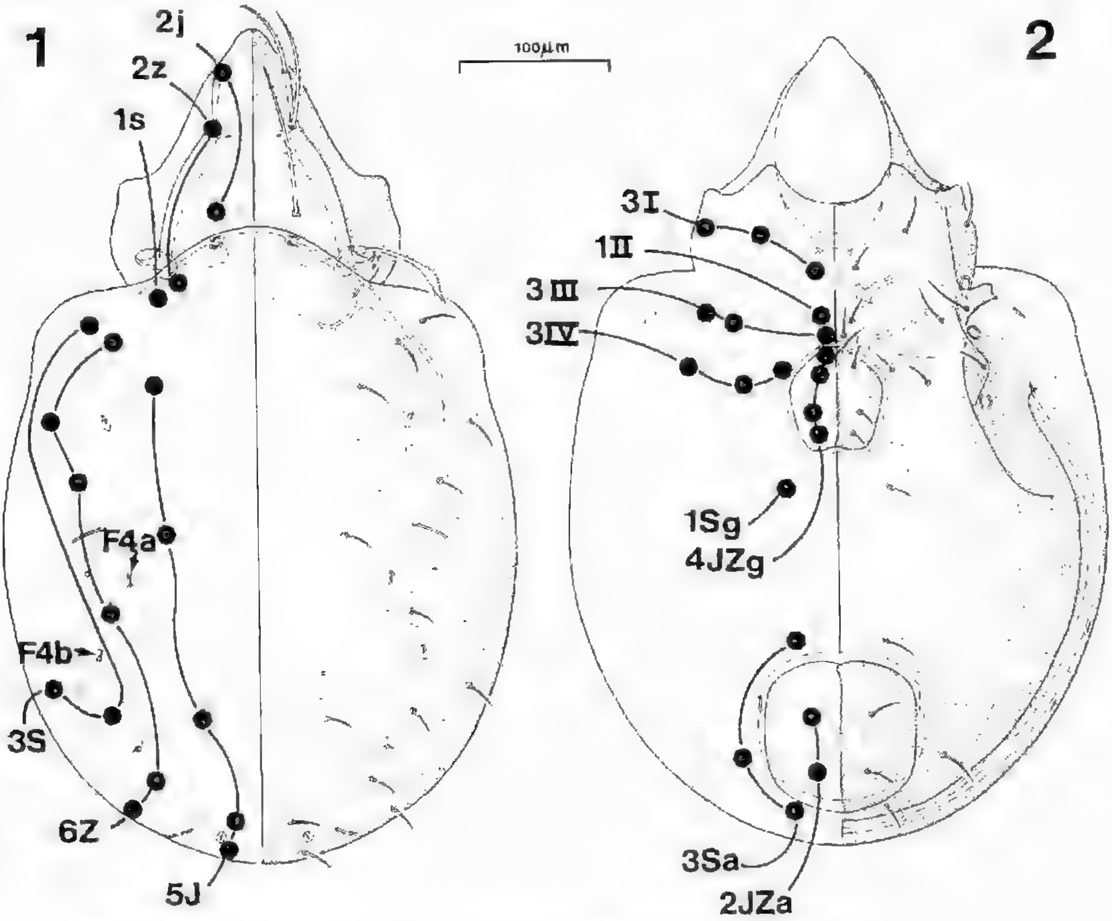
Setobates Balogh, 1962

Setobates Balogh, 1962, p. 122 (type-species by original designation: "*Setobates magnus* sp. n."); Coetzer 1968, p. 91; Luxton 1985, p. 68.

Type-species: Setobates magnus Balogh, 1962.

Diagnosis: Scheloribatidae. Hysteronotum with 11–14 pairs (2–5*J*, 6*Z*, 2–3*S*) of setae and four or five pairs of normal (not fissuriform) sacculate foramina. Proteronotal sensory seta (*z*2) usually lanceolate, rarely capitate or fusiform, not setiform. No translamella or complete interlamella line (setae *z*1–*z*1), prelamella (setae *z*1–*j*1) sometimes present. Pteromorph present, either short or long, anterior margin merging with dorsosejugal furrow without dorsally obscuring aperture to bothridium (base of seta *z*2). Hysteronotal surface without tubercles, granulations or conspicuous longitudinal striae. Four pairs of genital setae (*JZg*). Discidium present. Tarsus I with three proximoventral setae (*av*1, *pv*1, *v*2). Trochanter IV semisquare in vertical outline, distodorsal surface right-angulate. Pretarsus with three claws.

Morphology of Australian Species: Somal length range: 328–586. Somal chaetotaxy: 2*j*, 2*z*, 1*s*; 5*J*, 6*Z*, 2–3*S*; 3*I*, 1*II*, 3*III*, 3*IV*; 4*JZg*, 1*Sg*, 2*JZa*, 3*Sa*. All setae of normal length, no microsetae. Bothridium base without posterior flange. Proteronotal setae *j*2–*j*2 well separated (distance greater than *j*1–*z*1). Two pairs of unnamed hysteronotal circular pores (anterior pair between seta *Z*2 and pore of *F*3; posterior pair just anterior to seta *J*4), only posterior pair illustrated (Figs 1 and 4), anterior pair indistinct. Hysteronotum with 5 pairs of large slit-shaped pores, dorsally placed *hf*3 and *hf*6 larger, *hf*1, *hf*4, *hf*5 apparent from ventral aspect, *hf*2 not located. Multituberculate cerotegument lying between leg bases and



Figs. 1–2. *Setobates ultraforaminosus* sp. nov., female. 1, notum of soma; 2, sternum of soma.

pteromorph base plus lamella, terminating level with middle of legs I and IV. Lateral coxite setae (*I2*, *I3*, *III2*, *III3*, *IV3*) longer than those around midline. Adaxial end of apodeme base III level with seta *JZg2* and seta *IV1*. Discidium triangulate, equilateral. Custodial ridge merging with pedotectum II base and not discidial ridge. Some leg segments always with porose areas and rugae. Legs of medium-length (mean femur-tarsus: 44% of soma) and stout or of medium-girth (mean maximum tibial height: 35–43% of mean length). Femur II with seta *v* between 0.5–0.75 × flange depth towards periphery. Tibia I dorsal surface sloping upwards from base to solenidium. Tibia II with proximoventral spur. Tarsi I and II gradually tapering distally for more than half their length (subtriangulate). Pretarsi with lateral claws much slimmer.

Distribution: Probably cosmopolitan, but records only from Argentina and Bolivia (NTc), Tanzania (Ee), Europe (Pe, Pm); New Zealand (An) and now known from Australia (Aa). The South Australian material is from three dry sites (with encompassing mean annual rainfalls): Arid tussock grassland (125–150 mm); Semi-arid shrubland (150–200 mm); Mallee-heath, tall open shrubland (450–500 mm). Records from other regions of the world are from a wide range of habitats including mostly moist sites.

Remarks: Setobates is used here to include most species of Scheloribatidae that have more than ten pairs of hysteronotal setae. Other genera in this category are *Topobates* Grandjean, 1958 with 14 pairs of hysteronotal setae but a granulated hysteronotum, *Samoabates* Hammer, 1973 with 14 pairs of hysteronotal setae but only one pretarsal claw and *Striatobates* Hammer, 1973 with 11 pairs of hysteronotal setae and a striated tuberculate hysteronotum. The following 13 species are grouped in *Setobates*: *S. alvaradoi* (Pérez-Iñigo, 1968) comb. nov. ex *Scheloribates*; *S. campestris* (Mihelčič, 1966) comb. nov. ex *Scheloribates*; *S. coronopubes* sp. nov.; *S. labyrinthicus* (Jeleva, 1962 in Csiszar & Jeleva 1962) comb. nov. ex *Scheloribates*; *S. latipes* (Koch, 1841; Shaldybina, 1975) comb. nov. ex *Scheloribates*; *S. longior* (Hammer, 1958); *S. magnus* Balogh, 1962 (type-species); *S. medius* Hammer, 1967 (syn. *S. discors* Hammer, 1967); *S. pallidus* (Michelčič, 1956) comb. nov. ex *Scheloribates*; *S. parvialatus* (Hammer, 1958); *S. scheloribatoides* (Ramsay, 1966) (syn. *S. minor* Hammer, 1967); *S. ultraforaminosus* sp. nov., *S. umbraili* (Schweizer, 1956). *Setobates* is very similar to *Scheloribates*. For some species, the greater number of hysteronotal setae is the only substantial difference from species of the *euselosus*-complex (*Scheloribates*) and the delineation of the two genera as presented here is provisional. *S. labyrinthicus* in particular, with only a spine-like seta *S1* extra to the ten pairs of *Scheloribates*, may well have to be returned to that genus.

Setobates ultraforaminosus sp. nov.
FIGS 1–3

Female: Idiosomal length, 561 (semi-arid shrubland, 6, 515–586), 531 (arid tussock grassland, 2, 527–535). Leg lengths (femur-tarsus for 560, semi-arid shrubland): I–263, II–239, III–211, IV–262. Tibial maximum heights (for 560, semi-arid shrubland): I–27, II–22, III–18, IV–19.

Proteronotum with complete prelamella (seta *j1*–*z1*) accompanied by dark sclerotization in integument. Sublamella distinct from lamella along nearly entire length. Interlamella seta (*j2*) able to reach to about level of base of rostral seta (*j1*). Sensory seta (*z2*) long, able to reach to beyond level of seta *j2*, exposed stalk more than half length, caput lanceolate with one dorsal and one ventral cilia file; in dorsal aspect at times appearing parallel-sided and nearly setose with cilia not evident. Seta *s2* length about ×3 diameter of bothridium. Hysteronotum with 14 (*5J*, *6Z*, *3S*) pairs of medium-sized setae present, seta *S1* present on all specimens. Five pairs of foramina (*F3*, *F4a*, *F4b*, *F5*, *F6*) with narrow slit-shaped pore and duct leading to small globular sac.

Narrow gap between apodemes I, slightly less than distance between setae *I1*–*I1*. Circumpedal ridge long and curved, merging with discidial ridge. Seta *Sa2* substantially longer (about ×1.5) than *Sa3*. Egg subellipsoidal, exochorion mainly granulate, at poles rugose, 213 × 125 (for 560, semiarid shrubland) and 210 × 118 (for 527, arid tussock grassland). Females examined (6) from semi-arid shrubland with four eggs each. Females examined (2) from arid tussock grassland had either no eggs or eight eggs.

Legs of medium-girth (mean maximum tibial height: 35% of mean length). Small ventral flange on femur I. Femur III with ventral flange running entire length of segment. Tibia I with posterior proximoventral ridge obscuring outline of proximoventral spur. Tarsi longer (+ 2 to 9 µm) than their respective tibia.

Male: Similar to female but shorter mean length. Idiosomal length, 496 (semi-arid shrubland, 3, 481–511), 504 (arid tussock grassland, 5, 473–560).

Material examined: Holotype female (N1987715), five paratype females (N1987716–N1987720), three

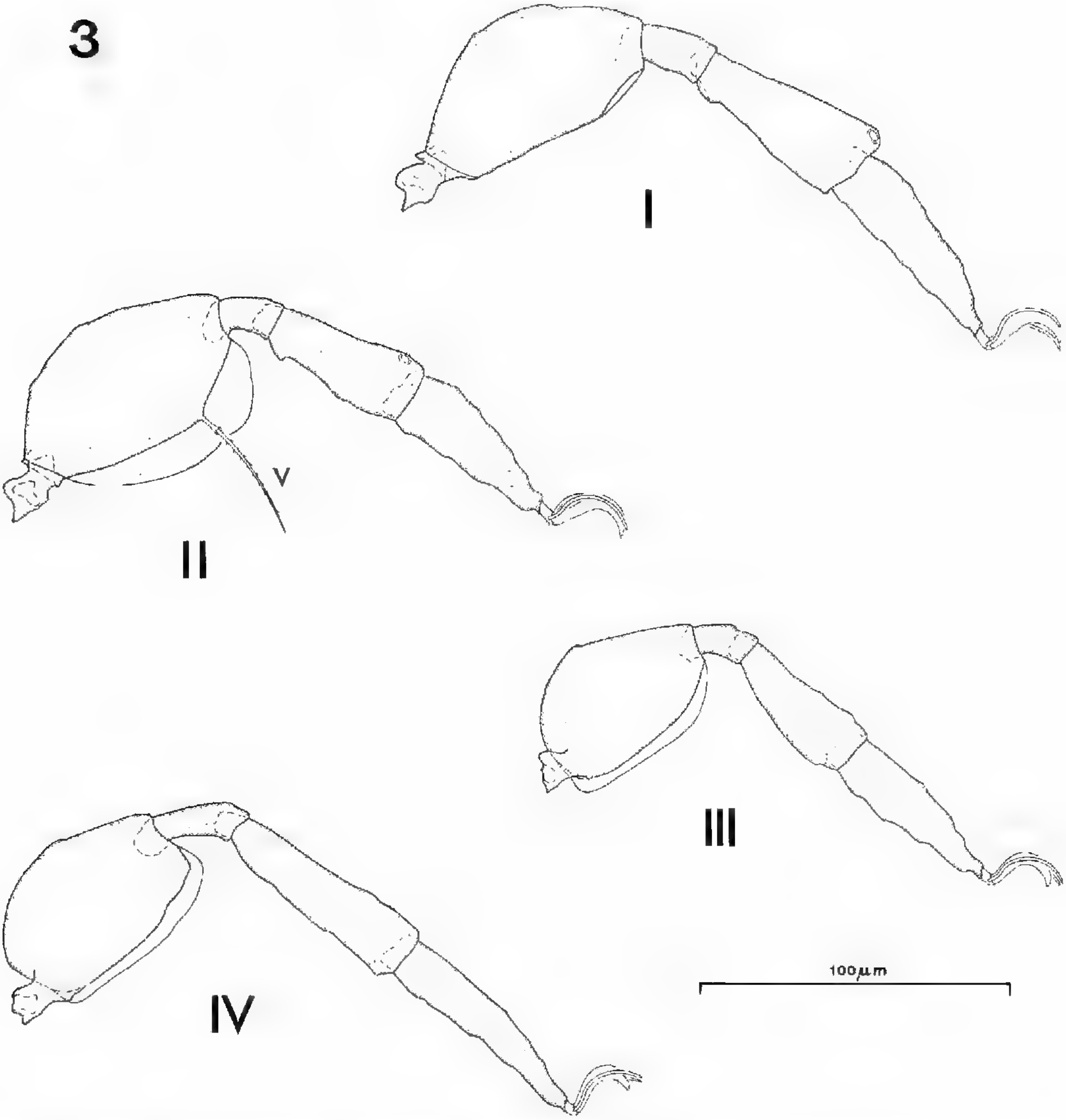


Fig. 3. *Setobates ultraforaminosus* sp. nov., female, posterior aspect of part (femur-pretarsus) of right legs, only one seta (*v* femur II) illustrated.

paratype males (N1987721—N1987723), soil, litter, moss and other low growth plants under bladder saltbush (*Atriplex vesicaria*) amongst sparse false sandlewood (*Myoporum platycarpum*), Koonamore Vegetation Reserve (32°07'S, 139°21'E), 27.vi.1974, D. C. Lee. Two undesignated females (N1987724, N1987725), third female lost, five undesignated males (N1987726 -N1987730), bases of love grass (*Eragrostis eriopoda*) tussocks, near Emu (28°41'S, 132°08'E), 11.x.1974, D. C. Lee.

Distribution: Australia (Aa). South Australia. Lake Frome Basin, semi-arid shrubland, six females and three males in 4 of 8 × 25 cm^2 samples. Great Victoria Desert, arid tussock grassland, three females and five males in 4 of 8 × 25 cm^2 samples.

Remarks: S. ultraforaminosus is very similar to *S. alvaradoi* from Spain, having 14 pairs of hysteronotal setae and five pairs of foramina (*F*4 divided into *F4a* and *F4b*). *S. alvaradoi* differs in that sensory seta *z*2 is rounded distally, hysteronotal seta *Z*1 is less than half the length of *S*1 and that on femur II the ventral flange is not very big. It is likely, on the basis of adult form, that *S. ultraforaminosus* occurs at the two sites listed, but, because the number of eggs per female in the small series from near Emu is eight, rather than uniformly four as in the large series from Koonamore, it has been excluded from the type series.

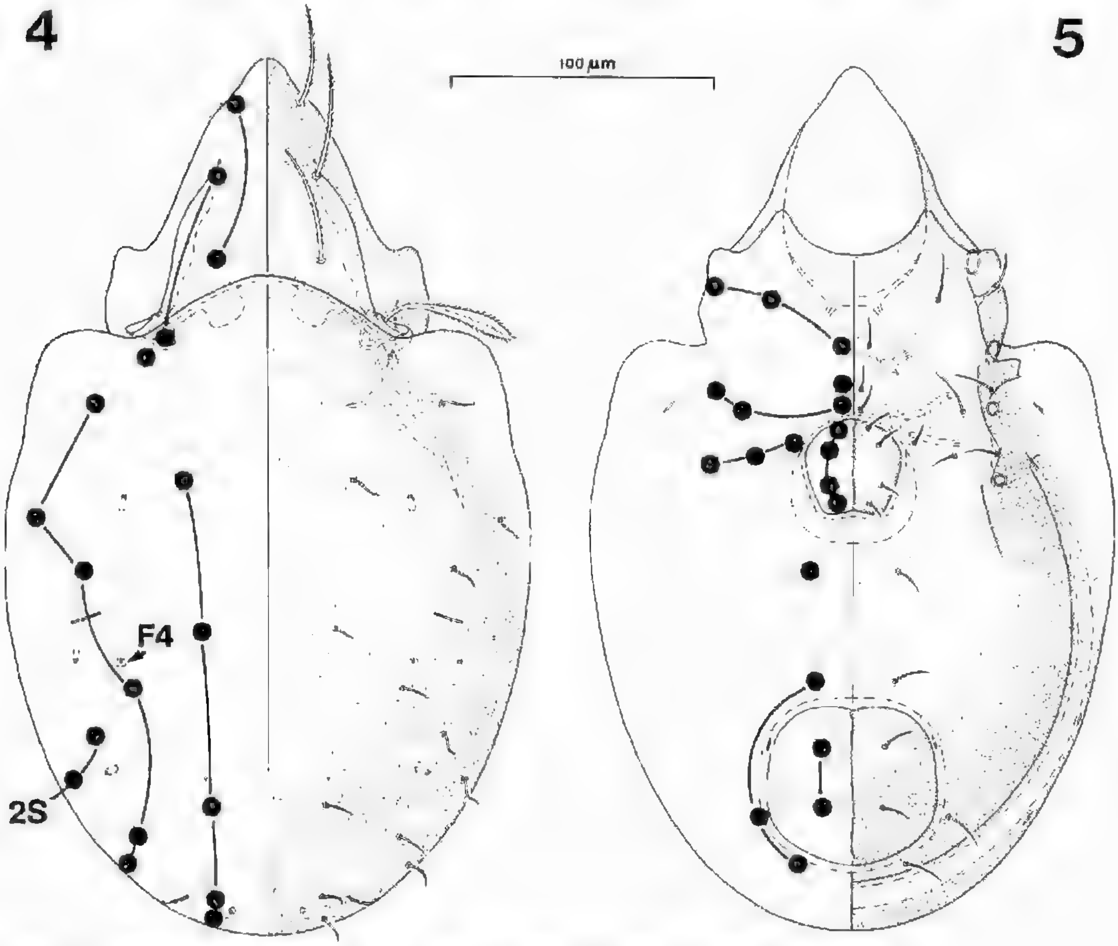
Setobates coronopubes sp. nov.
FIGS 4–6

Male (female not known): Idiosomal length, 331 (2, 328 and 334). Leg lengths (femur-tarsus for 328): I–159; II–146; III–127; IV–150. Tibial maximum heights (for 328): I–20; II–17; III–15; IV–13.

Proteronotum with prelamella restricted to short ridge near seta *z*1. Sublamella distinct from lamella along nearly entire length. Interlamella seta (*j*2) unable to reach level of base of rostral seta (*j*1). Sensory seta (*z*2) long, able to reach beyond level of seta *j*2, exposed stalk less than half length, caput lanceolate, indistinctly delineated from stalk, with three cilia files. Seta *s*2 length about ×2 diameter of bothridium. Hysteronotum with 13 pairs of medium-sized setae, seta *S*1 absent. Four pairs of foramina (*F*3, *F*4, *F*5, *F*6) with circular pore leading to small globular sac.

Moderate gap between apodemes I, more than distance between seta *I*1–*I*1. Zone of integument around lateral and posterior margin of genital orifice denser with concentric subsurface striations, forming "halo" with transmitted light for which boundaries indicated by broken line in illustration (Fig. 5). Circumpedal ridge short and straight, not merging with discidial ridge. Seta *Sa*2 subequal in length to *Sa*3.

Legs stout (mean maximum tibial height: 43% of mean length). No ventral flange on femur I. Femur III with ventral flange restricted to distal two-thirds of segment. Tibia I without



Figs. 4–5. *Setobates coronopubes* sp. nov., male. 4, notum of soma; 5, sternum of soma.

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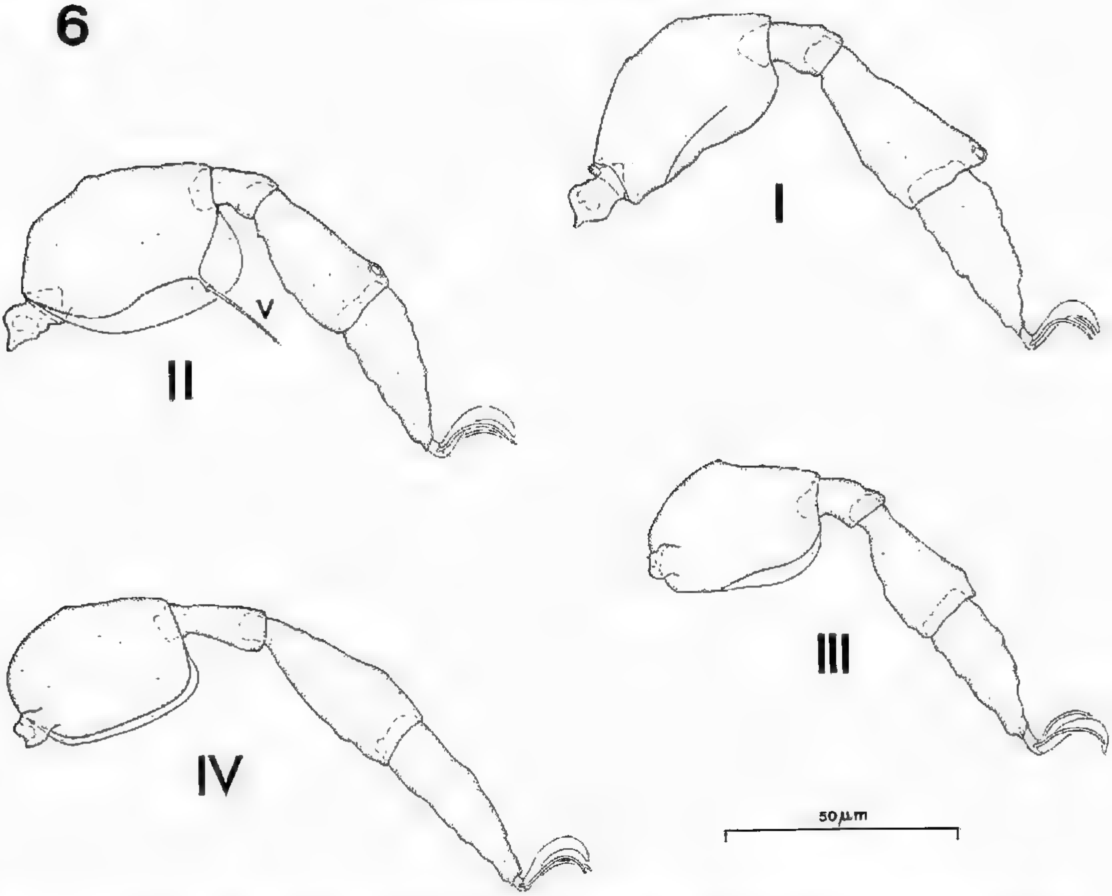

Fig. 6. *Setobates coronopubes* sp. nov., male, posterior aspect of part (femur-pretarsus) of right legs, only one seta (*v*, femur II) illustrated.

proximoventral spur, but girth increases conspicuously from stalk to caput. Tarsi subequal to length to their respective tibia (−2 to +2 µm).

Material examined: Holotype male (N1987731), paratype male (N1987732), soil, litter under banksia shrubs (*Banksia ornata*) amongst other sclerophyllous shrubs and sparse brown stringybark mallee (*Eucalyptus baxteri*), Tamboore Homestead (35°57′S, 140°29′E), 4.vii.1974, D. C. Lee.

Distribution: Australia (Aa). South Australia. Ninety Mile Desert (nutritional desert), mallee-heath, tall open shrubland, two males in 2 of 8 × 25 cm^2 samples.

Remarks: S. coronopubes, known only by the male, has a generically unique "halo" around the posterior margin of the genital orifice. The hysteronotal chaetotaxy is as for five other species of *Setobates*, including the type-species, but besides the characteristic genital "halo" it is about 100 µm shorter than any other species of *Setobates*.

Acknowledgments

We wish to thank the Australian Biological Resources Study for a grant to D.C.L., funding the salary of G.A.P., Ms Jenni Thurmer for the notation and presentation of the figures and Mrs Debbie Brunker for typing the manuscript.

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A NEW SPECIES OF *NOTADEN* (ANURA: LEPTODACTYLIDAE) FROM THE KIMBERLEY DIVISION OF WESTERN AUSTRALIA

BY G. M. SHEA & G. R. JOHNSTON†*

Summary

Notaden weigeli sp. nov. is described from the northern Kimberley of Western Australia. It is distinguished from congeners by its longer legs (TL/S-V 0.34-0.38 *vs* 0.25-0.34), more prominent subarticular and palmar tubercles, red to fawn dorsum without black markings and lack of a pale mid-rostral streak. The cranial skeleton is very reduced. *N. weigeli* is apparently allopatric to other species of *Notaden* and is associated with rocky habitats.

KEY WORDS: *Notaden,* Anura, new species, morphology, osteology, discriminant function analysis.

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KEY WORDS: *Notaden*, Anura, new species, morphology, osteology, discriminant function analysis.

Introduction

The known anuran fauna of the Kimberley division of Western Australia currently comprises 38 species, the majority (22 species) having been first described or recorded from the region since 1976. Ten of these species are apparently endemic to the Kimberley or nearly so (Tyler, Smith & Johnstone 1984; Tyler, Davies & Watson 1987). This paper describes a further new species apparently endemic to the Kimberley.

Materials and Methods

Specimens cited here are located in the Australian Museum, Sydney (AM), South Australian Museum, Adelaide (SAM) and Western Australian Museum, Perth (WAM).

All measurements were made to 0.1 mm with a pair of dial calipers. Snout-vent length (S-V), head width (HW), eye diameter (E), eye to naris interval (E-N) and internarial span (IN) are as defined by Hosmer (1962). Head length was not measured. Tibia length (TL) was measured from the heel to the point of the tibial tuberosity, with the leg flexed. Foot length (FL) was measured from the heel to the tip of the fourth toe, with the foot straightened. A single specimen was cleared and double stained for bone and cartilage following the method of Hanken & Wassersug (1981).

Descriptive statistics were calculated for S-V and a number of morphometric ratios (Table 1) from samples of all *Notaden* species. Multiple comparisons of arcsine-transformed ratios were made using single classification ANOVA (Sokal & Rohlf 1981). A multiple discriminant function analysis (Reyment, Blackith & Campbell 1984) of raw measurements was done using SPSS PC+ (Norusis 1986) on a Pantek PC-16 computer. Sexes were pooled for all analyses.

Ontogenetic variation was examined by fitting TL, FL and HW for *N. bennetti*, *N. melanoscaphus* and *N. nichollsi* to the allometric equation $Y = b\text{S-V}^{a}$ (Huxley 1932; Gould 1966), where Y is the variable being examined, S-V is used as a measure of overall size, *a* is the allometric coefficient (slope) and *b* is a constant. Allometric coefficients were tested against unity using standard normal deviates (Zar 1974).

Notaden weigeli sp. nov.

FIGS 1–9

Notaden sp. nov: Tyler, Davies and Watson 1987, p. 545.

Holotype: WAM R77419, Sandstone Ck, WA, (14°53'30"S 125°45'00"E), collected by C. Kemper on 26.x.1981.

Paratypes: AM R123896–99, Mitchell Plateau, WA, (14°51'S 125°40'E), J. Weigel, G. Shea and A. Harwood, 6–8.i.1987; WAM R83428–29, 23 km NW old Mount Elizabeth HS, WA (16°12'S 126°00'E), H. Ehmann and G. R. Johnston, 29.xi.1982.

Diagnosis: *Notaden weigeli* differs from all other *Notaden* species in its longer legs (TL/S-V 0.34–0.38 *vs* 0.25–0.34), more prominent subarticular and palmar tubercles, red to fawn dorsum without black markings and lack of a pale mid-rostral streak.

Description of holotype: Size large (S-V 54.4 mm). Head small, as broad as long, length approximately ¼ S-V (Fig. 1). Snout truncated when viewed from above; high and bluntly rounded in profile (Fig. 2). HW/S-V 0.30. Nostrils superior. Eye-naris interval equal to internarial span (E-N/IN 1.00). Nostrils nearer to tip of snout than to eye. Canthus rostralis poorly defined, very short. Eye prominent (E/S-V 0.13), diameter approximately twice E-N. Tympanum covered by glandular skin. Maxillary and vomerine teeth absent. Tongue oval.

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TABLE 1. *Comparative morphometrics of post-metamorphic specimens of* Notaden *species. Values are given as* $\bar{x}$ *(SD) over range.*

	N. bennetti	*N. melanoscaphus*	*N. nichollsi*	*N. weigeli*
N	22	40	49	7
S-V (mm)	38.4 (14.83) 20.7–67.4	43.3 (6.25) 27.9–50.7	46.2 (5.68) 37.9–60.4	57.0 (10.05) 46.6–71.1
TL/S-V	0.29 (0.02) 0.25–0.34	0.28 (0.02) 0.25–0.34	0.29 (0.01) 0.26–0.32	0.35 (0.01) 0.34–0.38
FL/S-V	0.50 (0.04) 0.43–0.59	0.51 (0.04) 0.40–0.61	0.53 (0.03) 0.49–0.59	0.58 (0.03) 0.55–0.64
HW/S-V	0.31 (0.03) 0.26–0.34	0.29 (0.02) 0.25–0.34	0.29 (0.02) 0.25–0.33	0.29 (0.02) 0.25–0.31
E-N/S-V	0.06 (0.01) 0.04–0.09	0.06 (0.01) 0.04–0.08	0.05 (0.01) 0.04–0.06	0.06 (0.01) 0.05–0.08
E-N/IN	0.98 (0.12) 0.75–1.25	1.17 (0.18) 0.92–1.65	0.83 (0.08) 0.68–1.00	1.18 (0.23) 1.00–1.59
E/S-V	0.12 (0.01) 0.10–0.14	0.11 (0.01) 0.10–0.13	0.14 (0.01) 0.11–0.17	0.11 (0.02) 0.09–0.13

Fingers moderately long, unwebbed, cylindrical, without lateral fringes (Fig. 3); finger length $3>1>2\geq4$. Tips of fingers slightly dilated. Subarticular tubercles large and sharply defined proximally, poorly defined to absent distally; several moderately large, rounded palmar tubercles.

Hind limbs short (TL/S-V 0.34; FL/S-V 0.58); toe lengths $4>3>5>2>1$; toes with weak lateral fringes and basal webbing, reaching to base of antepenultimate phalanx of fourth toe (Fig. 3); subarticular tubercles prominent at base of toes, poorly defined to absent distally. Outer metatarsal tubercle absent; inner metatarsal tubercle large, projecting, shovel-shaped with smoothly rounded free margin, length approximately equal to its distance from tip of first toe.

Skin of dorsal and lateral surfaces of body and head thickened, pustulose to tubercular (Fig. 1);

Fig. 1 *Notaden weigeli* sp. nov. (Mitchell Plateau) in life. (Photograph: J. Weigel).

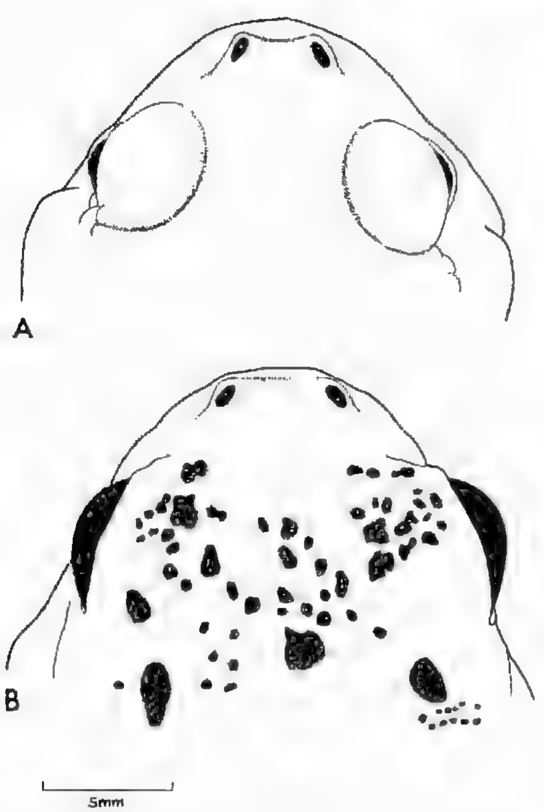

Fig. 2. Dorsal view of heads of A, *Notaden weigeli* sp. nov. and B, *N. nichollsi.*

snout more finely and weakly tubercular; a distinct crease from commissure of lips to lateral canthus of eye, bordered posteriorly by a broad ridge. Individual glands obvious subdermally on posterolateral margins of body. Skin extends from body to knee laterally, so that groin is not distinct in life. Skin on ventral surfaces smooth.

In preservative, dorsum of head and body reddish brown, obscurely marbled with lighter and darker shades, and with a few white to cream tubercles. Limbs dark grey, with prominent to obscure white or cream flecks. Face and upper lips dark grey, finely variegated and flecked with cream; pale midrostral streak absent; pale vertical canthal streak weakly developed. Venter cream, with weak brown flecking on mandible. Inner metatarsal tubercle unpigmented.

Measurements of holotype (in mm): S-V 54.4, TL 18.7, FL 31.6, HW 16.5, E. 7.0, E-N 3.0, IN 3.0.

Variation

Overall variation in limb and cranial proportions is presented in Table 1.

The Mitchell Plateau paratypes are similar to the holotype, ranging in size from 46.6 to 60.8 mm. In preservative, the dorsal ground colour is fawn. The pale dorsal tubercles and canthal streak are absent on some specimens.

Gravid females have 1.3 mm diameter oocytes with black animal poles and white vegetal poles.

The two Mount Elizabeth Stn paratypes are very much larger than the Mitchell Plateau series (S-V 68.7–71.1 mm), and have a longer snout (E-N/S-V 0.07–0.08 *vs* 0.05–0.06, E-N/IN 1.42–1.59 *vs* 1.00–1.12). However, in other characters, including all significant diagnostic characters, they agree with the topotypic sample.

Color in life (based on AM R123896–99): Dorsum fawn with numerous white-tipped orange tubercles and scattered indistinct grey-green patches. Limbs grey with a few fine white tubercles above, sharply demarcated from fawn of dorsum. Hindlimb also with a few small orange flecks. Face grey with white tubercles. Venter greyish. Inner metatarsal tubercle unpigmented.

Pupil horizontally elliptic, with a distinct ventral notch. Iris finely variegated golden green with a gold pupillary margin.

Osteology (based on AM R123898)

Cranium poorly ossified (Fig. 4). Sphenethmoid not ossified either dorsally or ventrally, cartilage extending ¼–⅓ length of orbit in dorsal view.

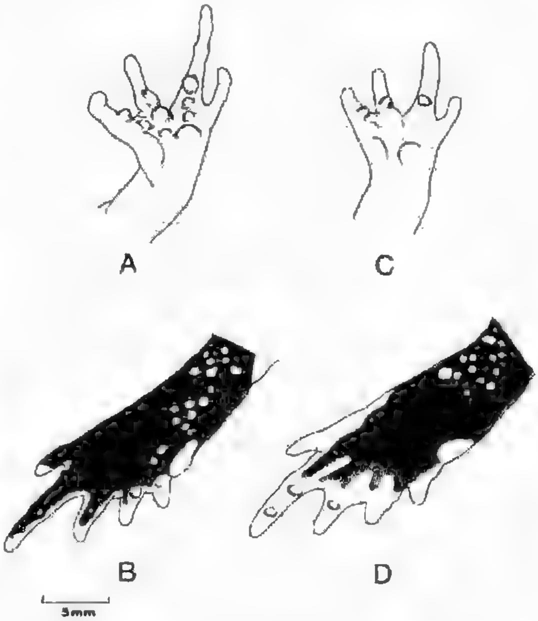

Fig. 3. A, B, Hand and foot of *Notaden weigeli* sp. nov.; C, D, hand and foot of *N. nichollsi.*

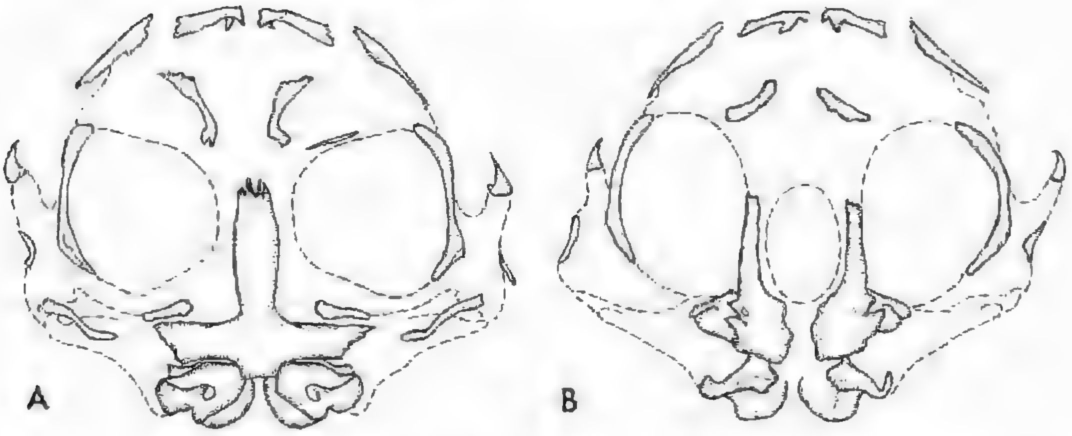

Fig. 4. A, Ventral and B, dorsal views of skull of *Notaden weigeli* sp. nov. Approximate extent of some cranial cartilages and frontoparietal fontanelle indicated by dashed lines.

Exoccipitals and prootics paired, unfused. Crista parotica non-ossified, moderately long, robust. Frontoparietal fontanelle fully exposed, ovoid. Frontoparietals poorly ossified, anterior extremities slender, parallel, extending anteriorly ¾ length of orbit. Anterior margin of frontoparietal fontanelle formed by cartilaginous sphenethmoid, posterior margin formed by prootic cartilage. Nasals small, widely separated, not in osseous contact with any other cranial bones. Palatines very reduced to absent (represented by a sliver of bone on left, absent on right). Parasphenoid robust, with broad, moderately long and terminally bifid cultriform process; alae moderately short, broad, at right angles to cultriform process. Pterygoid reduced; anterior ramus not contacting maxilla; medial ramus short, slender, well ossified; posterior ramus minute. Quadratojugal reduced, widely separated from maxilla. Squamosal reduced, with long acuminate zygomatic ramus and lacking otic ramus. Maxilla reduced, edentate; pars facialis shallow, with low, poorly developed preorbital process, widely separated from nasals. Alary process of premaxilla narrow, tall, acuminate and vertical; pars palatina very shallow; palatine process short. Vomers reduced, with narrow elongate edentate dentigerous process; alae bordering rostral margin of choanae. Columella long, sinuous, with a medial posterior convexity and lateral anterior convexity; ossified medially.

Hyoid plate slightly broader than long (Fig. 5). Anterior hyale without anteromedial process. Alary process pedunculate, without distal expansion. Posterolateral process prominent, dilated distally. Posterior cornu ossified, with a distal cartilaginous expansion.

Pectoral girdle arciferal and robust (Fig. 6). Epicoracoid cartilages broadly overlapping. Omosternum cartilaginous, dilated distally. Xiphisternum, mesosternum present, cartilaginous. Clavicles moderately robust, curved, moderately separated medially. Coracoids robust, moderately separated medially, broadly expanded at both ends. Scapula bicapitate, approximately 1.5x length of clavicle. Suprascapula ossified anteriorly, with a hook-like cartilaginous process projecting posteroventrally.

Phalangeal formula of manus 2.2.3.3. Terminal phalanges pointed, slightly knobbed distally, recurved. Carpus poorly ossified. Prepollex cartilaginous.

Eight non-imbricate presacral vertebrae (Fig. 7). Vertebrae I and II fused; centra of Vertebrae II and III fused. Cervical cotyles very narrowly separated, almost confluent. Neural arches completely ossified, robust. Relative widths of transverse processes

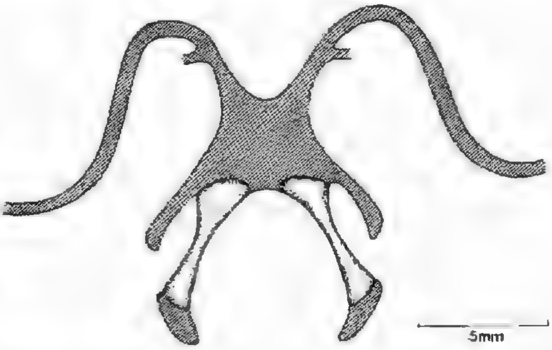

Fig. 5. Hyoid of *Notaden weigeli* sp. nov. Hatched areas are cartilage.

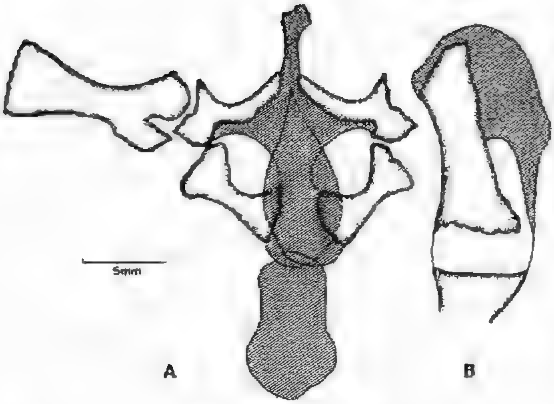

Fig. 6. Pectoral girdle of *Notaden weigeli* sp. nov.: A, sternal region, B, left suprascapula. Hatched areas are cartilage.

sacrum > III > IV > II = V = VI > VII > VIII > I. Sacral diapophyses moderately expanded. Bicondylar sacrococcygeal articulation. Well-developed dorsal crest along anterior third of urostyle.

Ilium with well-developed dorsal prominence bearing a shallow notch on dorsal margin (Fig. 8). Dorsal protuberance small. Ilial shaft round in section, moderately curved. Pubis largely cartilaginous, slightly calcified ventrally. Ischium with a well-defined vertically ovoid ossification.

Phalangeal formula of pes 2.2.3.4.3. Well-developed cartilaginous prehallux reinforcing inner metatarsal tubercle. Distal tarsal elements poorly ossified.

Etymology

This species is named after Mr John Weigel of Gosford, NSW, co-collector of the Mitchell Plateau paratypes, in honour of his efforts to promote amateur herpetology in Australia.

Comparison with other species

Distribution: Notaden weigeli is apparently allopatric to its three congeners: *N. bennetti* Günther, *N. melanoscaphus* Hosmer and *N. nichollsi* Parker (Cogger 1986; Tyler, Smith & Johnstone 1984; Tyler & Davies 1986). Within the Kimberley Division, *N. nichollsi* is largely confined to the southwest and south, *N. melanoscaphus* to the far east, with a single record from the central Kimberley, and *N. weigeli* to the north (Fig. 9). Known localities for *N. weigeli* are separated from those of *N. melanoscaphus* by 87 km and from those of *N. nichollsi* by 188 km.

External morphology: In addition to the characters given in the diagnosis, *N. weigeli* differs from *N. bennetti* in having a reddish dorsum without black tubercles (*vs* yellow dorsum with rounded black and red tubercles arranged in vertebral and transverse series) and inner metatarsal tubercle subequal in length to its distance from tip of first toe (*vs* 1.2–2.0 times as long; Parker 1940).

N. weigeli further differs from *N. melanoscaphus* in having an unpigmented inner metatarsal tubercle (*vs* black) and in lacking large discrete islands of

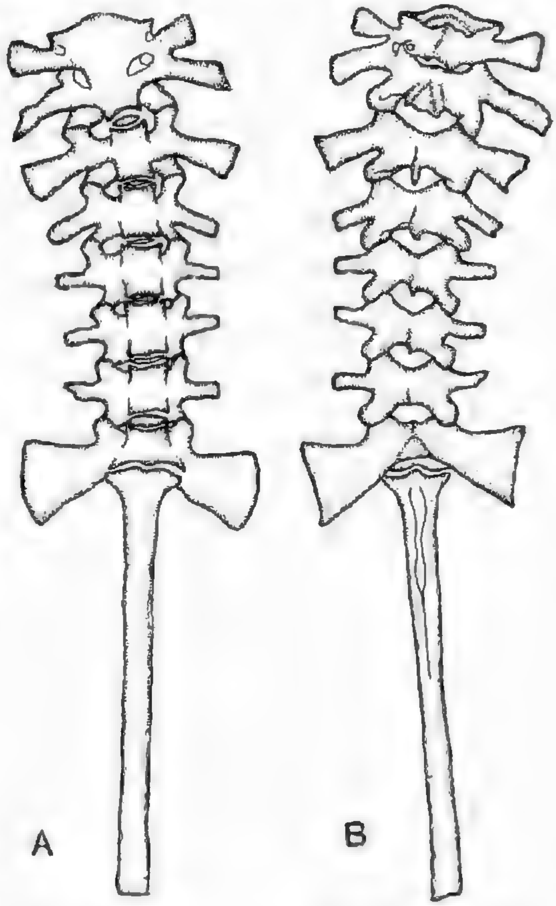

Fig. 7. A, Ventral and B, dorsal views of vertebral column of *Notaden weigeli* sp. nov.

Fig. 8. Pelvis of *Notaden weigeli* sp. nov. Hatched areas are calcified.

dark pigmentation on the back (cf. Hosmer 1962; Tyler, Smith & Johnstone 1984, Plate 4; Tyler & Davies 1986, Plate 40).

N. weigeli further differs from *N. nichollsi* in lacking black tubercles on the body, and in having more narrowly spaced nostrils (Table 1).

Osteology: Few comparative data have been published on the osteology of other *Notaden* species. The skull of *N. nichollsi* has been figured by Lynch (1971 Figs. 18, 56, 57), who also described a number of postcranial characteristics in his diagnosis of the genus, based on *N. bennetti* and *N. nichollsi*. However, there are several discrepancies in Lynch's osteological descriptions and figures of *Notaden* that suggest that re-examination of the osteology of these species is warranted.

The ossified portions of the skull of *N. weigeli* are even more reduced than in *N. nichollsi* and *N. melanoscaphus* (M. Davies pers. comm.). This reduction is most notable in the loss of ossification of the sphenethmoid and palatines, and the reduction of the anterior extremities of the frontoparietals. The apparent lack of distal dilations of the alary processes of the hyoid of *N. weigeli* is consistent with Tyler's (1972) observations on congeners. The fusion of the centra of the second and third presacral vertebrae present in the *N. weigeli* specimen examined has not been recorded for other *Notaden* species, but may be an individual anomaly. The transverse processes of the more posterior presacral vertebrae, while short, are not knob-like (cf. Lynch 1971, p. 56).

The ilia of *N. nichollsi* and *N. melanoscaphus* are illustrated and described by Lynch (1971) and Tyler (1976). The round ilial shaft of *N. weigeli* resembles that of congeners.

Discriminant function analysis: Discriminant function analysis of seven measurements, using species of *Notaden* as *a priori* groupings, resulted in the correct identification of 93.2% of specimens overall. All *N. weigeli*, 95% of *N. melanoscaphus*, 93.9% of *N. nichollsi* and 86.4% of *N. bennetti* were correctly grouped.

The first two discriminant functions accounted for 92.45% of the variance (Table 2). Unstandardised discriminant function coefficients and their correlations with the discriminant functions are presented in Table 2. All characters show the highest correlation with the second discriminant function, which most clearly separates *N. weigeli* from its congeners (Fig. 10).

Allometry: In *N. bennetti*, *N. melanoscaphus* and *N. nichollsi*, HW showed significant negative allometry. In *N. nichollsi*, TL and FL also show negative allometry (Table 3). The ratio of E–N/IN, however, varied independently of S-V in all three species ($R^2 \le 0.04$). Comparisons of HW, TL and FL between species should therefore be made between similar-sized specimens. The frequency distribution of S-V varied significantly between the samples of each taxon used here ($F_{3,114} = 10.1062$, $P < 0.01$). Consequently, although ratios showed significant differences (P's < 0.01; Table 1) between taxa, it is unclear whether these differences are real or an artefact of unequal size frequencies between samples.

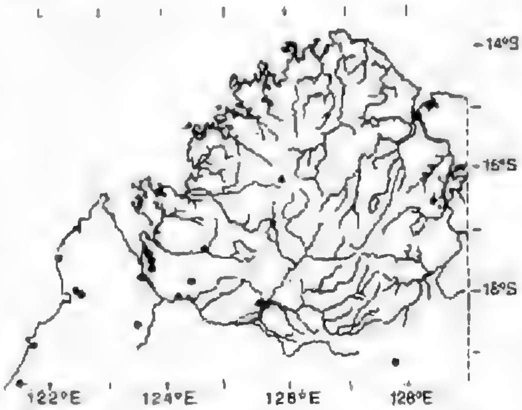

Fig. 9. Distribution of *Notaden weigeli* sp. nov. (triangles), *N. melanoscaphus* (inverted triangles) and *N. nichollsi* (dots) in the Kimberley region (based on SAM and WAM records).

TABLE 2. *Unstandardised discriminant function coefficients (and pooled-within-groups correlations with discriminant functions) of seven characters from all species of* Notaden.

	Discriminant Function		
Variable	I	II	III
S-V	−0.651 (0.071)	−0.267 (0.302)	0.125 (0.233)
HW	−0.949 (0.098)	−0.322 (0.333)	−0.438 (0.164)
E	1.301 (0.334)	0.847 (0.490)	0.911 (0.287)
E–N	−1.514 (−0.159)	0.106 (0.313)	2.355 (0.306)
IN	5.353 (0.353)	1.383 (0.398)	−1.426 (0.118)
TL	−0.520 (0.042)	0.917 (0.560)	−1.370 (0.076)
FL	−0.137 (0.074)	0.258 (0.545)	0.630 (0.307)
constant	−2.963	−3.161	−3.831
% of variance	67.93	24.51	7.55

Habits and habitat

The holotype was collected in open low woodland of *Planchonia australis, Xanthostemon paradoxus, Buchanania obovata* and *Eucalyptus brachyandra* over open scrub and hummock grasses on rugged sandstone (Kitchener *et al.* 1981).

The Mount Elizabeth Stn paratypes were collected between 2030–2400hr within and near the entrance to a small gorge in an isolated 4–6 m high quartzite outcrop. Open *Eucalyptus* spp woodland with negligible understorey and a groundcover of grasses and forbs surrounded the outcrop. The gorge itself was overgrown with *Mimosa*. Isolated clumps of *Pandanus* occurred on drainage channels associated with the outcrop. Both specimens were active after light rain on rock ledges covered with leaf litter.

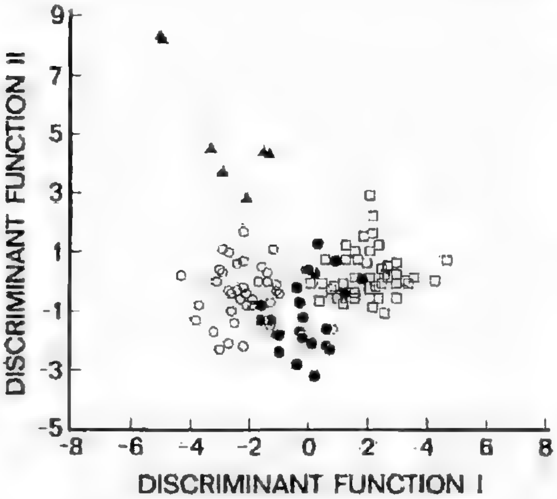

Fig. 10. Plot of individual *Notaden weigeli* sp. nov. (triangles), *N. bennetti* (dots), *N. melanoscaphus* (open circles) and *N. nichollsi* (open squares) on the first two discriminant function axes.

The Mitchell Plateau paratypes were collected within 200 m of the Mitchell River. The habitat at this site consists of a yellow sandplain with densely packed, small to moderate-sized *Plectrachne* and *Triodia* tussocks and an open woodland of tall shrubs and trees dominated by *Eucalyptus* spp and *Acacia* spp. There are numerous, extensive quartzite rock platforms, often with clifflike margins, raised up to 3 m above the level of the plain, bearing scattered *Plectrachne* tussocks on a skeletal sandy soil. Closer to the Mitchell River, these rock platforms are higher (up to 6m), their bases riddled with rock shelters and narrow tunnels, and the sandplain is reduced to narrow sand drifts with numerous partially buried boulders and smaller stones. The bed and bordering overflow area of the Mitchell River consists of a bare sheet of rock with several steps and scattered piles of waterworn boulders, and *Pandanus* and *Melaleuca*-fringed pools. Specimens were active at night, in a puddle on top of a raised rock platform (AM R123897), on a low rock platform partially buried by coarse river sand and surrounded by dense *Triodia* thickets (AM R123898), and on a rock ledge 1.5 m above the surrounding sandplain, following light rain two days previously (AM R123896).

One individual was observed to run rapidly in a zig-zag fashion for more than 10 m on a rock platform at night when being photographed. Similar behaviour has been reported for *N. melanoscaphus* and *N. nichollsi* (Tyler & Davies 1986).

TABLE 3. *Allometric coefficients and calculated values for limb lengths and head width in* Notaden *spp. Regression lines are of the form* $y = bS\text{-}V^a$. C_{40} *and* C_{60} *values are calculated proportions of S V at 40 and 60 mm. Probabilities are based on standard normal deviates of the allometric coefficient compared to isometry.*

	R^2	*a*	*b*	n	P	C_{40}	C_{60}
			Notaden bennetti				
TL	0.95	0.9615	0.3286	22	0.227	.29	.28
FL	0.96	0.8913	0.7294	22	0.006	.49	.47
HW	0.97	0.7782	0.6797	22	<0.001	.30	.27
			Notaden melanoscaphus				
TL	0.86	1.0595	0.2265	40	0.192	.28	.29
FL	0.82	0.9643	0.5859	40	0.316	.51	.51
HW	0.81	0.7350	0.7761	40	<0.001	.29	.26
			Notaden nichollsi				
TL	0.84	0.7448	0.7677	49	<0.001	.30	.27
FL	0.83	0.7886	1.1800	49	<0.001	.54	.50
HW	0.79	0.8342	0.5493	49	0.004	.30	.28

Collection of these specimens in rocky situations suggests that *N. weigeli* may not burrow to the same extent as its congeners (Lucas & le Souëf 1909; Slater & Main 1963; Mebs 1975; Barker & Grigg 1977; Tyler, Crook & Davies 1983).

When handled roughly, all *N. weigeli* specimens we collected exuded from the dorsal surface a viscous sticky white secretion, which rapidly dried like glue on surfaces exposed to it. Similar exudates have been reported for other *Notaden* species (Lucas & le Souef 1909; Parker 1940; Main & Storr 1966; Mebs 1975; Barker & Grigg 1977; Tyler, Crook & Davies 1983; Tyler, Smith & Johnstone 1984; Tyler 1987).

Faeces from the Mitchell Plateau paratypes consisted almost entirely of remains of the ant *Crematogaster* sp. (Myrmicinae; sample deposited in Australian National Insect Collection, Canberra). This species of ant was common in caves and amongst rocks in the area, and rapidly attacked and killed any frogs and small lizards held in open-weave cloth bags or thin plastic bags. The gorge from which the Mount Elizabeth Stn paratypes were collected was so heavily populated with ants that field work was extremely uncomfortable; no other reptiles or amphibians were found there, despite an extensive search at night and during daylight hours. The secretion produced by *N. weigeli* may play a role in resisting the attacks of the ants on which it feeds.

Myrmecophagy has been recorded in congeners (Lucas & le Souef 1909; Parker 1940; Calaby 1960) although the prevalence of ants in the diet has been interpreted as an artefact of food availability at times of emergence (Calaby 1960).

Comparative material examined

N. bennetti: AM R11779, "The Plains", Nyngan, NSW; R32163, Murrumbidgee River nr Hay, NSW; R45628, R51216, R51218–20, 16–32 km S Condobolin on West Wyalong Rd, NSW; SAM R3684, 23.3 km S St George, Qld; SAM R4736–38, nr Rockhampton, Qld; SAM R15224a-i, R17617-18, Coonamble, NSW.

N. melanoscaphus: AM R53462, R53569–71, R53573, R53591-92, R53703, Caranbirini Waterhole, 21 km N McArthur River camp, NT; SAM R9663–97, SAM R9669, Strathgordon HS, Qld; SAM R9695-96, Edward River Stn, Qld; SAM R16536–37, Stonewall Ck, 19–26 km NE Lake Argyle, WA; SAM R17904a–c, 0.4 km S Jabiru, NT; SAM R27676-79, 15 km S Northern/Duncan junction, WA; SAM R27680–92, 29 km S Northern/Duncan junction, WA

N. nichollsi: AM R26002–05, nr The Granites, NT; R49375, R49444–67, R49599–604, 25 km NW Refrigerator Bore, NT; R51653–55, 38.1 km N Neale Junction, WA; R60346, Elliott, NT; R96371–76, 47.6 km SE The Granites by rd, NT; R100739, 4.6 km S of turnoff to Nita Downs on Northern Hwy, WA; R110616–18, 8 km N Mirrica Bore, "Ethabuka", NW Bedourie, Qld.

Acknowledgments

J. Weigel, A. Harwood, C. Hemsley, H. Floriani and H. Ehmann are thanked for field assistance. H. Ehmann provided measurements for the Mt Elizabeth Stn material. Specimens were collected under permits issued by the Dept of Conservation and Land Management, Western Australia.

C. Cathcart, M. Davies, A. Greer, M. Mahony, A. Martin, S. Richards, R. Sadlier, L. Trueb, M. Tyler and K. Walker provided useful comments on the manuscript. T. Schwaner (SAM) permitted access to specimens in his care. L. Smith provided data on material in the Western Australian Museum. P. J. M. Greenslade kindly identified the ant sample. B. Jantulik prepared the final illustrations.

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THE GENUS ARTHROCARDIA (CORALLINACEAE: RHODOPHYTA) IN SOUTHERN AUSTRALIA

BY H. B. S. WOMERSLEY & H. W. JOHANSEN†*

Summary

Two taxa of *Arthrocardia* Decaisne (tribe Corallineae, subfamily Corallinoideae) occur in south-eastern Australia: *A. wardii* (Harvey) Areschoug and *A. flabellata* (Kuetzing) Manza ssp. *australica* ssp. nov. The former was first described by Harvey (1849), and the latter is a new subspecies of a species that is common in South Africa. Neither entity is common in south-eastern Australia and neither has been collected west of Eyre Peninsula.

The genus *Arthrocardia* is closely related to *Corallina*, a genus that is much more widely distributed and probably more primitive. Within Arthrocardia differences have evolved in the organization of the fertile branches. In both genera the conceptacles are axial, but in Arthrocardia fertile intergenicula all have the propensity for bearing branches, no matter what the reproductive type. These branches usually consist of more fertile intergenicula and, hence, a branching system of several fertile intergenicula develops. In *Corallina* the fertile intergenicula typically lack surmounting branches, although in carposporangial plants, and less often in tetrasporangial plants, they are occasionally present. Fertile intergenicula in male plants of *Corallina* invariably lack branches.

KEY WORDS: Articulated coralline algae, Corallinacae, *Arthrocardia*, southern Australia, Rhodophyta, marine algae.

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By H. B. S. WOMERSLEY* & H. W. JOHANSEN†

Summary

WOMERSLEY, H. B. & JOHANSEN, H. W. (1988) The genus *Arthrocardia* (Corallinaceae: Rhodophyta) in southern Australia. *Trans. R. Soc. S. Aust.* 112(1), 39-49, 31 May 1988.

Two taxa of *Arthrocardia* Decaisne (tribe Corallineae, subfamily Corallinoideae) occur in south-eastern Australia: *A. wardii* (Harvey) Areschoug and *A. flabellata* (Kuetzing) Manza ssp. *australica* ssp. nov. The former was first described by Harvey (1849), and the latter is a new subspecies of a species that is common in South Africa. Neither entity is common in south-eastern Australia and neither has been collected west of Eyre Peninsula.

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KEY WORDS: Articulated coralline algae, Corallinacae, *Arthrocardia*, southern Australia, Rhodophyta, marine algae.

Introduction

Of the nine genera of Corallinoideae, tribe Corallineae (Johansen & Silva 1978) only *Arthrocardia* (Decaisne 1842, p. 365) and *Corallina* Linnaeus occur in southern Australia. These genera, plus the three in the tribe Janieae, *Cheilosporum* Areschoug, *Haliptilon* (Decaisne) Lindley and *Jania* Lamouroux, represent the subfamily Corallinoideae in this area. *Amphiroa* Lamouroux (in the Amphiroideae) and *Metagoniolithon* Weber van Bosse (in the Metagoniolithoideae) also are present. The species in these genera of geniculate (articulate) corallines constitute a conspicuous component of the shallow water biota on southern (and also other) Australian coasts, especially where water motion is considerable. However, as in many other parts of the world, uncertainty exists in the identification at both generic and specific levels of many geniculate corallines. This uncertainty has resulted in the publication of records from southern Australia under a variety of names, many of which are synonymous as exemplified by *Haliptilon* (Johansen & Womersley 1986). Resolution of the taxonomic problems can only be achieved by studying these plants, as well as related entities, from many parts of the world.

Two species of *Arthrocardia* have been described from southern Australia, both originally by Harvey (1849, p. 99): *A. mallardiae* (Harvey) Areschoug (1852) and *A. wardii* (Harvey) Areschoug (1852). This account aims at describing *Arthrocardia* in southern Australia so as to (1) understand the taxonomy of the included species, (2) gain a general appreciation of the ecological importance of these species in the marine environment and (3) further establish the diagnostic features of *Arthrocardia* vis-a-vis other genera in the subfamily Corallinoideae.

Arthrocardia Decaisne (1842), with the South African *A. corymbosa* (Lamarck) Decaisne as the lectotype species, is characterised (Johansen 1969, 1981) by pinnate branching with terete to flat intergenicula, sometimes with acute to obtuse lobes, and with 20–40 tiers of medullary cells. The conceptacles are axial and deeply embedded and the fertile intergenicula each bear two (rarely one) branchlets, one on each side of the conceptacle pore. The conceptacles originate in medullary tissue at the apices of intergenicula and the chambers become deeply embedded, swelling the intergeniculum only slightly, with the pores centrally positioned or just below the apices on the flat surface. Thalli are dioecious, the female with the carposporophyte producing gonimoblast filaments from anywhere on the upper surface of the fusion cell, and the male conceptacles with beaks sometimes as much as 1 mm long. Bisporangia or tetrasporangia occur. *Arthrocardia* is closely related to *Corallina*, and the differences between them are clarified in the Discussion.

Materials and Methods

Collections from many areas along the coast of southern Australia were examined; there was,

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however, a paucity of specimens from the little explored Great Australian Bight. Specimens in ADU provided a foundation for the study, but other herbaria (notably MEL) also house historically and nomenclaturally important collections. Collections in the following herbaria were examined: ADU, BM, CN, CUW, L, LTB, MEL, NSW, S, TCD, and UC.

Branches were decalcified in dilute hydrochloric acid and squashed or teased apart to discern tissues or conceptacular contents. Other branches were fixed and decalcified in Susa solution (Suneson 1937) after which they were embedded in wax, sectioned at 8–10 μm thick, and stained with haematoxylin (Johansen 1969).

Results

The specimens of *Arthrocardia* from Australia (Table 1) comprise two distinct species. The characteristics of one entity, a robust, compactly branched form, agree with the type specimens of *A. wardii* (Fig. 1A) and *A. mallardiae*; the other entity (Fig. 2C, D) is undescribed. The diagnostic characteristics of *A. wardii* (including as a synonym *A. mallardiae*), together with those of the new entity named *A. flabellata* ssp. *australica* Womersley & Johansen, are presented in Table 1.

Arthrocardia wardii (Harvey) Areschoug 1852:551). Bailey 1883,791, Guiler 1952:87, Harvey 1863:xxix. Lucas 1909:56. Sonder 1881:20. Tisdall 1898:507. Wilson 1892:177.

Amphiroa wardii Harvey 1849:99, pl. 38 (figs 1, 2), 1859:310. Yendo 1905:8.
Cheilosporum wardii (Harvey) DeToni 1905:1828. Bailey 1913:829. Garnet 1971:96. Lewis 1984:13. Lucas 1912:164 Lucas & Perrin 1947:397. May 1965:356.
Amphiroa mallardiae Harvey 1849:99. Yendo 1905:8.
Arthrocardia mallardiae (Harvey) Areschoug 1852:552 Guiler 1952:87. Harvey 1863:xxix. Lucas 1909:56. Sonder 1881:20. Tisdall 1898:507.
Cheilosporum mallardiae (Harvey) DeToni 1905:1828 Lucas 1912:164; 1929:27. Lucas & Perrin 1947:397. May 1965:356.

Habit: thalli (Figs 1, 2A, B) light to medium red, (2–) 5–12 cm high, robust, with clusters of 2–10 complanate fronds from a discoid, crustose, holdfast, essentially complanately branched, epilithic.

Branching: densely pinnate from axes in which most of the intergenicula branch, lateral branches frequently also pinnately branched; sexual plants often with fertile branchlets displaced from plane of branching. *Intergenicula:* in lower parts of fronds terete, 0.5–1.0 (–1.5) mm in diameter; in middle and upper parts flat and not or slightly lobed; axial intergenicula (1.5–) 1.7–3 (–4) mm long and 1.4–3.5 mm wide at widest parts, length to width ratio 1–1.5; 20–40 (–45) tiers of medullary cells (Fig. 3A), each 50–75 (–95) μm long, per intergeniculum, cortex filamentous, with cells 6–10 μm in diameter, L/D 1–2; epithallium 1 (or 2) cells thick, with cells 6–10 μm in diameter, L/D about 1. *Genicula:* uncalcified parts of cells 80–250 μm long, genicula (250–) 350–1000 μm broad, less in lateral branches. *Carpogonial conceptacles:* not observed. *Carposporangial conceptacles* (Fig. 3B): with or without surmounting branchlets, chamber diameter 300–500 μm, fusion cell 250–300 μm in diameter, and 8–10 μm thick, bearing 2–4-celled gonimoblast filaments, carposporangia subspherical to ovoid, 40–60 μm in diameter. *Male conceptacles* (Fig. 3C): beaked, usually without surmounting branchlets, chambers 250–350 (–390) μm in diameter, 260–330 μm high, canals 300–700 μm long. *Bisporangial* (or tetrasporangial) *conceptacles* (Fig. 3A): common, terminal on axial or lateral branches, becoming surmounted by two branches, chambers 250–520 μm in diameter, 325–500 μm high; bisporangia 160–240 (–260) μm long, 40–65 μm in diameter; tetrasporangia (in ADU, A57658) 200–280 μm long, 60–90 μm in diameter.

Type: from Port Phillip, Victoria (*Mallard*; holotype in TCD; Fig. 1A).

Distribution: From Cape Willoughby, Kangaroo I., S. Aust., to Norah Head, N.S.W. and around Tasmania.

Selected specimens: Cape Willoughby, Kangaroo I., S. Aust., upper sublittoral (*Woelkerling*, 23.ii.1979; LTB, 11563; ADU, A57530). Port Fairy, Vic., upper sublittoral (*Woelkerling*, 6.i.1977; LTB, 11339; ADU, A57534). Lawrence Rock, Vic., 12–15 m deep (*Watson*, 30.xi.1981; ADU, A52798, bisporangia, male). Lady Julia Percy I., Vic., 5–8 m deep (*Shepherd*, 3.i.1968; ADU, A32317, male).

TABLE 1 *Features distinguishing southern Australian taxa of* Arthrocardia.

Features	*A. wardii*	*A. flabellata* ssp. *australica*
Frond height (cm)	5–12	2–4 (–6)
Percentage of main intergenicula producing lateral branches	95–100	50
L/W ratio of main intergenicula (approx.)	1	2
Diameter of basal intergenicula (mm)	0.5–1.0	0.3–0.5
Percentage of *Arthrocardia*-like sporangial conceptacles	50	95
No. spores per sporangium	usually 2 (occasionally 4)	4

Lady Julia Percy I., Vic., 3-6 m deep (*Shepherd*, 4.i.1968; ADU, A32436, with *mallardiae* habit; ADU, A32437, cystocarpic male). Port Phillip, Vic., type of *Amphiroa mallardiae* (Mrs *Mallard*; TCD, isotype at BM). Rye (Ocean Beach), Vic., upper sublittoral (*Woelkerling*, 14.ii.1977; LTB, 11342; ADU, A57536). Green Cape, N.S.W., 1-6 m deep (*Shepherd* 13.ii.1973; ADU, A43297 and A43298, bisporangial). Port Jackson, N.S.W. (*Harvey*, Alg. Aust. Exsicc. 453; NSW, A3281). Long Reef, N.S.W., below rock platform (*May* 2307, Feb. 1936; NSW). Green Point, Broken Bay, N.S.W., in wave-washed gutters and pools, upper sublittoral (*Martin*, 19.i.1969; NSW, A3284). Tuggerah Lakes, N.S.W. (*Lucas*, April 1911; NSW, A3287). Norah Head, N.S.W., very low eulittoral (*Pope* 13.xii.1947; ADU, A10772). Fluted Cape, Bruny I., Tas., 16 m deep (*Shepherd*, 10.ii.1972; ADU, A41485). Lady Bay, Southport, Tas., 2-3 m deep (*Brown & Kenchington*, 14.x.1986; ADU, A57658, tetrasporangial).

The basis of the Queensland records of Bailey (1913) and Lewis (1984) is unknown, since this was not indicated in the publications and no Queensland specimens are known.

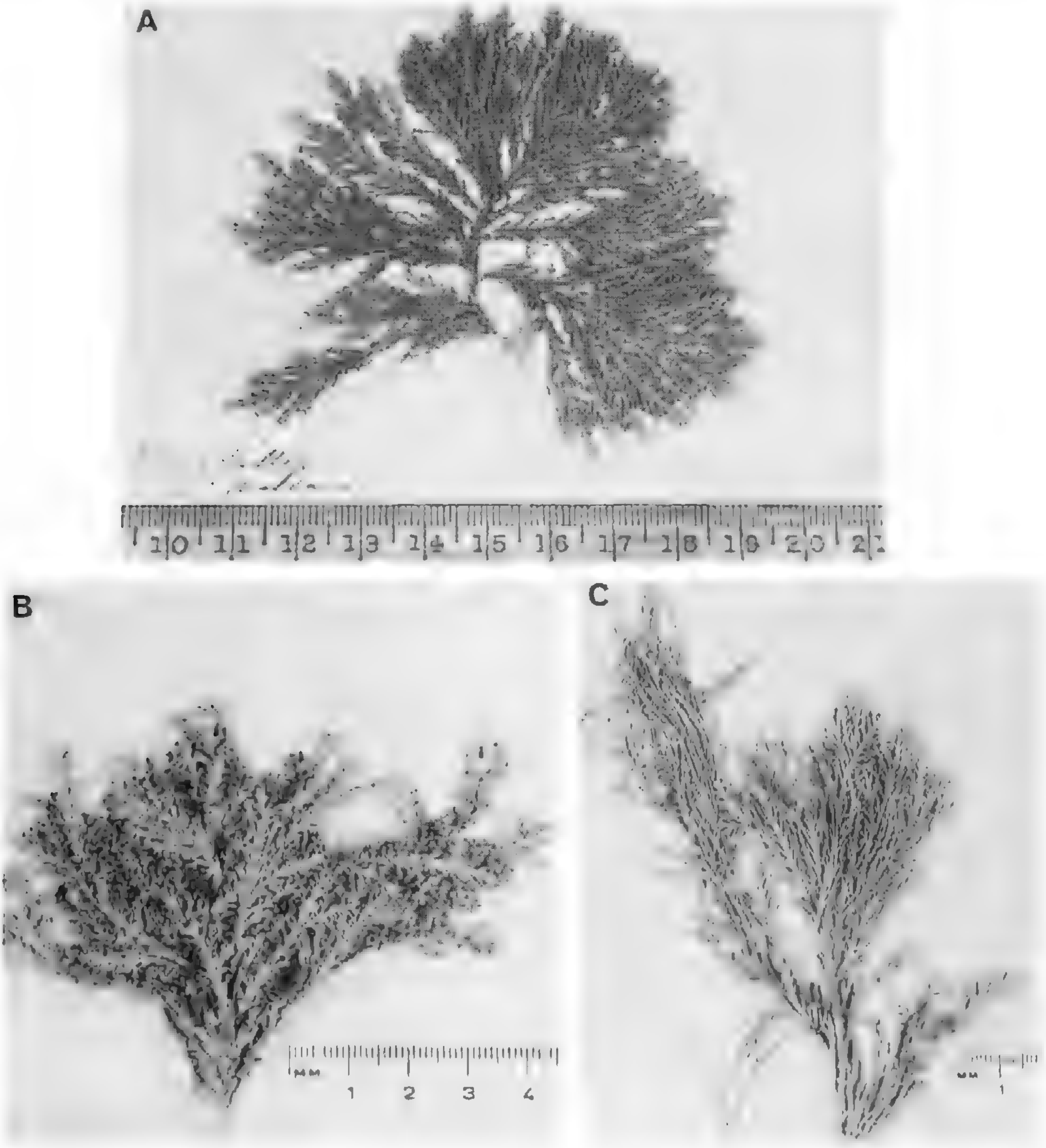


Fig. 1. *A. Arthrocardia wardii* (holotype in TCD). *B. A. warc* (ADU, A32317). *C. A. wardii* (*A. mallardiae* habit) (ADU, A32426).

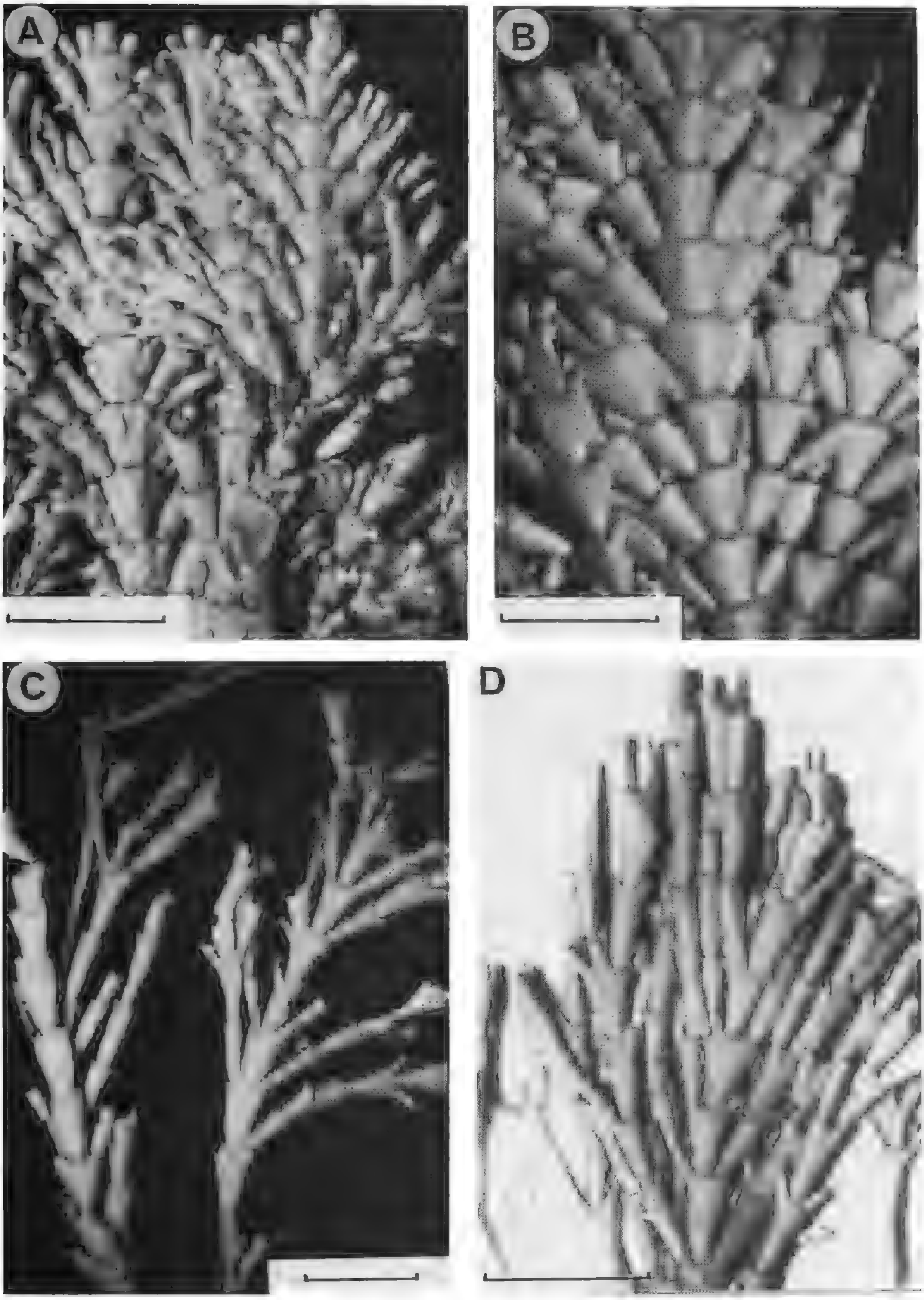


Fig. 2. Fronds of *A. Arthrocardia wardii* (ADU, A43297). *B. A. wardii* (A43298). *C. Arthrocardia flabellata* ssp. *australica* (ADU, A52790, holotype). *D. A. flabellata* ssp. *australica* (ADU, A31943). Scales = 5 mm.

Arthrocardia wardii also has been recorded from New Zealand by Reinbold (1899, p. 299) from the Chatham Is., by Adams (1972, p. 75) from the Wellington area, and by Chapman & Parkinson (1974, p. 174, pl. 566, as *Cheilosporum*) from various localities throughout New Zealand. The New Zealand plants are similar superficially to Australian *A. wardii* but the intergenicula are shorter, with fewer medullary tiers. Further comparative studies on the New Zealand plants are necessary.

A. wardii is predominately a low-light plant, with collections from 3–22 m deep or from shaded upper sublittoral regions. However, several collections from just below low tide level are known from N.S.W.

The holotype specimen of *A. wardii* is a well-preserved frond with dense branching and robust intergenicula. Unfortunately, it lacks conceptacles. The type specimen of *A. mallardiae* (see Fig. 1C for habit) also has large axial intergenicula, but they are smaller than in the type of *A. wardii*. More strikingly it differs from *A. wardii* in having thinner lateral branches which arise from most axial intergenicula (Fig. 1C). The type specimen of *A. mallardiae* falls within the range of forms attributable to *A. wardii*, but it is not characteristic of most specimens examined. Both type specimens are from Port Phillip Bay (Harvey 1849, pp. 99–100).

In *A. wardii*, deviation from the *Arthrocardia*-type of branching occurs more often than in *A. flabellata* ssp. *australica*. A survey of 233 fertile intergenicula containing mature conceptacles in six bisporangial collections of *A. wardii* revealed that 21% lacked branches although most of these had broadened *Arthrocardia*-like upper parts. The remaining 79% had 1 or 2 branches, or processes in lieu of the branches.

Arthrocardia flabellata (Kuetzing) Manza ssp.
australica Womersley & Johansen, ssp. nov.

Thallus 2–4 (–6) cm altus, epilithicus, fasciculatus. Axes principales sparse pinnati. Intergenicula infra teretia, 300–500 µm diam., in partibus mediis et distalibus compressa, interdum parvilobis obtusis, non ramosis vel 1–2 ramis lateralibus. Intergenicula axialia 1.5–3.5 mm longa et 0.7–1.2 mm lata, ratio longitudinis et latitudinis circa 2, 20–40 stratis cellularum medullariarum 50–75 µm longarum praedita. Conceptacula carposporangialia ramos in uno vel utroque latere pori, habent, interdum concatenata; loculus 300–520 µm diam. cellula coalescenti 220–310 µm diam. et 8–10 µm crassa; carposporangia 55–80 µm diam. Conceptacula spermatangiata rostrata, ramis utroque latere pori; loculus 375–575 µm diam., 400–550 µm altus, canali 800–900 µm longo. Conceptacula tetrasporangialia paululum tumida, loculus 500–750 µm diam., 600–700 µm altus, tetrasporangia 180–280 µm longa, bisporangialia ignota.

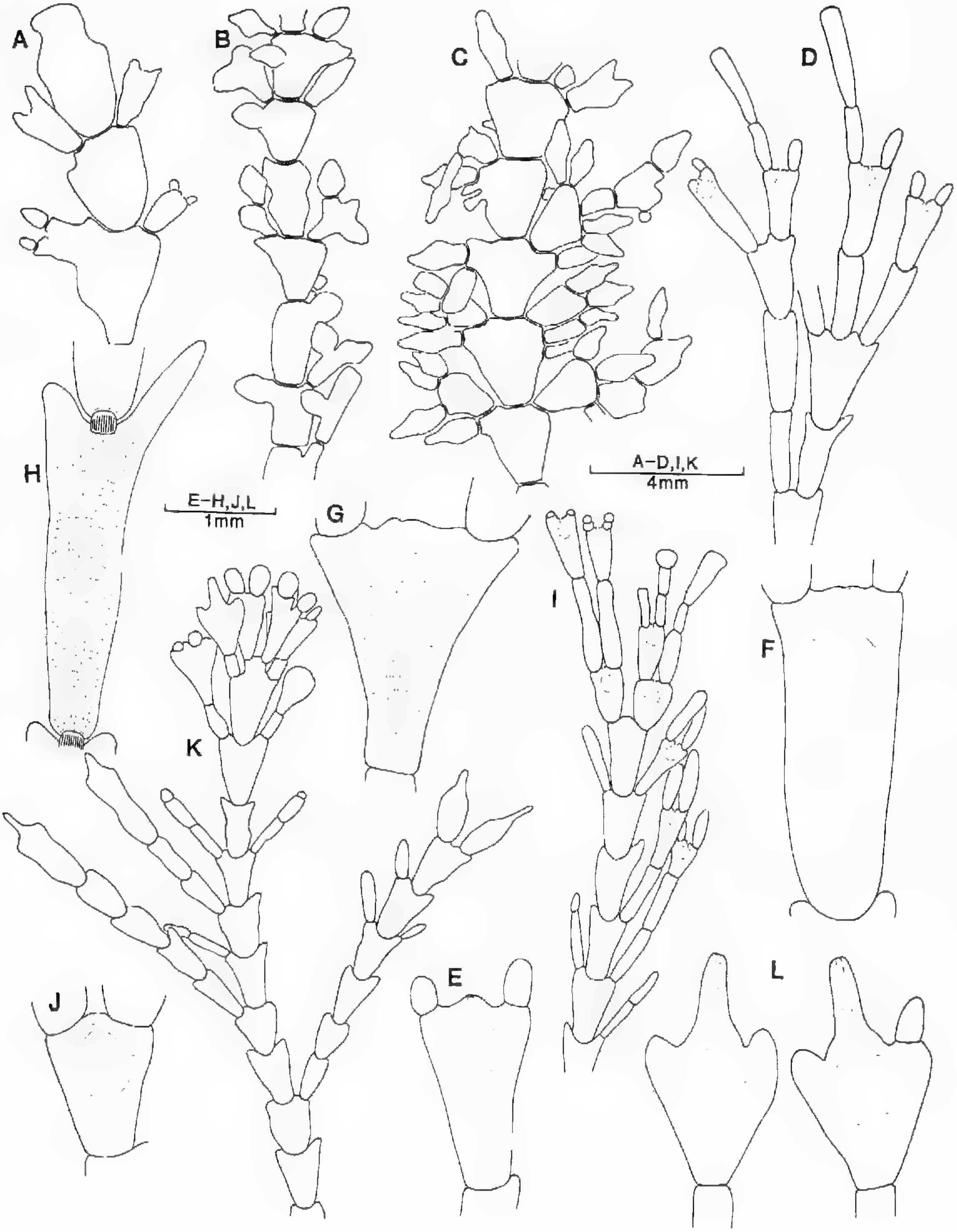
Habit: thalli (Fig. 2C, D) pale red (usually bleached), 2–4 (–6) cm high, relatively slender with fronds in small groups, epilithic. *Branching:* main axes sparsely pinnate. *Intergenicula:* (Fig. 4A, B): in lower parts terete, 300–500 µm in diameter; in middle and upper parts flat, sometimes with small obtuse lobes; unbranched or with 1 or 2 lateral branches; axial intergenicula (Fig. 3I, K) 1.5–3.5 mm long and 0.7–1.2 mm wide at their widest, ratio of length to width about 2; 20–40 tiers of medullary cells (Fig. 3G, H), each 50–75 µm long (Fig. 4B), per intergeniculum. *Genicula:* uncalcified parts of cells 120–200 µm long, genicula 300–500 µm broad. *Carpogonial conceptacles* (Fig. 4C): originating at apices of short lateral branchlets. *Carposporangial conceptacles* (Figs 3I, J, 4D): with branches on one or both sides of ostiole, sometimes concatenate, chamber diameter 300–520 µm, fusion cell 220–310 µm in diameter and 8–10 µm thick; carposporangia (Fig. 4D) 55–80 µm in diameter. *Male conceptacles* (Fig. 3K, L): beaked, with branches or processes on each side of ostiole; chamber diameter 375–650 µm, height 400–550 µm, canal 800–900 µm long. *Tetrasporangial conceptacles* (Fig. 3D, E, F): not markedly swollen, chamber diameter 500–750 µm, height 600–700 µm, tetrasporangia 180–280 µm long; bisporangia unknown.

Type: Nora Creina, S. Aust., upper sublittoral in large shaded pool (*Johansen* 81–9–49, 16.ix.1981, carposporangial, male; holotype in ADU, A52790).

Distribution: From Streaky Bay, S. Aust. to Walkerville, Vic. and around Tasmania, in shallow water but usually in shaded situations.

Selected specimens: Smooth Pool, near Streaky Bay, S. Aust. (*Johansen* 81–10–21d, 28.x.1981, tetrasporangial). West Bay, Kangaroo I., S. Aust., near low tide (*Woelkerling*, 21.ii.1979; LTB, 11612; ADU, A57529). Point Gillian, West I., S. Aust., 0.5–1 m deep (*Shepherd*, 27.v.1967; ADU, A31943). Robe, S. Aust., sublittoral (*Jones & Johansen* 81–9–24, 4.ix.1981, carposporangial; ADU, A52792). Nora Creina, S. Aust., in large shaded pool (*Johansen* 81–9–25, 5.ix.1981, carposporangial; ADU, A52791 and 81–9–43, 15.ix.1981). Point Lonsdale, Vic., upper sublittoral (*Johansen* 81–8–16, 31.viii.1981, tetrasporangial), Walkerville, Vic., low eulittoral (*Pope & Bennett*, 19.v.1949; ADU, A12218). Curries R. mouth, Tas., upper sublittoral (*Womersley*, 28.i.1949; A10326). Stapleton Point, Prosser Bay, Tas., 0–3 m deep (*Shepherd*, 10.iii.1970; ADU, A35686). Lady Bay, Southport, Tas., 7 m deep (*Brown & Kenchington*, 14.x.1986; ADU, A57693, carposporangial and male).

Arthrocardia is the most common genus of articulated corallines in southern Africa, and based


A
B
C
D
H
E–H,J,L
1mm
A–D,I,K
4mm
G
I
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L

on recent studies (by H.W.J.) it appears that there are four species in this area (in contrast to the seven species listed by Seagrief, 1984). One of them, *A. flabellata* (Kuetzing) Manza, is abundant from Capetown to Mozambique. Subsequent to being described by Kutzing (1858, p. 29, fig. 60, II), it has been described under several other names, e.g. *A. gardneri* Manza and *A. linearis* Manza. *Arthrocardia flabellata* is distinguishable from the other currently recognized South African species, *A. corymbosa* (Lamarck) Decaisne, *A. duthiae* Johansen and *A. filicula* (Lamarck) Johansen, by conceptacular pores that are strictly apical, branching that is lax, and small intergenicular lobes that are acute or subacute. In *A. flabellata* spp. *flabellata* from Africa most plants produce clusters of conceptacles in extensive branching corymbs where the successive intergenicula are all fertile. In *A. flabellata* spp. *australica* from south-eastern Australia, the conceptacles are produced in single intergenicula which rarely branch to produce other fertile intergenicula. The South African species is also more robust, having clustered fronds to 10 cm high, branching more or less pinnate, intergenicula terete below (to 1 mm diameter), flat above, 1-3 (-3.5) mm long and 1-2 (-2.5) mm wide (L/W 1.5-3), with acute lobes up to 0.5 mm long often present and with sharp edges, and with the upper margin of the intergenicula sometimes concave and urn-shaped. Fertile intergenicula are at first similar to sterile ones, but succeeding intergenicula are much smaller, 0.7-1 mm long and 0.5-0.8 mm wide; when crowded, some have only one surmounting branch.

Discussion

Two species from southern Australia now assignable to *Arthrocardia* were described as new by Harvey (1849) under *Amphiroa*: *A. wardii* and *A. mailardiae*. Harvey's descriptions and illustrations (of *A. wardii* only) and the type specimens (TCD) reveal two similar entities, with the main distinction being that the first is slightly more robust than the second. Unlike the situation for many other geniculate corallines from southern Australia, no other specific names have subsequently been applied to Harvey's two species, although they have at times been placed under *Amphiroa* (Harvey 1849) and *Cheilosporum* (De Toni 1905). Most authors have placed them in *Arthrocardia*, but they have not been examined closely. Our studies reveal that the type specimens and other plants that can be assigned to one or the other all belong to the single species *A. wardii*.

Arthrocardia flabellata ssp. *australica* is more representative of the genus *Arthrocardia* than is *A. wardii* and has tetrasporangial conceptacles that are always of the "*Arthrocardia* type", as are also the carposporangial conceptacles. The male conceptacles of *A. flabellata* spp. *australica* resemble those of *Corallina*, but not as much as do those in *A. wardii*.

The simplest way of distinguishing the two taxa of *Arthrocardia* in southern Australia is by branching and intergenicular characteristics (Table 1). *Arthrocardia wardii* is a robust plant and *A. flabellata* ssp. *australica* is considerably more delicate. The lower unbranched intergenicula constituting the stipes differ in diameter in the two taxa (0.3-0.5 mm in *A. flabellata* ssp. *australica* and 0.5-1.0 (-1.5) mm in *A. wardii*). In the latter, unbranched intergenicula are rare, but in *A. flabellata* ssp. *australica* they constitute about 50% of the axial intergenicula. Instead of producing lateral branches, short obtuse lobes tend to develop and bracket the lower part of the intergeniculum immediately above (Figs 2C, D, 3K, I).

Sporangial characteristics are also helpful in separating the two Australian taxa. Conceptacle dissection usually reveals bisporangia (undivided when immature) in *A. wardii* (tetrasporangia in one Tasmanian specimen), and tetrasporangia in *A. flabellata* ssp. *australica*, but more study of their reproduction is warranted.

In the two southern Australian taxa, most male conceptacles lack branches, but usually the potential for branch growth is present in *A. flabellata* ssp. *australica* as evidenced by processes where branches might have developed (Fig. 3I, K). In the few richly fertile male collections of *A. wardii* studied, there were very few branching conceptacles (Fig. 3C). The carposporangial conceptacles bear surmounting

Fig. 3. *A–C Arthrocardia wardii*. *A*. A branch of a bisporangial plant, with branchlets above the conceptacles and medullary tiers shown in one intergeniculum (ADU, A52798). *B*. Branch of a cystocarpic plant (ADU, A32437). *C*. Branch of a male plant (ADU, A32317).

D–L Arthrocardia flabellata ssp. *australica*. *D*. Branches of a tetrasporangial plant, showing position of conceptacles (Johansen 81-8-16). *E*. A tetrasporangial conceptacle surmounted by young branchlets (Johansen 81-10-21d). *F*. Enlargement of part of D, with a tetrasporangial conceptacle surmounted by older branchlets. *G*. An intergeniculum showing tiers of medullary cells (Johansen 81-10-21d). *H*. A more elongate intergeniculum showing tiers of medullary cells, and genicula (Johansen 81-9-25; ADU, A52791). *I*. Branches of a cystocarpic plant with conceptacles (Johansen 81-9-24; ADU, A52792). *J*. Enlargement of part of *I* with a cystocarpic conceptacle. *K*. Branches of a male plant (Johansen 81-9-49; ADU, A52790). *L*. Two male conceptacles of *K* with elongate beaks and narrow canals to the spermatangial chambers.

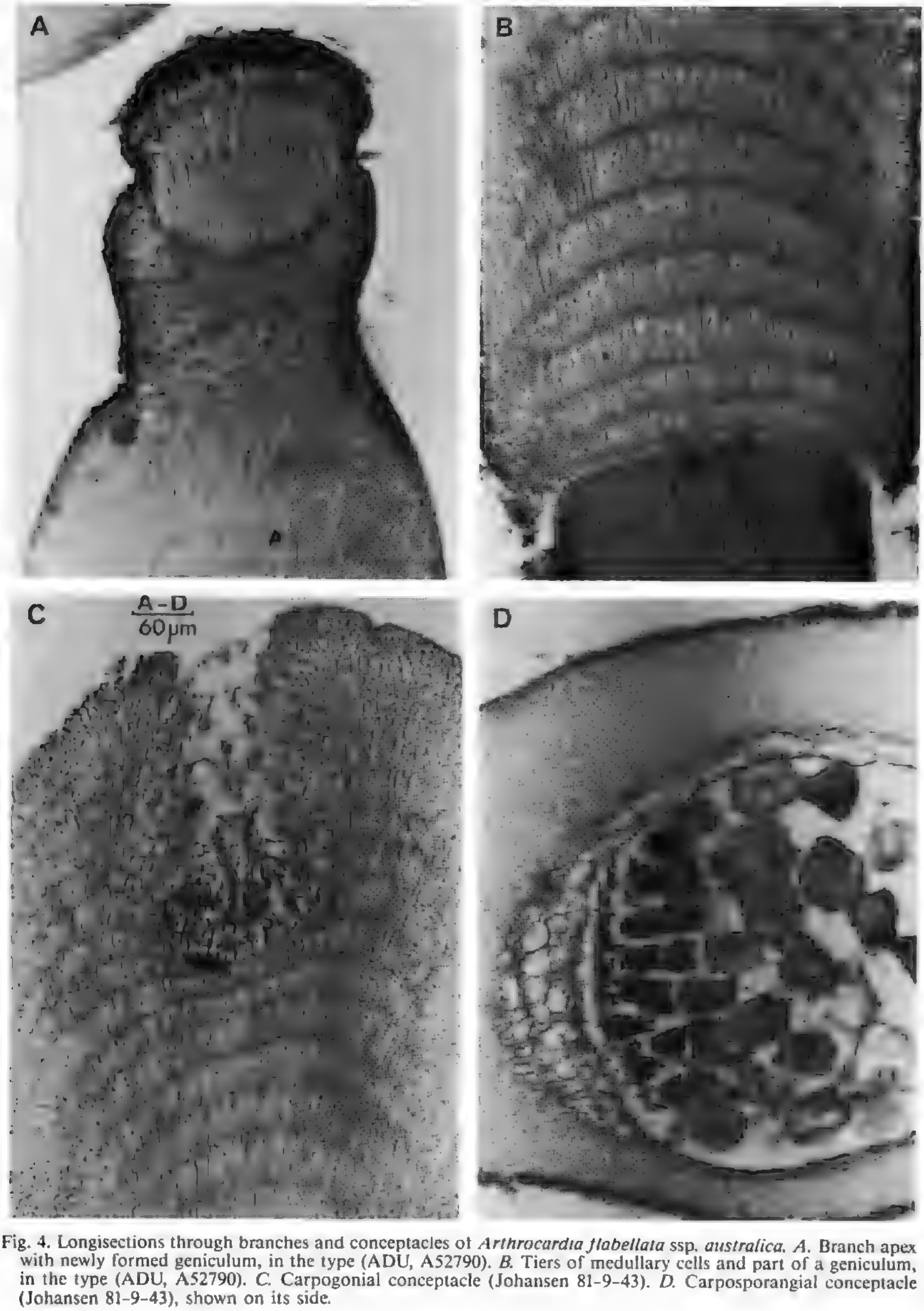

Fig. 4. Longisections through branches and conceptacles of *Arthrocardia flabellata* ssp. *australica*. *A*. Branch apex with newly formed geniculum, in the type (ADU, A52790). *B*. Tiers of medullary cells and part of a geniculum, in the type (ADU, A52790). *C*. Carpogonial conceptacle (Johansen 81-9-43). *D*. Carposporangial conceptacle (Johansen 81-9-43), shown on its side.

branches in *A. flabellata* ssp. *australica* (Fig. 3I, J), but may or may not bear such branches in *A. wardii* (Fig. 3B).

Arthrocardia flabellata ssp. *australica* is rare in southern Australia. Although overlapping in Victoria, the known ranges extend to the east and north for *A. wardii* and westward for *A. flabellata* ssp. *australica*.

Arthrocardia is probably most closely related to *Corallina*, a genus that is distributionally and structurally well known. Differences between *Arthrocardia* and *Corallina* concern (1) branches on tetrasporangial (or bisporangial) conceptacles in *Arthrocardia* but only rarely in *Corallina*; (2) configuration of intergenicula containing tetrasporangial conceptacles (only slightly swollen in *Arthrocardia*); (3) branches on male conceptacles in *Arthrocardia*; (4) configuration of intergenicula containing male conceptacles, with more pronounced beaks in *Arthrocardia*; (5) the position of gonimoblast filaments on fusion cells, where they are peripheral only in *Corallina*; (6) the number of medullary tiers per intergeniculum (20–40 in *Arthrocardia*, 10–20 in *Corallina*); and (7) plant and intergenicular sizes, with *Arthrocardia* generally greater than *Corallina*. From Manza (1937, 1940), Ganesan (1967), Johansen (1969, 1971), unpublished data on South African plants (Johansen) and the study of various type specimens, a revised concept of the genus *Arthrocardia* has emerged (Johansen 1981) and can be reviewed here.

The intergenicular medullary tiers in the tribe Corallineae are uniform in dimensions, with the cells 50–75 (–90) μm long. There are usually 10–20 tiers per intergeniculum in *Corallina* and 20–40 in *Arthrocardia*, a feature corresponding to the usually greater intergenicular length in the latter genus.

The best diagnostic feature of *Arthrocardia* is the growth of branches from conceptacle-bearing intergenicula and the potential formation of more conceptacles by these branches (Johansen 1981). However, this characteristic must be analysed for both tetra- or bisporangial plants and for male or female plants. In sporangial plants the formation of branch primordia on the broadened shoulders of fertile intergenicula (usually when the conceptacles contain immature sporangia) is an integral part of development (see e.g., Johansen 1969, pl. 18). On the other hand, in *Corallina* the usual condition is for intergenicula containing tetrasporangial conceptacles not to flatten and broaden and for surmounting branches, if produced, not to contain conceptacles (Johansen 1981).

Conceptacles in *Arthrocardia* are axial in that they originate at intergenicular apices (Johansen 1969). Cells destined to become reproductive originate in the apical medullary meristems in a straight line with the intergenicular axis. The filaments surrounding the young fertile cells separate so that a space, the future conceptacular chamber, forms between them. Further growth and development result in a roofed chamber and a canal leading to a pore.

Male conceptacles of *Arthrocardia flabellata* from South Africa have been recorded (unpublished data) with beaks more than 1 mm long and, although the data are meagre, it appears that beaks in *Arthrocardia* are longer than in *Corallina*. In *A. flabellata* sp. *australica* variation in beak lengths (Fig. 3K, L) suggests an intermediate position for this species. Male conceptacles in *A. wardii* are very similar to those in *Corallina*.

The position of gonimoblast filaments on carposporophytic fusion cells may be significant as an added feature distinguishing *Arthrocardia* and *Corallina*. The few studies of *Arthrocardia* (Ganesan 1967; personal observations of H.W.J. on South African specimens) all record the filaments arising seemingly anywhere on top of the fusion cell. In contrast, in *Corallina* they are restricted to the margin, or nearly so (Suneson 1937, p. 33; Segawa 1942; Ganesan 1968; Johansen 1970). Caution in using this feature should be observed, however, until definitive studies on carposporophyte

TABLE 2. *Characteristics distinguishing* Arthrocardia *and* Corallina, *and comparisons with* Arthrocardia wardii

	Arthrocardia	*A. wardii*	*Corallina*
Branches from tetra (or bi-) sporangial conceptacles.	usually	usually	seldom
Branches from male conceptacles.	usually	never	never
Upper parts of inter-genicula containing tetra (or bi-) sporangial conceptacles	wide, conceptacles protruding only slightly	wide, conceptacles protruding	narrow, conceptacles protruding
Beaks of male conceptacles	long (800–1200 μm)	short to medium (300–700μm)	short (200–600 μm)
Gonimoblast filaments on fusion cell	over upper surface	probably over upper surface	at or near margins
Medullary cell tiers per intergeniculum	20–40	20–40	10–20

development are made (see Johansen 1972; Lebednik 1977).

Fertile tetrasporangial conceptacles of *Corallina officinalis* usually lack surmounting branches. Furthermore, the conceptacles are more conspicuous than in *Arthrocardia* because the upper parts do not expand into a platform upon which branches can arise. The characteristics of *Arthrocardia* in southern Australia show that it is possible and reasonable to segregate it from *Corallina* (Table 2), but unusual male plants of *A. wardii* with conceptacles like those in *Corallina* have necessitated some re-evaluation.

Arthrocardia is most prevalent in the southern hemisphere, being most prominent in southern Africa (Seagrief 1984, pp. 5, 6). As currently recognised, as well as from South Africa (Manza 1937) the genus has been reported from Gough Island (Chamberlain 1965), India (Ganesan 1967), northern California (Johansen 1971), Brazil (Joly 1965), and south-eastern Australia. *Arthrocardia flabellata* ssp. *flabellata* is extremely common on the east coast of southern Africa in various forms. In contrast, the Australian subspecies is known from few collections.

Acknowledgments

Assistance from MST grant 80/2004 to the first author supported a research visit by the second author to Adelaide in 1981. Thanks also go to the Curators of the herbaria listed in "Materials and Methods" for help in studying collections of *Arthrocardia*. Our gratitude goes also to Scoresby A. Shepherd (who supplied the Latin diagnosis), Eric J. Johansen, Douglas Pabst and the first author's colleagues in Adelaide for assistance in field work and in other ways. Mrs Doris Sinkora kindly assisted in enquiries about specimens in MEL and Dr Michael J. Wynne helped in clarifying the nomenclature of the South African *Arthrocardia flabellata*.

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TRANSACTIONS OF THE

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

VOL. 112, PART 2

AMINO ACID RACEMISATION DATING OF THE "OLDER PLEISTOCENE MARINE BEDS", REDCLIFF, NORTHERN SPENCER GULF, SOUTH AUSTRALIA

BY C. V. MURRAY-WALLACE[1], R. W. L. KIMBER*, V. A. GOSTIN† & A. P. BELPERIO‡*

Summary

Amino acid racemisation dating of the "Older Pleistocene marine beds", Redcliff, northern Spencer Gulf, South Australia. *Trans. R. Soc. S. Aust.* 112(2), 51-55, 31 May 1988. Amino acid racemisation reactions are applied in relative and quantitative age assessments of the "Older Pleistocene marine beds" from Redcliff, northern Spencer Gulf. The extent of racemisation (epimerisation) for a range of amino acids in specimens of the fossil bivalve *Anadara trapezia* suggests a Penultimate Interglacial age (oxygen isotope stage 7) of approximately 200 000 yrs B.P., consistent with the geological context of the fossiliferous marine strata.

KEY WORDS: Amino acid racemisation, Middle Pleistocene, marine sediments, sea level change.

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Summary

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Amino acid racemisation reactions are applied in relative and quantitative age assessments of the "Older Pleistocene marine beds" from Redcliff, northern Spencer Gulf. The extent of racemisation (epimerisation) for a range of amino acids in specimens of the fossil bivalve *Anadara trapezia* suggests a Penultimate Interglacial age (oxygen isotope stage 7) of approximately 200 000 yrs B.P., consistent with the geological context of the fossiliferous marine strata.

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Introduction

Until recently, age assessments of Quaternary marginal marine sediments have been frustrated by complex stratigraphic relationships and the limitations of some established dating techniques. In response to these difficulties, considerable research undertaken recently has resulted in the development of a variety of dating methods including amino acid racemisation, thermoluminescence and electron spin resonance (Mahaney 1984; Rutter 1985). Although the principles on which these techniques are based are long established, their application in Quaternary studies is relatively new.

Some of the difficulties of establishing chronologies in Quaternary marginal marine settings have included the interfingering relationship of terrestrial and marine sediments, the lack of fossils in terrestrial sediments, and a complex of environmental controls on the distribution of biota in marine and paralic situations (Murray-Wallace 1987[1]). Stratigraphic relationships influenced by geomorphic setting, lack of continuous outcrop, irregular facies development and homotaxis have presented further complications (Charlesworth 1957; Vita-Finzi 1973; Ager 1981; Bowen 1985).

Notwithstanding the "apparent" complexity of stratigraphic relationships in Quaternary sequences, the problems in Australia are further complicated by the need to correlate over large distances. Until recently, assessments of the age of Quaternary coastal deposits in Australia relied on correlations with European models of Alpine glaciation, which themselves were poorly established (Tindale 1933, 1947; Bauer 1961; Sprigg 1952, 1959, 1979; Ward 1965; Twidale *et al.* 1977). The general absence of widespread glaciation during the Australian Quaternary has meant that its indirect expression, glacio-eustatic sea-level fluctuations, have figured prominently in chronostratigraphic classification of marine and paralic sediments. In particular, a range of geomorphological evidence has been cited in this connection and has proved unreliable (Bauer 1961; Twidale *et al.* 1977; Buckley *et al.* 1987). Such approaches generally resulted in erroneous age assessments and an incomplete understanding of process rates in coastal evolution. Altitudinal relationships of strandlines and the construction of shoreline relation diagrams formed the basis of these early studies and are still used by some (Ward 1985).

In this paper, we report results of amino acid racemisation dating of Pleistocene fossiliferous marine strata from Redcliff, northern Spencer Gulf. These results serve to illustrate the significant potential of applying amino acid racemisation reactions to the dating of Australian Quaternary sediments.

"Older Pleistocene marine beds"

In a regional investigation of the submarine Quaternary geology of northern Spencer Gulf, Hails *et al.* (1984a, b) and Belperio *et al.* (1984a) described a sedimentary unit they termed the "Older Pleistocene marine beds" (Fig. 1). These sediments are represented by poorly sorted sandy clays with low calcium carbonate contents. Although they have similar lithological characteristics to distal alluvial

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[1] Murray-Wallace, C. V. (1987) Evaluation and application of the amino acid racemisation reaction in studies of Quaternary coastal and marine sediments in Australia. Ph.D. thesis, Univ. Adelaide (Unpubl.)

fan sediments, the presence of foraminifera and the bivalve *Anadara trapezia* attests to their marine origin. According to Billing (1984) these sediments experienced intense pedogenic modification involving decalcification and clay illuviation. The presence of *Anadara trapezia* suggested a coastal-intertidial depositional environment for these sediments (Hails *et al.* 1984a, b; Ludbrook 1984).

Relative lithostratigraphic relationships indicate these sediments are older than the Mambray Formation (equivalent to the Glanville Formation of the Adelaide region) (Fig. 1). In the absence of quantitative data, Hails *et al.* (1984b) invoked a generalised global glacioeustatic sea level curve, to fit an age to the "Older Pleistocene marine beds". Based on altitudinal relationships of the strata, and the suggested heights of former sea levels that were likely to have penetrated northern Spencer Gulf, a Penultimate Interglacial age (220 ka, oxygen isotope Stage 7) was assigned to these sediments (Hails *et al.* 1984b).

Amino acid racemisation dating

In recent years a large literature has emerged on the principles of amino acid racemisation dating. In particular, useful reviews are provided by Schroeder & Bada (1976), Williams & Smith (1977), Davies & Treloar (1977), Wehmiller (1982, 1984) and Rutter *et al.* (1985).

Amino acid racemisation dating is based on the principle that in living organisms, amino acids bound in protein appear essentially in the left-configuration (L-amino acids). With the death of an organism, the enzymic reactions that maintained the former disequilibrium condition cease, and a racemisation reaction commences. This results in the gradual change to right handed (D-amino acids) until an equilibrium condition is attained (i.e., D/L = 1). As amino acid racemisation is a chemical reaction, it is sensitive to a range of environmental factors, particularly prolonged changes in the diagenetic temperature history of the host fossils (Murray-Wallace & Kimber 1987). However, with cautious sampling, the technique has potential uses in chronostratigraphy, stratigraphic correlation, studies of reworking (Belperio & Murray-Wallace 1984; Cann & Murray-Wallace 1986), and geothermometry.

Sample Collection

Several specimens of the fossil bivalve *Anadara trapezia* (Deshayes) were collected from two vibrocores (Fig. 2) from Redcliff, northern Spencer Gulf. The cores were obtained as part of a wider study of carbonate sedimentation (Belperio *et al.* 1984a). Only disarticulated *Anadara* were present, and were sampled from cores RED 40 and RED 41 within the depth interval 90-135 cm. Intrashell amino acid D/L ratio variation was avoided by analysing only the hinges.

Analytical Methods

The analytical procedures undertaken in this investigation follow those described more extensively in Kimber & Griffin (1987) and Murray-Wallace & Kimber (1987). Analyses reported are for the 'total acid hydrolysate', a complex mixture of high molecular weight peptides, smaller peptides and free amino acids.

Results and Discussion

Representative results of the extent of amino acid racemisation for the *Anadara trapezia* from the Redcliff Cores are presented in Table 1. These data are compared with Last Interglacial and radiocarbon-calibrated Holocene specimens which provide a regional chronostratigraphic framework.

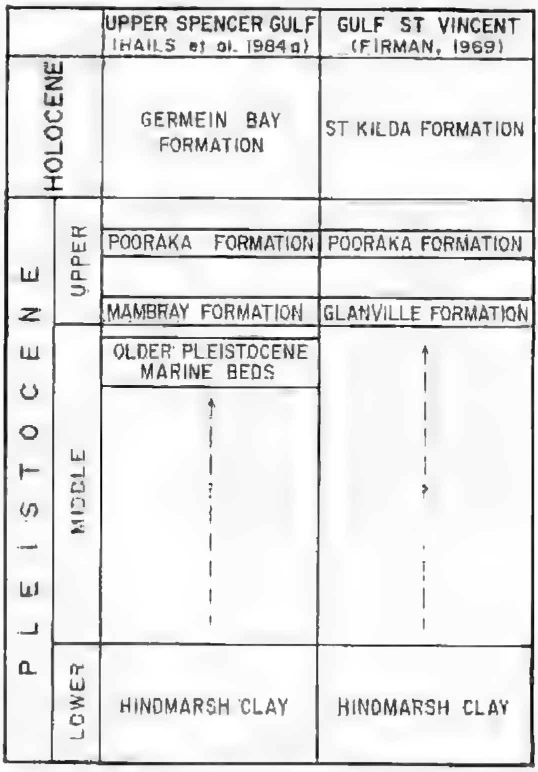

Fig. 1. Summary of local lithostratigraphic nomenclature of Quaternary marginal marine strata, after Firman (1969) and Hails *et al.* (1984a), plotted in a chronostratigraphic context and showing the relative stratigraphic position of the "Older Pleistocene marine beds". The gaps represent depositional breaks.

As *Anadara trapezia* became extinct in South Australian coastal waters after the Last Interglacial, the Holocene specimen was obtained from Hervey Bay in southern Queensland. The radiocarbon age reported was calibrated to sidereal years using the tables of Klein *et al.* (1982), and has also been corrected for the marine reservoir effect according to Gillespie & Polach (1979). The mean annual temperatures (M.A.T.) of the sample sites are also indicated in Table 1.

Results are reported for aspartic acid (ASP), alanine (ALA), valine (VAL), isoleucine (ALLO/ISO), glutamic acid (GLU) and phenylalanine (PHE). The relative extent of racemisation of the different amino acids in *Anadara trapezia* is in accord with those generally accepted for mollusc fossils of similar age (Lajoie *et al.* 1980). By analogy with the calibration samples, the *Anadara* from the "Older Pleistocene marine beds" are clearly older than the Last Interglacial, which is most reliably dated at 125,000 ± 10,000 yrs by Uranium series disequilibrium dating (Stearns 1984).

A quantitative age assessment of the "Older Pleistocene marine beds" was undertaken by applying the integrated rate expression for the amino acid racemisation reaction (Mitterer 1975), and using the Last Interglacial *Anadara trapezia* as a basis for calibration. This approach takes into account the non-linear nature of molluscan

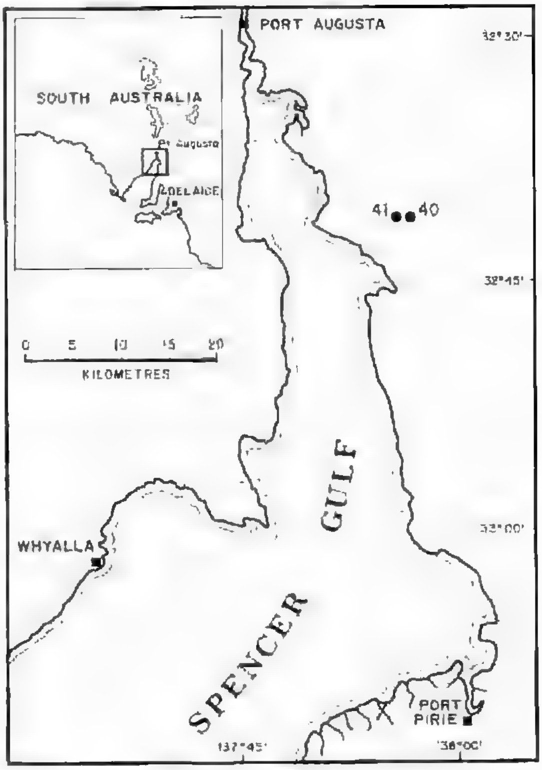

Fig. 2. Location map of Redcliff cores RED 40 and RED 41.

TABLE 1. *Extent of amino acid racemisation in* Anadara trapezia *obtained from the "Older Pleistocene marine beds", Redcliff, northern Spencer Gulf, compared with Holocene and Last Interglacial results*[1].

Lithostratigraphic unit/locality	No of specimens	Age	M.A.T.* (°C)	Amino acid D/L ratio † ASP	ALA	VAL	ALLO /ISO	GLU	PHE
Modern beach surface Quarantine Bay New South Wales	2	modern	14.7	0.05	—	0.02	0.02	0.08	—
Holocene sediments Hervey Bay Queensland	2	6400 ± 140	21.5	0.44 ± 0.005	0.52 ± 0.02	0.15 ± 0.01	0.17 ± 0.002	—	—
Glanville Formation Port Wakefield Gulf St Vincent South Australia	8	125,000	17	0.54 ± 0.03	0.68 ± 0.02	0.32 ± 0.06	0.43 ± 0.04	0.42 ± 0.01	0.73 ± 0.06
"Older Pleistocene marine beds" Redcliff	4	—	19	0.76 ± 0.02	0.83 ± 0.03	0.48 ± 0.01	0.55 ± 0.02	0.62 ± 0.02	0.89 ± 0.03

[1] Holocene and Last Interglacial results are reported in Murray-Wallace, C. V. (1987) Evaluation and application of the amino acid racemisation reaction in studies of Quaternary coastal and marine sediments in Australia (Unpubl. Ph.D. thesis, Univ. Adelaide) 352 pp.

* Mean annual temperature.

† ASP = Aspartic acid, ALA # Alanine, VAL # Valine, ALLO/ISO # Alloisoleucine/Isoleucine, GLU # Glutamic acid, PHE # Phenylalanine.

racemisation kinetics and therefore integrates the kinetic complexities of the transition zone in the non-linear model of Wehmiller (1984). The racemisation rate constant (k) used was 1.89×10^{-6}. In view of the slight amount of racemisation that occurs during sample preparation (acid hydrolysis), the extent of racemisation evident in modern *Anadara* was subtracted from the *Anadara* obtained from the "Older Pleistocene marine beds".

A mean age of 200,000 ± 50,000 yrs BP was calculated based on the extent of racemisation in aspartic acid, valine, glutamic acid and phenylalanine. The error term allows for a diagenetic temperature history uncertainty of approximately 3°C.

These data therefore indicate the "Older Pleistocene marine beds" were deposited during the Penultimate Interglacial (Stage 7 of the marine oxygen-isotope record), and supports the preliminary age assessment made by Hails *et al.* (1984b). A global glacio-eustatic sea level event of about this age is also known from coastal deposits in New Guinea, Barbados, Bermuda, New Zealand, Western Australia and various localities in southern Australia (Chappell 1974; Gill 1977; Fairbanks & Matthews 1978; Harmon *et al.* 1983; Hewgill *et al.* 1983, Belperio *et al.* 1984b).

Acknowledgments

This research was part of a Ph.D. project by C. V. Murray-Wallace undertaken jointly at the University of Adelaide and the CSIRO Division of Soils, South Australia under the supervision of Drs V. A. Gostin and R. W. L. Kimber. A. P. Belperio publishes with permission of the Director General, South Australian Department of Mines and Energy.

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A REDESCRIPTION OF *FZLARZNEMA DZSSZMZLE* (WOOD, 1931), WITH NEW RECORDS OF OTHER SPECIES OF *FILARINEMA* MOENNIG, 1929 (NEMATODA: TRICHOSTRONGYLOIDEA) FROM MACROPODID MARSUPIALS

BY IAN BEVERAGE & D. M. SPRATT†*

Summary

Filarinema dissimile (Wood, 1931) (Nematoda: Trichostrongyloidea) is redescribed from material collected from the type host, *Macropus robustus* Gould, 1841, from *Petrogale assimilis* Ramsay, 1877 and from *Lagorchestes conspicillatus* Gould, 1842, all from Queensland. *E cassonei* nom. nov. is proposed as a new name for *F. asymmetricum* (Cameron, 1926) *sensu* Cassone & Baccam, 1985 from free-living *Macropus rufogriseus* (Desmarest, 1817) and *Wallabia bicolor* (Desmarest, 1804) and from captive M. *robustus* Gould, 1841 and *M. antilopinus* (Gould, 1842). *F. woodi* Cassone & Baccam, 1985 is suppressed as a synonym of *F. asymmetricum* (Wood, 1931). Host records are revised. New records are given for *F. australe* (Wood, 1931), *F. asymmetricum,* and *F. mawsonae* Cassone & Baccam, 1985.

KEY WORDS: Nematoda, Trichostrongyloidea, *Filarinema,* Macropodidae.

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By IAN BEVERIDGE* & D. M. SPRATT†

Summary

BEVERIDGE, I. & SPRATT, D. M. (1988) A redescription of *Filarinema dissimile* (Wood, 1931), with new records of other species of *Filarinema* Moennig, 1929 (Nematoda: Trichostrongyloidea) from macropodid marsupials. *Trans. R. Soc. S. Aust.* 112(2), 57–61, 31 May 1988.

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KEY WORDS: Nematoda, Trichostrongyloidea, *Filarinema*, Macropodidae.

Introduction

Species of the nematode genus *Filarinema* Moennig, 1929 are restricted to the pyloric antrum of the sacculated stomachs of kangaroos and wallabies (family Macropodidae). The genus was recently reviewed by Cassone & Baccam (1985) who redescribed all but one of the known species and added five new ones. *F. dissimile* (Wood, 1931) was not redescribed since no new material was available and because the male types deposited by Wood (1931) are apparently no longer extant. Since publication of the revision by Cassone & Baccam (1985), considerable additional material has been collected, including new material of *F. dissimile*, and hence a full description of this species can be given for the first time. While undertaking this redescription, and identifying the many additional specimens recently collected from related macropodid hosts, it became evident that an additional species, previously referred to as *F. asymmetricum* by Cassone & Baccam (1985), existed within the genus. This new species is named in this paper.

Materials and Methods

Specimens examined were from the Helminth Collection (AHC), of the South Australian Museum, Adelaide (SAM) and from the helminth collection of the Division of Wildlife and Ecology, C.S.I.R.O, Canberra. Specimens deposited in the British Museum (Natural History), London (BMNH), the CAB International Institute of Parasitology, St Albans (CIP) and in SAM were also examined. Nematodes were cleared in lactophenol for examination and drawings were made with the aid of a drawing tube attached to an Olympus BH microscope. *En face* preparations of the cephalic end and mid-body sections were cut by hand, under a stereomicroscope, using a fragment of razor blade mounted in a holder. Specimens of the species described in this paper have been deposited in SAM and BMNH. Measurements are given in the text in millimetres as the range followed by the mean in parentheses.

Filarinema dissimile (Wood, 1931)

FIGS 1–13

Trichostrongylus dissimilis Wood, 1931

Asymmetricostrongylus dissimilis (Wood, 1931) Nagaty, 1932

Types: 5♂ cotypes, from stomach of *Macropus robustus woodwardi*, Western Australia. Whereabouts unknown.

Material examined: From *M. robustus:* 6♂♂ Warrawee Station via Charters Towers, Qld (SAM V4032–4034; AHC 16281; BMNH 1986.1005–1006); from *Petrogale assimilis:* 5♂♂, Frederick Creek, Collinsville, Qld (AHC 14447); from *Lagorchestes conspicillatus:* 1♂, Fletcher View Station via Charters Towers, Qld (AHC 12325).

Description (measurements of 6 specimens from *M. robustus*): Small slender nematodes, 8.0–10.4 (9.5) long, maximum width 0.10–0.15 (0.12). Body covered with numerous, fine, transverse striations. Synlophe absent; slight cuticular thickening present on right-hand side of body (Fig. 5). Mouth opening triangular in apical view (Fig. 3); 2 lateral amphids and 4 sub-median cephalic papillae present. Buccal capsule poorly developed, tri-radiate in section.

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surrounded by musculature of oesophagus; dorsal tooth present but very poorly developed (Figs 2, 4). Oesophagus filiform 0.74–0.85 (0.79); nerve ring in anterior oesophageal region, 0.20–0.30 (0.26) from anterior end; excretory pore immediately posterior to nerve ring, 0.21–0.32 (0.27) from anterior end (Fig. 1); deirids not seen. Bursa covered with fine striations; lobes of bursa indistinct (Fig. 7); ventro-ventral rays symmetrical, divergent, anteriorly directed, thick, almost reach margin of bursa; ventro-lateral and lateral rays grouped together; ventro-lateral ray terminates near margin of bursa; externolateral ray short, terminates some distance from margin of bursa; mediolateral ray longer than other rays, terminates near margin of bursa; posterolateral rays slender, shorter, do not reach margin of bursa; externo-dorsal rays broad, slightly asymmetrical, left ray thicker than right, arise from base of dorsal ray, do not reach margin of bursa; dorsal ray asymmetrical (Fig. 8), trunk divides at ⅓ length into 2 unequal branches, which terminate at bursal margin in small but distinct bifurcations. Genital cone prominent (Figs 6, 7); ventral lobe small, appears as low eminence in ventral view with simple papilla; dorsal lobe longer, composed of two separate raylets. Spicules heavily sclerotised, dark brown in colour, 0.20–0.23 (0.21) long (Figs 9–11); body of spicule tapers gradually to fine point; dorsal subsidiary branch 0.080–0.095 (0.086) long, arises at middle of spicule body, 0.078–0.096 (0.083) from anterior end, pointed at extremity; ventral branch 0.072–0.087 (0.078) long, arises just posterior to origin of dorsal branch, more robust than dorsal branch, blunt and enlarged at tip. Gubernaculum thick, curved (Figs 12, 13), 0.13–0.15 (0.14) long, 0.010–0.020 (0.015) thick, slightly curved ventrally in lateral view.

Variation: specimens from *P. assimilis* and *L. conspicillatus* exhibit greater variation in dimensions of spicules than specimens from *M. robustus*. From *P. assimilis* (5 specimens): body length 8.6–9.5 (9.2), maximum width 0.11–0.12 (0.12), oesophagus 0.66–0.77 (0.72), nerve ring 0.20–0.25 (0.23) from anterior end, excretory pore 0.24–0.28 (0.25) from anterior end, spicule length 0.15–0.20 (0.17), gubernaculum 0.11–0.14 (0.12); single specimen from *L. conspicillatus*: length 11.6, maximum width 0.18, oesophagus 0.96, nerve ring 0.20 from anterior end, excretory pore 0.35 from anterior end, spicules 0.28, gubernaculum 0.17

Filarinema cassonei nom. nov.

Filarinema asymmetricus (*sic*) (Cameron, 1926) *sensu* Cassone & Baccam, 1985 (from *Macropus rufogriseus*) pp. 353–355, fig. 2 A–H.

Types: Holotype ♂ from pylorus of *Macropus rufogriseus* (Desmarest, 1817), Cape Barren Island, Tas., 12.iii.1973, in SAM V3678

Material examined: From *M. rufogriseus:* holotype; 9♂♂, same collection data (AHC 16284, BMNH 1986.1007–1008); 2♂♂, Melbourne Zoological Gardens, Vic.; 1♂, Grampian Ranges, Vic.; 4♂♂, Cape Conran, Vic.; 8♂♂, Bondo State Forest, Tumut, N.S.W.; 4♂♂, Timbillica State Forest, Eden, N.S.W.; 23♂♂, "Icena", Gladstone, Tas.; from *Wallabia bicolor* (Desmarest, 1804): 3♂♂, Orbost, Vic. (det. as *F. woodi* by Cassone & Baccam); from *M. fuliginosus* (Desmarest, 1817): 2♂♂, Melbourne Zoological Gardens, Vic.; from *M. antilopinus* (Gould, 1842): 1♂, captive colony, CSIRO, Canberra, "Gungahlin".

Description: See Cassone & Baccam (1985). Spicules amber in colour, 0.29–0.25 (0.22) long (mean of 10 measurements), tapering distally to extremely fine point; anterior undivided part of spicule 0.076–0.090 (0.078) long; dorsal branch of spicule arises proximal to ventral branch, blunt-tipped, 0.052–0.070 (0.060) long; ventral branch sharper-tipped, 0.050–0.060 (0.053) long; gubernaculum 0.12–0.15 (0.13) long, slightly sinuous in lateral view, very thick, maximum thickness 0.014–0.022 (0.016)

New host records

The following collections represent new host records.

Filarinema mawsonae Cassone & Baccam, 1985: *Petrogale assimilis* Ramsay, 1877, South Edge Stn via Mareeba, Qld (AHC 13404), Mt Claro near Ingham, Qld (AHC 13394), Expedition Creek, Blue Range, Qld (AHC 11921), Lander's Creek Stn via Clare, Qld (AHC 13397), Valley of Lagoons Stn via Ingham, Qld (AHC 13393), Glen Harding Stn via Ingham, Qld (AHC 11929); *Petrogale godmani* Thomas, 1923, Kings Plains Stn via Cooktown, Qld (AHC 13399); *Thylogale stigmatica* Gould, 1860, Peeramon, Qld (AHC 8978); *Aepyprymnus rufescens* (Gray, 1837), Inkerman Stn via Home Hill, Qld (AHC 11935).

Filarinema australe (Wood, 1931): *Lagorchestes conspicillatus* Gould, 1842, Barrow Island, W.A. (AHC 10860); *Petrogale inornata* Gould, 1842, Mynna Stn via Collinsville, Qld (AHC 14398); *Petrogale assimilis* Ramsay, 1877, Frederick Creek, Collinsville, Qld (AHC 14446), Mt Claro via Ingham, Qld (AHC 13394), Mt Wickham Stn via Collinsville, Qld (13398), Natal Downs Stn via Charters Towers, Qld (AHC 11928).

Filarinema asymmetricum (Cameron, 1926): *Potorous tridactylus* (Kerr, 1792), Tas. (AHC 11915).

Discussion

F. dissimile is most similar to *F. asymmetricum* (Cameron, 1926) (syn. *F. woodi* Cassone & Baccam, 1985), *F. cassonei* nom. nov. (= *F. asymmetricum sensu* Cassone & Baccam 1985) and *F. haycocki* Cassone & Baccam, 1985 in having a long slender spicule, tapering gradually to a long, fine point, and two branches of equal length arising from the spicule body. *F. dissimile* differs from *F.*

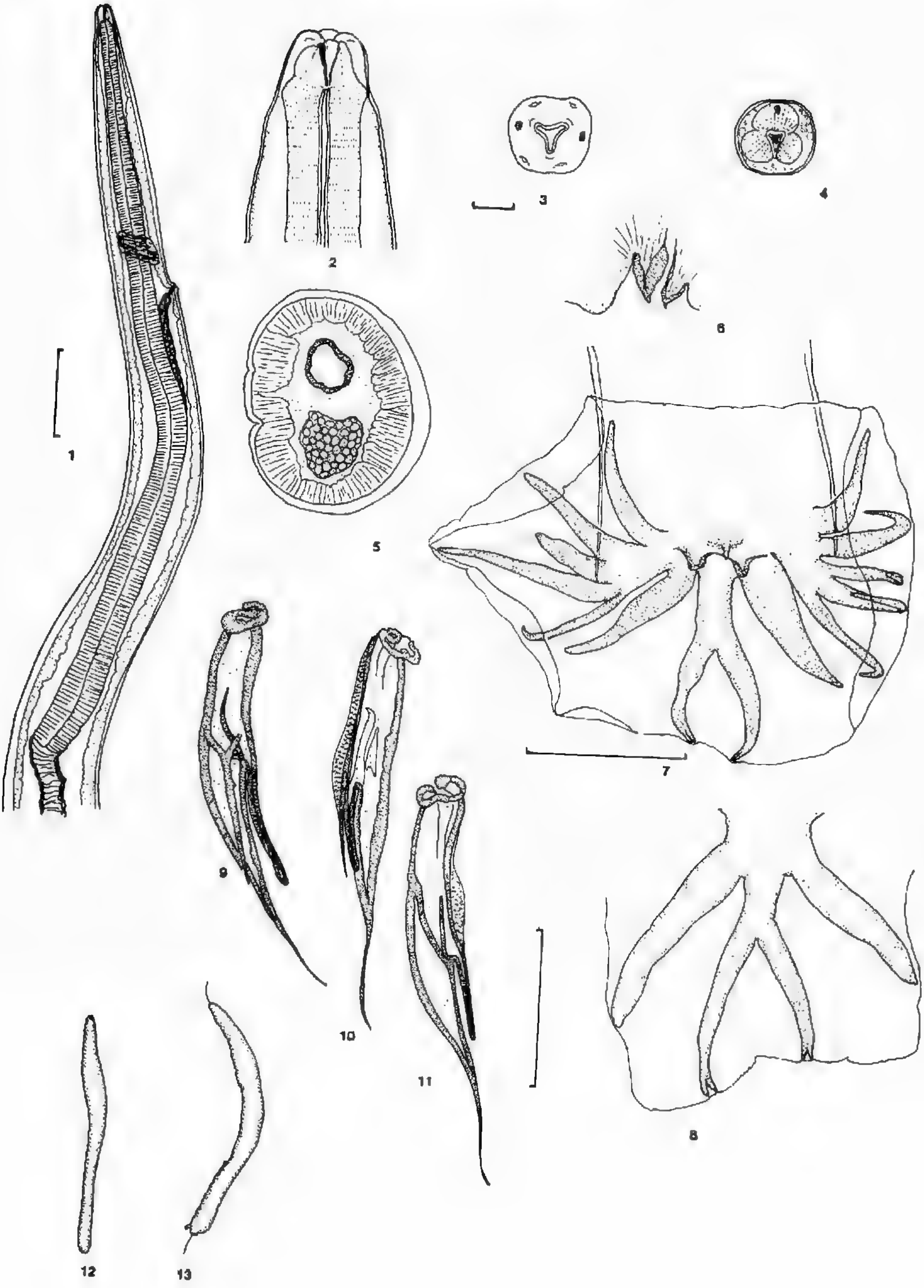
asymmetricum in having much more robust spicules which are dark brown in colour compared with amber in the latter species, and in having much longer and more robust spicule branches than in *F. asymmetricum*. The gubernaculum of *F. asymmetricum* has a characteristic twist when viewed laterally, and a similar twist is lacking in the gubernaculum of *F. dissimile*. *F. cassonei*, for which an excellent discription was given by Cassone & Baccam (1985) (as *F. asymmetricum*), is distinguished by its amber coloured spicules, and by the level at which the spicule branches terminate, being closer to the spicule tip in *F. dissimile*. In addition, the shorter spicule branches in *F. cassonei* and the fact that the more robust of the two spicule branches is dorsal in *F. cassonei* but ventral in *F. dissimile* distinguish the two species. *F. dissimile* differs from *F. haycocki* in having darker spicules as well as in the shape and disposition of the branches of the spicule.

Wood (1931) provided a very poor description of *F. dissimile* based on specimens obtained from several *Macropus robustus* (syn. *M. woodwardi*) which died soon after their importation into England from Western Australia. The original description is brief, lacks many important details, and the legends to the figures of his paper are incorrectly applied. Nagaty (1983) re-examined Wood's type specimens and gave a more detailed description of them in support of the erection of the genus *Asymmetricostrongylus* Nagaty, 1932 to which he had earlier assigned the species. By contemporary standards, Nagaty's drawings of the spicules are poor, but they agree in all important features with the new material. A redescription of the species is warranted to facilitate its separation from congeners. The male types are no longer present in BMNH and we have therefore deposited additional specimens in that museum.

The present specimens of *F. dissimile* are from the same host species as Wood's specimens, though not the same subspecies. Wood's material came from *M. robustus woodwardi*, a subspecies limited to northern Western Australia and the Northern Territory, while the present material comes from *M. robustus robustus* which occurs along the Great Dividing Range from Cape York to New South Wales (Richardson & Sharman 1976). The new specimens differ from Wood's and Nagaty's descriptions only in the following details. Wood (1931) and Nagaty (1938) described a cuticular "flange" on the right-hand side of the body and similar cuticular thickenings were described in several species by Cassone & Baccam (1985). In our specimens, the thickening is slight and is only evident in transverse sections of the body. Wood (1931) described the lateral lobes of the bursa as being markedly asymmetrical and the ventro-ventral ray being more divergent on one side of the body than the other. In our specimens, the asymmetry is not as marked, the ventro-ventral rays are equally divergent and only the externodorsal rays are obviously asymmetrical. In spite of these minor differences, our specimens are assigned to *F. dissimile* pending the availability of new collections from *M. robustus woodwardi* from Western Australia to resolve the significance of the differences noted.

In their redescription of *F. asymmetricus* (sic) from *Macropus rufogriseus* (syn. *M. benetti*), Cassone & Baccam (1985) noted discrepancies between the original description of Cameron (1926) and the comments made on the same species by Wood (1931). Wood (1931) himself noted that Cameron's description was inaccurate in several points, and sought to correct it based on a re-examination of the type specimens deposited in the British Museum. Nagaty (1938) provided a more detailed description of the same species. Cassone & Baccam (1985) hypothesised that Cameron in fact had two species in his material, but failed to recognise the fact. They concluded that Cameron had prepared the description from one of the species but had deposited as types, specimens of the second. Wood's (1931) comments on Cameron's inaccurate description would then stem from the fact that Wood had examined only the specimens which Cameron had deposited as types, and not the specimens which formed the basis of his published description. Cassone & Baccam's (1985) views are certainly supported by an examination of Cameron's figures of the spicules of *F. asymmetricum* which do not conform at all with the type specimens but do agree with a second species of *Filarinema* also found commonly in *M. rufogriseus*. On this basis, they designated a neotype for *F. asymmetricum* and renamed the type specimens of *F. asymmetricum* in BMNH as *F. woodi* Cassone & Baccam, 1985.

Recent collections from Tasmania, Victoria, New South Wales and Queensland indicate that there are indeed two species of *Filarinema* in the stomach of *Macropus rufogriseus* and that mixed infections are usual, thereby further supporting Cassone & Baccam's hypothesis that Cameron was dealing with a mixed infection of two species. Cameron deposited a total of 15 type specimens of *F. asymmetricum*. The holotype selected was a female and it, together with two males and two female paratypes, was deposited in 1926 (BMNH 1926.10.12.1–5). In addition, five male and five female paratypes were placed in the collection of the London School of Hygiene and Tropical Medicine, housed at the CAB International Institute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of Parasitology (collection no 178/A). We have examined all the type specimens and all the males are conspecific, belonging to the species described by Cassone & Baccam (1985) as *F. woodi*. The females are also similar to one another and conform to the description given by the same authors. The name *asymmetricum* is determined by the type specimens, rather than the published description, and all the male types clearly belong to the same taxon. We therefore propose that *F. woodi* be considered a synonym of *F. asymmetricum*. The co-parasitic species in *Macropus rufogriseus*, *F. asymmetricum sensu* Cassone & Baccam, 1985 therefore is un-named and we propose the name *F. cassonei* nom. nov. for it, in recognition of the important contributions made to the systematics of the genus by J. Cassone. The description of this species already published (Cassone & Baccam 1985) is excellent, and we have merely added metric data from the much wider range of specimens we have available to us. The additional material we examined came from the same host animal as that described by Cassone & Baccam (1985), and we have therefore designated as a holotype of *F. cassonei* the specimen in SAM formerly designated as the neotype of *F. asymmetricum* by Cassone & Baccam.

The nomenclatural changes made above result in significant alterations to host records. Cassone & Baccam (1985) recorded *F. woodi* from *Macropus rufogriseus*, *M. parryi*, *M. robustus* and *Wallabia bicolor*. We have re-examined all the available material to confirm the identifications and all now become records for *F. asymmetricum*.

Our new host records extend considerably the host range of *F. mawsonae*, *F. australe* and, to a more limited extent, that of *F. asymmetricum*.

Some confusion exists in the literature as to the gender of the genus *Filarinema*. *Nema* (= thread) is neuter both in Greek and Latin, and hence the gender of the genus is neuter. Moennig (1929) used the specific epithet *flagrifer* for the type species, and it is assumed he intended it to stand as a noun in apposition (= whipbearer) rather than as an adjective (= whip bearing), in which case it would have been *flagriferum*. We have retained Moennig's (1929) original spelling of the name, but have used *F. asymmetricum*, *F. dissimile* and *F. australe* in contradistinction to the use of Inglis (1968) and Cassone & Baccam (1985).

Acknowledgments

We wish to thank Dr D. I. Gibson, Mrs E. Harris and Dr L. Khalil for the loan of type specimens and ancillary information, and Dr R. Speare, Mr P. M. Johnson, Dr R. Close and Mr S. Barker for collecting specimens.

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Figs. 1-13. *Filarinema dissimile* (Wood, 1931). 1, anterior end, lateral view; 2, cephalic extremity, lateral view, dorsal aspect on left-hand side; 3, mouth opening, *en face* view; 4, optical transverse section through buccal capsule, showing buccal tooth and oesophageal masculature surrounding capsule; 5, transverse section in mid-body region, showing thickening of cuticle on right-hand side; 6, genital cone, lateral view; 7, bursa, ventral view; 8, dorsal lobe of bursa, dorsal view, showing terminal bifurcations of dorsal ray; 9–11, spicule from various oblique views; 12, gubernaculum, ventral view; 13, gubernaculum, lateral view. Scale lines: Fig. 1, 0.1 mm, figs 2–4 to same scale, 0.01 mm; figs 5–13 to same scale, 0.1 mm.

MAGMATIC BANDING WITHIN PROTEROZOIC GRANODIORITE DYKES NEAR STREAKY BAY, SOUTH AUSTRALIA

BY *R. F. BERRY* & R. B. FLINT†*

Summary

Early Proterozoic I-type granitoids are exposed on the west coast of Eyre Peninsula. Narrow granodiorite dykes within this complex exhibit conspicuous banded margins. The banding is best developed along the eastern margins of the dykes and is cyclic. A detailed petrological and geochemical investigation was made of one of these banded margins from Point Brown. The dark bands are strongly depleted in coarse-grained K-feldspar and enriched in fine-grained biotite. This mineralogical and grainsize variation correlates with a strong enrichment in MgO, MnO and Rb and depletion in Ba. The systematic variation in mineralogy, geochemistry and grainsize can only be explained by dynamic crystal sorting in a crystal-rich granitic magma due to grain dispersive forces (Bagnold effect) acting in the shear gradient along the margin of the dyke.

KEY WORDS: Early Proterozoic, granodiorite, magmatic banding, Gawler Craton.

MAGMATIC BANDING WITHIN PROTEROZOIC GRANODIORITE DYKES NEAR STREAKY BAY, SOUTH AUSTRALIA

By R. F. BERRY* & R. B. FLINT†

Summary

BERRY, R. F. & FLINT, R. B. (1988) Magmatic banding within Proterozoic Granodiorite dykes near Streaky Bay, South Australia. *Trans. R. Soc. S. Aust.* 112(2), 63-73, 31 May 1988.

Early Proterozoic I-type granitoids are exposed on the west coast of Eyre Peninsula. Narrow granodiorite dykes within this complex exhibit conspicuous banded margins. The banding is best developed along the eastern margins of the dykes and is cyclic. A detailed petrological and geochemical investigation was made of one of these banded margins from Point Brown. The dark bands are strongly depleted in coarse-grained K-feldspar and enriched in fine-grained biotite. This mineralogical and grainsize variation correlates with a strong enrichment in MgO, MnO and Rb and depletion in Ba. The systematic variation in mineralogy, geochemistry and grainsize can only be explained by dynamic crystal sorting in a crystal-rich granitic magma due to grain dispersive forces (Bagnold effect) acting in the shear gradient along the margin of the dyke.

KEY WORDS: Early Proterozoic, granodiorite, magmatic banding, Gawler Craton.

Introduction

Compositional banding and grading within magmatic rocks are relatively common and well studied in basic and ultrabasic lithologies but are much less well known within granitoids. Biotite-rich bands have been described from an annular zone of a porphyritic monzogranite in France, where they were interpreted as the result of a shear gradient at the edge of convection cells (Barrière 1981). Banding of this type has not previously been reported in South Australia, despite the abundance of granitoids and extensive geological mapping in the state. However, at Point Brown, between Streaky Bay and Ceduna, granodiorite dykes exposed on the shore platform have banded margins. The nature and origin of these bands are the focus of this paper.

Geological Setting

Rocks comprising the Gawler Craton range in age from late Archaean to Middle Proterozoic. The craton is composed of schist, gneiss, iron formation, quartzite, calcsilicate and acid to basic volcanic rock intruded by granitoid. Three main phases of igneous activity have been recognised; the Dutton Suite intruded during the Sleafordian Orogeny (2500-2300 Ma), syn-Kimban Orogeny granitoids (1850-1650 Ma) and anorogenic granitoids (1650-1450 Ma) (Parker *et al.* 1985; Webb *et al.* 1986). The syn-Kimban Orogeny granitoids are the most common rock type in the coastal exposures of western Eyre Peninsula (Fig. 1). All the rock types included in this study are from the exposures of this suite at Point Brown and were intruded after the second phase (D_2) and before the third phase (D_3) of the Kimban Orogeny.

A complex sequence of plutonism has been recognised within the syn-Kimban granitoids (Watkins & Flint 1983).[1] At Point Brown the oldest rock type is a coarse-grained red granite. This is intruded by two generations of diorite dykes and an extensive swarm of granodiorite dykes. The granodiorite dykes strike at 010-035°, dip steeply (~80°) to the east and vary in width from 1 to 15 m. Many of these dykes have a series of fine dark bands along these eastern margins (Figs 2 & 3). Other features of the granodiorite dykes are xenoliths of red granite and aggregates of diorite xenoliths.

The granodiorite dykes and surrounding granite have been deformed. A biotite foliation (S_3), which is subvertical and striking 350-010° is well developed and overprinted by crosscutting sinistral mylonite shear zones striking 140°.

Chemistry and Petrology

At Point Brown, the best example of layering was selected for detailed analysis. A slab of the banded granodiorite was collected and sliced into 10 domains approximately 1.5 cm thick enabling analysis of successive melanocratic and leucocratic bands. The average weight of these slices was 500 g. The aim here is to demonstrate the internal variability of the granodiorite, and the coherence of the analytical results, even for elements concentrated into accessory phases, confirms that 500 g samples were adequate for this purpose. In addition, 5 kg samples of the centre of the

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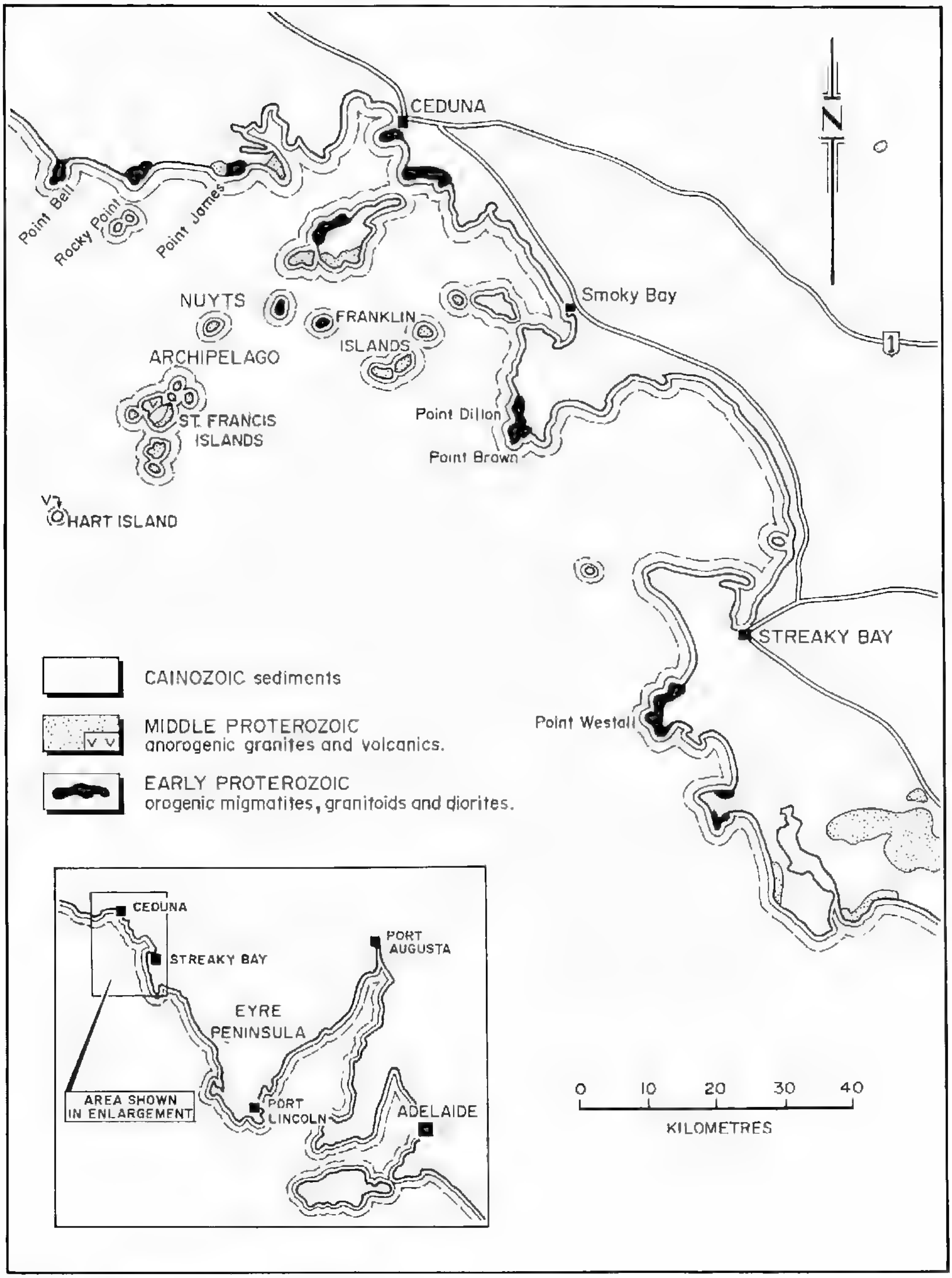

Fig. 1. Locality plan and regional geology.

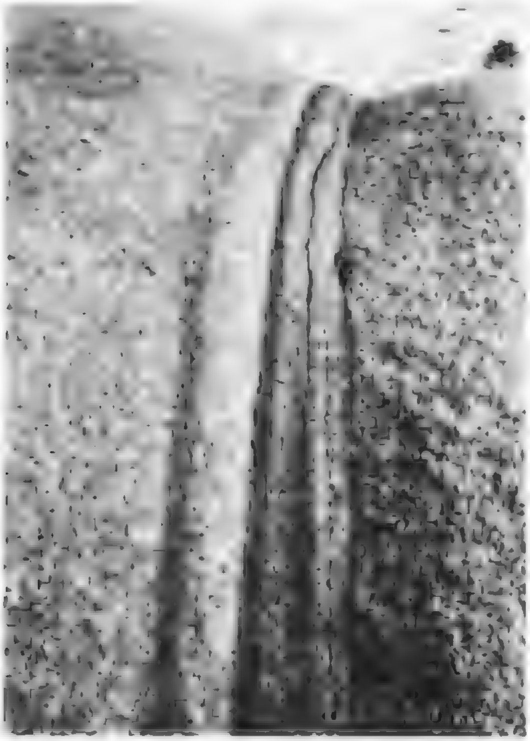

Fig. 2. Alternating melanocratic and leucocratic layers along the banded eastern margin of the granodiorite dyke at Point Brown selected for detailed analysis.

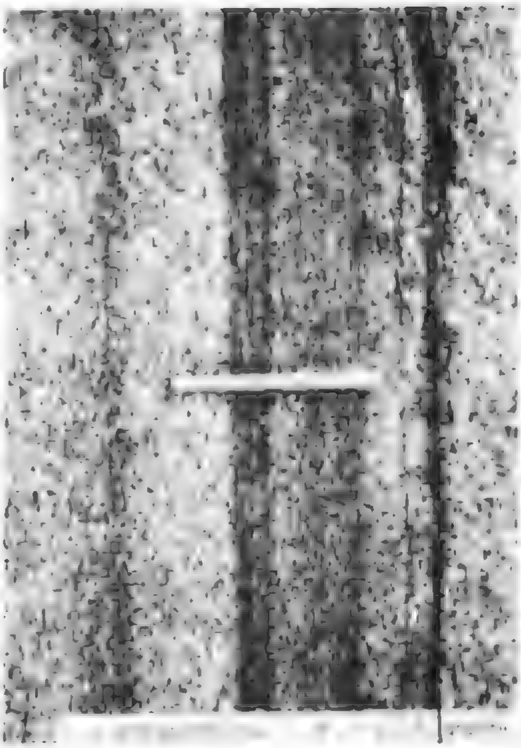

Fig. 3. Close up of the banding illustrating the major bands which reflect variations in biotite and microcline contents.

granodiorite dyke, the nearby granite and diorite dyke were collected. All the samples were analysed for major and trace elements by classical XRF techniques (Table 1). Polished thin sections were prepared across the banded zone to examine the mineralogy, texture and grainsize, and to compare these with the country rocks. The mineral chemistry (Table 2) was determined by EDS analysis on a JEOL-JXA 50A microprobe. Modal compositions were calculated from whole rock and mineral analyses using the mixing equations of Le Maitre (1979).

Massive granitoids

The red granite has a modal composition of 34% quartz, 33% plagioclase (An_{20}), 27% microcline and 4% biotite and is characterised by large (1 cm) phenocrysts of microcline. Accessory minerals include apatite, epidote, sphene, monazite, allanite and magnetite. The diorite is composed of 50% plagioclase (An_{35}), 20% hornblende, 15% biotite, 5% quartz and 5% K-feldspar. The central part of the granodiorite dyke sampled for this study (Fig. 4) contains 16% quartz, 59% plagioclase, 10% microcline, 8% biotite and 3% hornblende. Accessory minerals are apatite, sphene, monazite and magnetite. Epidote occurs as a metamorphic mineral overgrowing and replacing many of the accessory phases. Plagioclase phenocrysts are zoned. All the rims are An_{25} but core compositions vary up to An_{40} (Table 2). Sericitised cores are common. The microcline has a high BaO content (1-2%) similar to the red granite. Biotite is slightly more magnesian (Mg. No. 55) than the biotite in the red granite (Table 2). Fine-grained, post-crystallisation biotite has slightly lower TiO_2 but is very close in composition to larger early grains. The hornblende has green cores in larger grains but rims and small grains are blue-green, suggesting metamorphic re-equilibration.

Textures within the granodiorite indicate post-crystallisation metamorphism and deformation. The strong biotite foliation, epidote overgrowths, hornblende re-equilibration, recrystallisation of quartz, complete inversion of K-feldspar to microcline, and widespread sericitisation of plagioclase cores all support a medium-grade, probably low amphibolite facies metamorphic event. In addition, within the granite immediately adjacent to both the eastern and western boundaries of the granodiorite dyke, there are narrow (1 cm wide), leucocratic, quartz-rich, recrystallised zones with a

TABLE 1. *Chemical data for granitoids at Point Brown.*

	Granodiorite													
			Domains on the eastern margin											
	Western margin	Dyke centre	10	9	8	7	6	5	4	3	2	1	Granite	Diorite
SiO_2	59.55	63.58	64.99	58.08	62.14	59.84	60.04	59.46	64.14	62.47	65.18	59.26	74.00	54.98
TiO_2	0.72	0.43	0.42	0.89	0.63	0.76	0.72	0.85	0.55	0.59	0.46	1.15	0.17	0.92
Al_2O_3	17.86	17.49	17.32	18.25	17.84	17.87	17.64	17.89	17.34	17.38	17.41	16.23	13.55	18.85
FeO*	6.97	4.08	4.02	7.06	5.39	6.95	7.08	7.23	4.88	5.65	4.33	7.85	1.47	7.95
MnO	0.20	0.11	0.13	0.24	0.17	0.22	0.22	0.25	0.17	0.19	0.15	0.30	0.06	0.17
MgO	1.96	1.26	1.17	2.57	1.70	1.91	2.00	2.20	1.49	1.63	1.35	2.95	0.36	3.19
CaO	3.78	3.84	3.50	4.25	4.04	4.15	3.97	4.17	3.85	3.76	3.55	3.73	1.30	5.85
Na_2O	5.33	5.35	4.97	4.83	5.20	5.05	4.77	5.02	5.10	4.97	5.08	4.48	3.49	3.74
K_2O	2.23	2.65	2.90	2.43	2.17	2.25	2.21	2.37	2.14	2.20	1.99	2.65	4.46	2.49
P_2O_5	0.30	0.21	0.17	0.45	0.27	0.37	0.35	0.36	0.22	0.26	0.20	0.53	0.05	0.43
LOI	0.67	0.49	0.62	0.86	0.61	0.68	0.58	0.69	0.52	0.50	0.51	1.03	0.43	1.40
TOTAL	99.57	99.49	100.21	9.91	100.16	100.05	99.58	100.49	100.40	99.60	100.21	100.16	99.34	99.97
La	110	63	51	72	72	92	93	85	67	85	63	75	38	51
Ce	182	116	105	145	133	173	174	158	121	152	118	142	65	95
Nd	57	35	37	54	45	60	58	56	40	48	36	52	21	47
Zr	363	197	197	363	270	389	390	361	241	288	202	389	102	219
Y	32	23	29	47	32	43	40	38	26	28	21	47	16	27
Nb	12	10	12	19	13	16	15	17	11	12	9	27	6	6
Ba	894	2036	2155	969	1173	990	1008	880	1259	1110	986	529	736	2042
Rb	190	104	109	181	117	143	147	165	114	130	117	221	153	92
Sr	562	674	606	614	600	615	602	592	545	535	502	385	202	1125
V	100	55	46	86	68	93	96	93	60	73	48	94	16	182

* Total Fe as FeO.

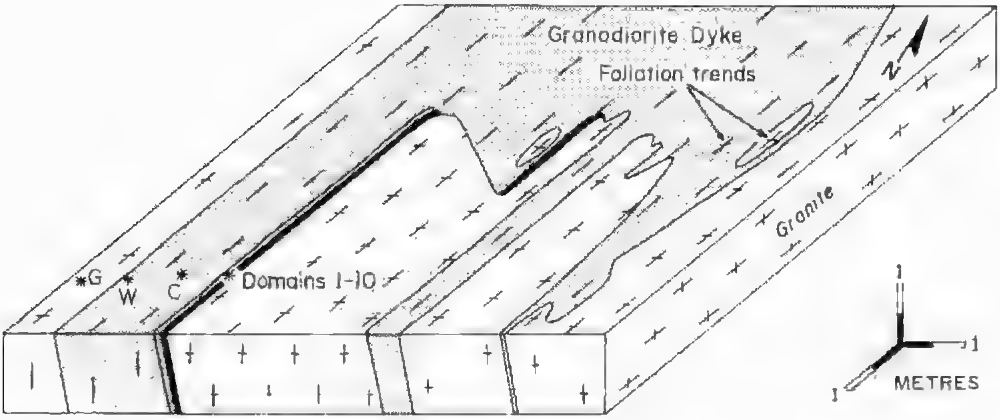

Fig. 4. Field sketch of granodiorite dyke studied showing sampling locations. The diorite sample was collected 300 m to the southwest on the tip of Point Brown.

mylonitic fabric. These observations are consistent with the regional evidence of deformation at moderate temperatures after the emplacement of all the granitoids (Watkins & Flint 1983).[1]

The granitoids of Point Brown are all geochemically related. For example, they have very similar trace element patterns (Fig. 5). We conclude that the granite, granodiorite and the diorite have a common source, based on this coherence across a wide range of trace elements, despite the wide range of major element composition. They all fit the criteria for I-type granitoids of White & Chappell (1983). They have low K_2O/Na_2O ratios and high Ca. The diorite and the granodiorite are metaluminous while the extremely fractionated granite is peraluminous but has a low Al content and a high Ca content for a granitoid with 74% SiO_2. The Cr and Ni contents are all near the detection limit of 2 ppm. The granitoids are dominated by hornblende and biotite with magnetite as the dominant oxide phase.

Pitcher (1982) suggested I-type granitoids can be divided into a Cordilleran and a Caledonian association. In this subdivision the Point Brown granitoids fit into the Caledonian association based on the predominance of biotite-rich granite and granodiorite. Pitcher suggested that the Caledonian-style I-type granitoids form during the uplift stage after a major orogeny and are largely post-kinematic. On the chemical variation diagrams of Pearce *et al.* (1984) the granitoids from this study plot in the field of volcanic arc granitoids (Fig. 6). This field is also occupied by post-orogenic granitoids which can have a very wide range of compositions. In combination with the classification of Pitcher, this suggests that the Point Brown granitoids are post-orogenic rather than having a Cordilleran/volcanic arc association.

Wyborn *et al.* (in prep.)[2] have summarised the Proterozoic granitoids of Australia. The syn-Kimban Orogeny granitoids at Point Brown are very similar to widespread "K-feldspar megacryst-

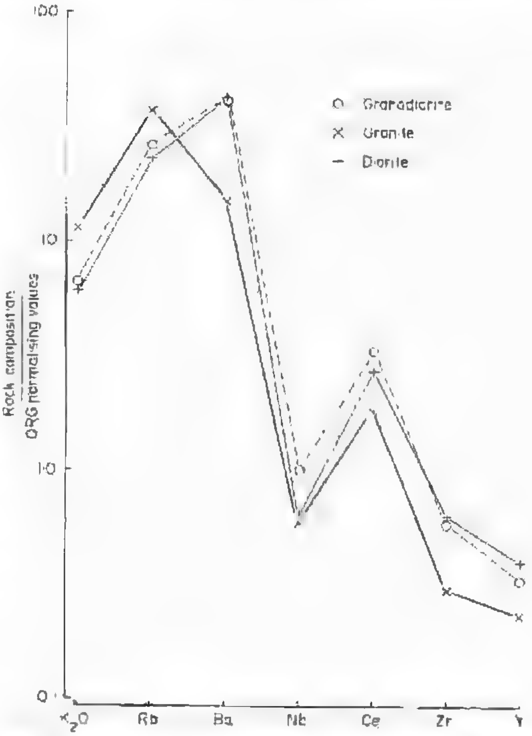

Fig. 5. Normalised geochemical patterns for the massive granitoids at Point Brown. Normalising factors are from Pearce *et al.* (1984).

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[2] Wyborn, L. A. I., Page, R. W. & Parker, A. J. (in prep.) Geochemical and geochronological signatures in Australian Proterozoic igneous rocks.

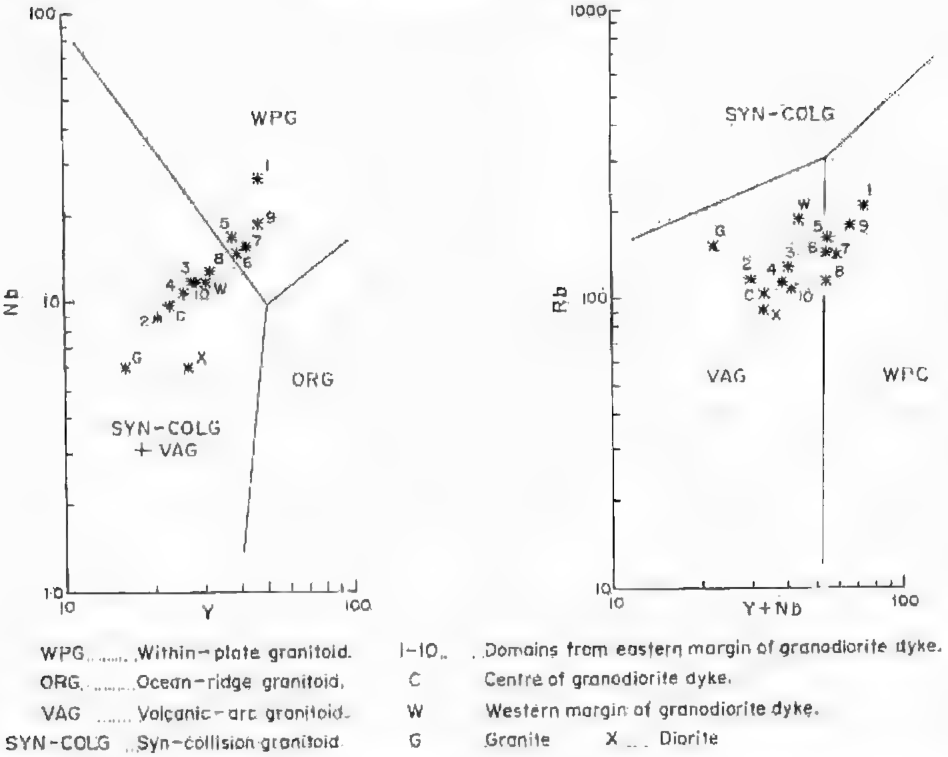

Fig. 6. Y/Nb and Rb/(Y + Nb) diagrams showing the fields of various granite types after Pearce *et al.* (1984).

bearing granodiorites and monzogranites" intruded between 1870 and 1820 Ma. For example, compared to the Kalkadoon and Ewen Batholiths at Mount Isa (Wyborn & Page 1983), they have nearly identical normalised trace element patterns and the same REE contents but are more like Phanerozoic I-type granitoids with higher Na_2O/K_2O ratios and CaO, and lower Rb. They are unlike the anorogenic granitoids which are most common from 1800 to 1620 Ma.

Banded Granodiorite

The eastern margin of the granodiorite dyke selected for this study has five dark, fine-grained bands on its eastern margin (Figs 2-4). The first of these, starting from the margin, has a sharp contact on both sides. Its texture is now largely metamorphic and substantial growth of chlorite and green biotite has resulted from mylonitisation in association with the quartz mylonite developed on the boundary of the adjacent granite. While there is little chemical evidence of element mobility in this layer (Table 1), textural evidence for recrystallisation suggests that the composition may have been modified by metasomatism associated with mylonite formation.

The second and third dark layers have sharp contacts near the dyke margin and gradational boundaries away from the dyke margin. The fourth dark layer has relatively sharp contacts on both sides. These first four dark bands are included in the 20 cm wide sample which was subdivided into 10 domains. A fifth dark layer is very diffuse and weak and was not included in this study.

The mineral chemistry within the banded granodiorite is very similar to that of the massive granodiorite in the centre of the dyke. Plagioclase, microcline and biotite have the same composition. In part, this may reflect metamorphic re-equilibration conditions, especially the low Na_2O in the microcline ($Or_{92}Ab_6An_2$). Hornblende was not found in domains 1 to 9 and is a trace component in domain 10, so it is not included in the subsequent discussion.

In contrast there are major changes in grainsize and modal composition which are illustrated in Fig. 7. Individual bands are easily recognised by the grainsize variation and modal biotite component. Domains 1 and 2 form the first band, 3 and 4 the second band, 5 to 8 the third band and 9 the unzoned fourth dark band.

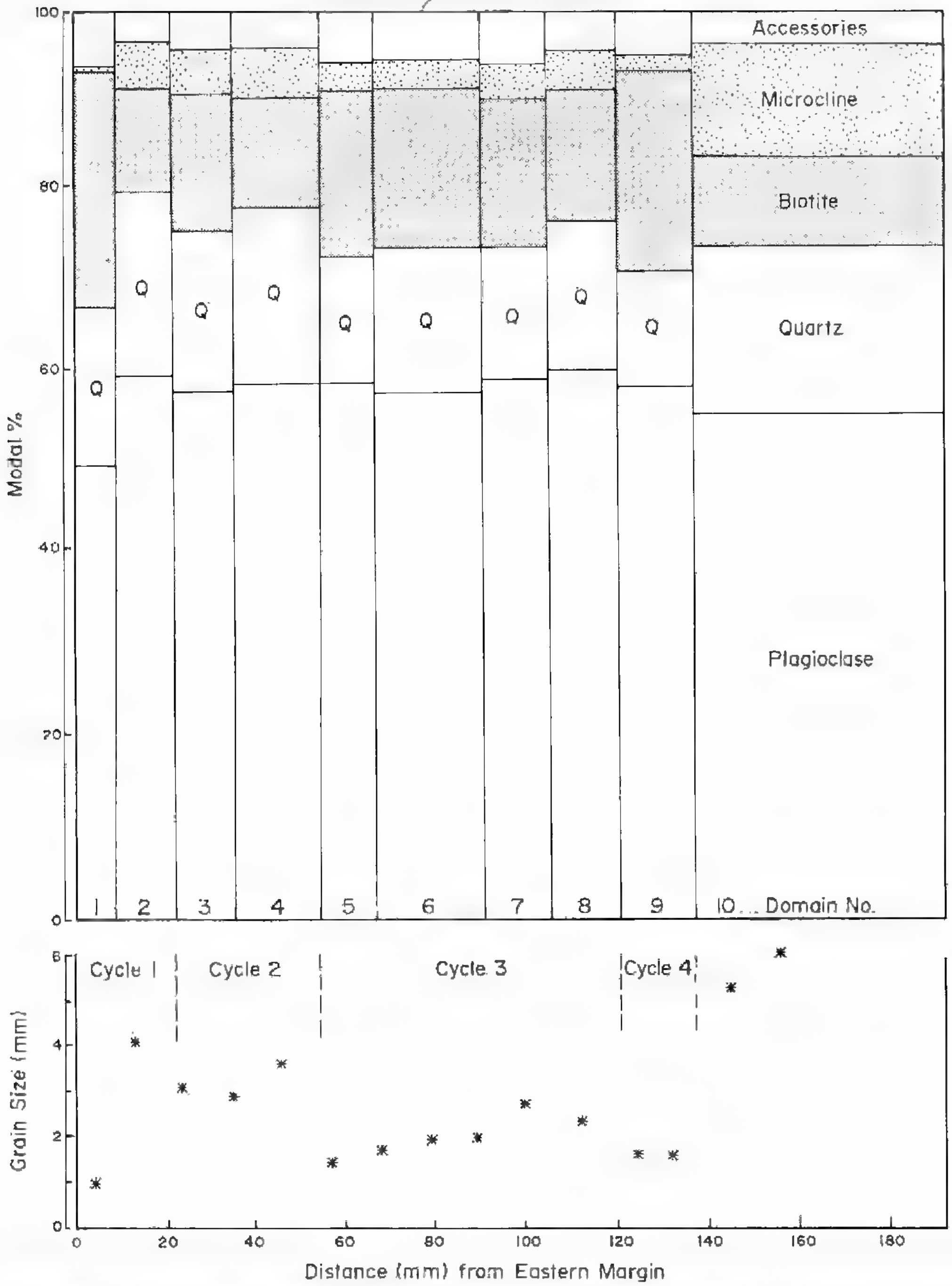

Fig. 7. Variations in modal mineralogy and grainsize across the banded eastern margin of the dyke. Grainsize is the average of the 10 largest plagioclase grains within 1 cm wide strips parallel to the layering. Modal compositions were calculated from major element chemistry of domains and microprobe analyses of the phases using Genmix (Le Maitre 1979).

Grainsize variations across these layers relate to the mineralogy. Biotite has an average grainsize of 0.2 to 0.3 mm across the whole dyke and does not vary significantly. Quartz mainly forms interstitial grains and mimics the grainsize of the feldspars. Both feldspars are relatively coarse grained in the massive granodiorite with microcline up to 10 mm and plagioclase up to 6 mm. The maximum grain-

TABLE 2. *Mineral analyses.*

	Microcline		Plagioclase				Biotite				Hornblende		Chlorite
	Granite	Granod.	Granite	Granod.		Diorite	Granite	Granod.	Diorite	Mylonite	Granod.	Diorite	Mylonite
				Core	Rim								
SiO_2	65.2	64.7	64.9	58.2	63.5	60.1	37.1	36.9	35.5	37.3	43.6	42.6	26.4
TiO_2	—	—	—	—	—	—	2.1	1.6	2.7	1.5	0.6	0.9	—
Al_2O_3	19.5	19.5	23.8	26.7	24.1	25.5	15.9	16.1	15.5	16.8	9.5	10.7	18.7
FeO*	—	—	—	—	—	—	19.2	18.3	20.1	17.6	19.2	19.7	23.6
MnO	—	—	—	—	—	—	1.2	0.8	0.4	1.1	1.1	0.5	0.3
MgO	—	—	—	—	—	—	10.7	12.6	10.6	12.1	9.9	9.4	17.3
BaO	1.5	1.4	—	—	—	—	—	—	—	—	—	—	—
CaO	—	—	4.3	8.0	5.0	7.3	—	—	—	—	11.4	11.8	—
Na_2O	0.8	0.7	9.0	6.8	8.3	7.0	—	—	—	—	1.3	1.0	—
K_2O	14.9	14.9	0.2	0.1	—	0.1	9.5	9.3	9.3	9.5	1.0	1.1	—
Total	101.9	101.2	102.1	99.9	100.9	99.9	95.8	95.6	94.1	96.1	97.6	97.6	87.7
Si	2.97	2.96	2.80	2.56	2.78	2.67	5.64	5.58	5.53	5.60	6.66	6.51	5.56
Ti	—	—	—	—	—	—	0.24	0.18	0.32	0.17	0.07	0.10	—
Al	1.05	1.05	1.21	1.41	1.24	1.34	2.85	2.88	2.85	2.97	1.70	1.92	4.64
Fe	—	—	—	—	—	—	2.44	2.32	2.61	2.22	2.45	2.51	4.15
Mn	—	—	—	—	—	—	0.16	0.10	0.05	0.14	0.14	0.06	0.33
Mg	—	—	—	—	—	—	2.43	2.83	2.46	2.71	2.25	2.14	5.44
Ba	0.03	0.03	—	—	—	—	—	—	—	—	—	—	—
Ca	—	—	0.20	0.39	0.23	0.35	—	—	—	—	—	1.93	—
Na	0.07	0.06	0.75	0.59	0.71	0.60	—	—	—	—	0.38	0.29	—
K	0.87	0.87	0.01	0.01	—	0.01	1.84	1.80	1.84	1.82	0.19	0.21	—
Total	4.98	4.98	4.97	4.99	4.96	4.97	15.61	15.70	15.66	15.66	15.70	15.68	20.12

FeO* is tota Fe as FeO.

— indicates not detected (less than 0.1 weight %).

Cation totals based on following 0 numbers: 8 for feldspar, 22 for biotite, 23 for hornblende, 28 for chlorite.

size of feldspar is dramatically reduced in the banded granodiorite and this is graphically displayed in Fig. 7.

The outstanding contrast between the banded and massive granodiorite is the distinctly lower microcline component in all the dark bands. The content drops from 12% in the massive granodiorite to between 1 and 5% in domains 2 to 9. This pattern is also shown in Fig. 8 where a distinct jump occurs between the massive granodiorite (C, 10) and the trend within the banded granodiorite. The grainsize range indicates the drop from 6 mm to 4 mm is associated with a loss of 5% microcline and, at 2 mm, very little microcline is present. The finer-grained biotite and accessory phases increase within the banded zones, but quartz and plagioclase contents show no significant variation.

Within the banded granodiorite Sr is the only element which linearly increases away from the dyke margin despite the variation in mineralogy. Delaney & Pollard (1982) pointed out that rims of dykes are commonly formed early in the dyke history whereas the cores represent the late magma. The subtle, but persistent, trend in Sr content may reflect variations within the magma chamber tapped by this dyke.

Most other trace-element concentrations are strongly correlated with MgO which is controlled by biotite enrichment (Figs 8, 9). Since biotite has a low distribution coefficient for many of these elements (e.g. REE, P) this correlation implies that accessory phases, such as apatite, are concentrated with the biotite (Miller & Mittlefehldt 1984; Watson & Capobianco 1981). However the within-band variation in K_2O, Ba and Sr is distinctly different from the variation between the banded and massive granodiorite. The K_2O and Ba variation is best explained by decoupling of K-feldspar depletion from biotite enrichment (Fig. 9). This geochemical evidence for the involvement of the mineral phases in the differentiation implies that the granodiorite was partly crystallised at the time of emplacement.

Origin of the banding

The bulk of the magmas are affected by crystal fractionation during their evolution (Huppert & Sparks 1984), in spite of evidence that crystal settling is implausible as a process in most magmas, and especially in the highly viscous and crystal-rich granitic magmas (McBirney & Noye 1979; Hildreth 1979). Recent work on the processes active in crystallisation of complex liquids during convection suggest that shear and/or convective flow at the boundary of circulating magmas is the major controlling influence on the segregation of liquids and crystals in the plutonic environment (Rice 1981; Thompson & McBirney 1985; Turner & Gustafson 1981). In the granitic system, Barriere (1981) demonstrated the importance of grain dispersive pressure in separating not only liquid from crystals, but also biotite from feldspar. Grain dispersive pressure has been widely recognised as the controlling influence on crystal-liquid distributions at the margin of dykes (Komar 1972a, b). This process produces a strong grainsize variation with small grainsizes concentrated near the margin. The finer-grained biotite is concentrated into this zone while the very coarse-grained K-feldspar is forced away from the boundary. Other processes which may produce crystal-liquid separation (e.g. filter pressing) do not explain the decoupling of the biotite from K-feldspar. The internal segregation between crystals and liquid within granites has been described by Sultan *et al.* (1986). Biotite and K-feldspar were removed in modal proportions to produce the range of compositions. The variations normally found within I-type granitoids contrast with the margins of the Point Brown dykes in just the same way. For example, the I-type granitoids from eastern Australia described by Hines *et al.* (1978) and Griffin *et al.* (1978) have fractionation trends indicating biotite is not decoupled from other crystal phases. The Point Brown cumulate margins are strongly enriched in Rb, Mn, Zr and P_2O_5, reflecting the enrichment in biotite and accessory phases, compared to I-type granitoids of similar composition. All other elements are consistent with this different behaviour.

Alternative models for fractionation in granitoids do not fit the chemical and textural variations observed in this study. Liquid-state diffusion produces coherent enrichment in the highly mobile alkali elements and volatiles (Miller & Mittlefehldt 1984; Cameron & Cameron 1986). Lesher (1986) measured the fractionation of many elements by thermal (Soret) diffusion. In andesitic and dacitic compositions K, Rb, Na and Si are depleted in the cold margins and most other elements, and especially Mn, Mg, Ca and LREE, are enriched. The predicted depletion in Rb, Na and K, and enrichment in Ca is inconsistent with the chemical zonation of the dyke margins at Point Brown.

Similarly the fractionation resulting from volatile fluxing is different in character from the granodiorite banding at Point Brown. Water-rich fluids produce extreme enrichment in Rb coupled with moderate depletions in SiO_2, MgO, CaO and LREE (Higgins *et al.* 1985). Boron-rich fluids produce extreme fractionation in K_2O with minor variation in MgO (Rockhold *et al.* 1987). CO_2-dominated fluids produce enrichment in Zr, Nb, Y and REE at relatively constant MgO (Taylor *et al.* 1981). None of these processes are consistent with the strong enrichment in MgO, MnO, TiO_2

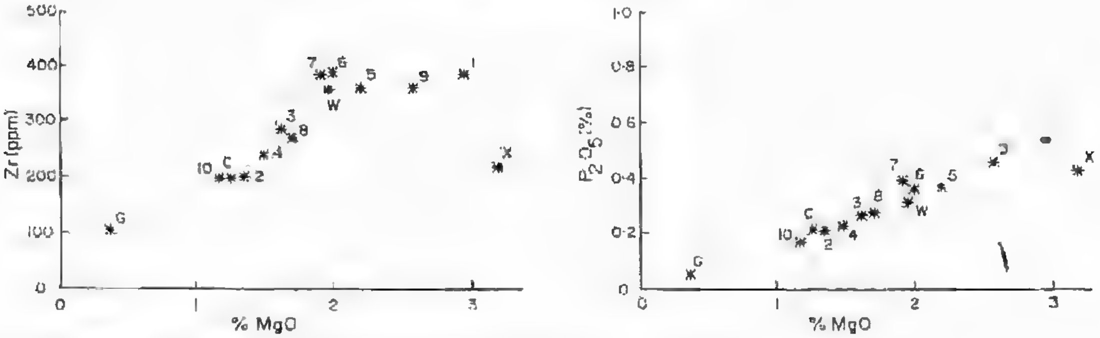

Fig. 8. P_2O_5/MgO and Zr/MgO diagrams. Symbols for rocks as in Fig. 6.

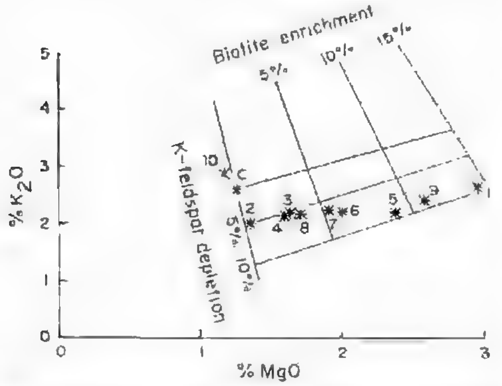

Fig. 9. K_2O/MgO variation diagram with symbols as in Fig. 6. The approximate effect of K-feldspar depletion and biotite enrichment is shown based on the analysed composition of these phases.

and Rb, with little variation in alkalis and CaO which occurs within the dark bands on the margin of the granodiorite at Point Brown.

The textural evidence for preservation of igneous mineralogy precludes any models involving depletion during mylonite formation on the margin of the dyke except in domain 1. The bands are continuous over the length of the contact and show no evidence of a lenticular form which would suggest they are deformed xenoliths. In addition their chemistry is coherent with the granodiorite and does not lie on a mixing line with the granite or with diorite. For example, both the granite and the diorite have a lower Nb content than the granodiorite but this element is enriched in the dark bands (Fig. 6).

A feature of the dykes at Point Brown is the asymmetric development of the banding. On the western side of the dykes the bands are usually absent or inconspicuous but where they occur these bands are very similar in composition to the banded granodiorites reported here (Table 1) demonstrating that the same process is active on both sides of the dyke. Theoretical considerations suggest the upper and lower surfaces may react differently in moderately dipping dykes (Komar 1972b). In general a better separation between biotite and K-feldspar should occur on the lower side of moderately dipping dykes and sills, due to the density differences. This effect was observed by one of us (RFB) in granitoid dykes on Cape Barren Island where dykes with dips less than 60° have stronger biotite enrichment on the lower margin.

At Point Brown the schistosity is subvertical and steeper than the east-dipping dykes, so the structural data suggest the banding is strongest on the upper side of the dykes. However, no viable mechanism is known which preferentially produces and preserves strong banding on the upper side of a large number of narrow dykes. The orientation of the dykes prior to deformation is not known, but the presence of well-developed banding along the eastern "upper" margins suggests the dykes may be overturned.

Acknowledgments

The whole rock analyses were carried out by Mr P. Robinson at the Geology Department, University of Tasmania. This paper is published with the permission of the Director General of the South Australian Department of Mines and Energy.

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A NEW INTERTIDAL BARNACLE OF THE GENUS *ELMINIUS* (CIRRIPEDIA: THORACICA) FROM SOUTH AUSTRALIA

BY *R. F. BERRY* & R. B. FLINT†*

Summary

A new species of intertidal barnacle from South Australia is described. *Elminius adelaidae* sp. nov. is common in the Adelaide region in sheltered localities and is very abundant in mangroves. It differs from *E. modestus*, with which it has been previously confused, by its brown colour, distinctive opercular plates, particularly the tergum which has a small and shallow articular furrow and its high intertidal habitat. The new species is compared in detail with *E. modestus*, which also occurs in South Australia, and *E. covertus* from New South Wales.

KEY WORDS: Cirripedia, *Elminius adelaidae* sp. nov., intertidal, South Australia, mangroves, taxonomy

A NEW INTERTIDAL BARNACLE OF THE GENUS *ELMINIUS* (CIRRIPEDIA: THORACICA) FROM SOUTH AUSTRALIA

By D. E. BAYLISS*

Summary

BAYLISS, D. E. (1988) A new intertidal barnacle of the genus *Elminius* (Cirripedia: Thoracica) from South Australia. *Trans. R. Soc. S. Aust.* 112(2), 75-79, 31 May 1988.

A new species of intertidal barnacle from South Australia is described. *Elminius adelaidae* sp. nov. is common in the Adelaide region in sheltered localities and is very abundant in mangroves. It differs from *E. modestus*, with which it has been previously confused, by its brown colour, distinctive opercular plates, particularly the tergum which has a small and shallow articular furrow and its high intertidal habitat. The new species is compared in detail with *E. modestus*, which also occurs in South Australia, and *E. covertus* from New South Wales.

KEY WORDS: Cirripedia, *Elminius adelaidae* sp. nov., intertidal, South Australia, mangroves, taxonomy.

Introduction

There is confusion over the identity of barnacles belonging to the Genus *Elminius* in Australia. Foster (1982) has described a species, *Elminius covertus*, from New South Wales which had previously been confused with *Elminius modestus* Darwin. Furthermore, Foster (1980, 1982) has suggested that *E. modestus* is a New Zealand species which was introduced into Australian waters in the nineteenth century from fouling on shipping.

South Australian barnacles have been neglected in the early taxonomic literature and *E. modestus* in Australia was only recorded from N.S.W., Victoria and Tasmania (Darwin 1854; Hoek 1883; Nilsson-Cantell 1926; Moore 1944; Pope 1945). The earliest report of *E. modestus* in S. Aust. is comparatively recent (Womersley & Edmonds 1958). Nevertheless, the gulf areas of S. Aust. provide a suitable habitat in which members of this genus are highly abundant.

In South Australia, *E. modestus* has been recorded on the pneumatophores of *Avicennia marina* in the Spencer Gulf and Gulf St Vincent (Womersley & Edmonds 1958; Hutchings & Recher 1982; Bayliss 1982), on rocks and wooden structures on Kangaroo Island (Thomas & Edmonds 1979) and at Adelaide (Foster 1982; Keough 1983). Foster (1982) also records *E. covertus* at Port Adelaide.

In this paper a new species of *Elminius* which is abundant in the Adelaide region is described. This species has escaped previous description through confusion with *E. modestus* and a neglect of thorough taxonomic work on South Australian barnacles.

SYSTEMATICS

Suborder Balanomorpha Pilsbry, 1916
Superfamily Balanoidea Leach, 1817
Family Archaeobalanidae Newman & Ross, 1976
Subfamily Elminiinae Foster, 1982
Genus *Elminius* Leach, 1825
Type species *Elminius kingii* Gray, 1831

Elminius adelaidae sp. nov.
FIGS 1-2

Synonymy: *Elminius modestus* Bayliss, 1982:212
Elminius covertus Foster, 1982:26

Holotype: SAM C4101, collected on leaves of *Avicennia marina* on Garden Island, Port Adelaide, S. Aust., by D. Bayliss, 22.ix.1986.

Paratypes: SAM C4102, NMV J14009, WAM 83-87, collected by D. Bayliss, 22.ix.1986, from same locality. Holotype and paratypes preserved in 75% alcohol, holotype dissected (partially).

Description of holotype: Shell (Fig. 1A and B): conical, light brown, almost translucent. Parietes slightly undulating with broad longitudinal folds. Orifice pentagonal in outline. Basis membranous, basal outline sinuous. Alae wider than radii with less oblique summits. Radii with oblique summits, narrow, not completely covering underlying alae. Holotype 9 mm in basal diameter, 8 mm in width, 4 mm in height.

Opercula (Fig. 2A, B): Scutum longer than high. Basal margin convex with upward curving at tergal corner of basal margin. Articular ridge, articular furrow moderately developed. Adductor ridge, adductor pit not apparent. Externally, growth ridges present.

Tergum with vertical articular ridge not folding inwards to form furrow except at apical end where small, very shallow furrow apparent. Articular

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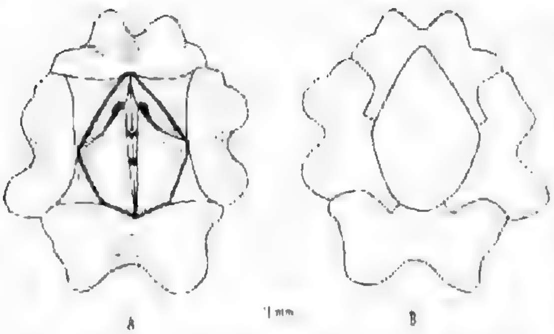

Fig. 1. *Elminius adelaidae* sp. nov. holotype. A: External view of shell; B: inner view of shell.

margin concave. Crests for depressor muscles at carinal end. No spur.

Mouthparts (Fig. 2C, E, F): Labrum with 3 teeth, with setulae on each side of central notch. Mandible with 5 teeth, short pectinate edge terminating in short curved spine. Maxillule with 2 large spines above notch, 5 smaller spines in notch, 4 large spines below notch. Five smaller spines about half length of large spines at lower angle.

Cirri (Fig. 2G–I): Cirrus I with anterior ramus twice as long as posterior ramus, distal segments of anterior ramus with long setae. Segments of posterior ramus slightly protuberant. Anterior ramus of cirrus II slightly longer than posterior ramus, segments slightly protuberant anteriorly. Cirrus III with anterior ramus slightly longer than posterior ramus. Setae on both rami extremely long; stout pectinate setae on the posterior ramus (Fig. 2I). Segments slightly protuberant anteriorly. Cirri IV to VI all subequal in length, segments have 4 large pairs and 1 small pair of setae on anterior face and small proximal pair of setae between segments (Fig. 2D). Penis as long as cirrus VI, with setae, no basidorsal point. Number of segments in the rami of cirri I–VI shown in Table 1.

Variation: Shell sometimes tubular; parieties can be smooth or, if undulating, can have variable number of gentle longitudinal folds. Maximum basal diameter 13 mm. Brown coloration can be slight. Specimens collected high in the intertidal zone are nearly translucent.

Etymology: The specific name is derived from the type locality, Adelaide.

Comparison with other species: E. adelaidae can be distinguished from *E. modestus* and *E. covertus* by differences in the opercular valves. The tergum of *E. adelaidae* has a concave articular margin and the articular furrow is restricted to the apical end. The vertical articular ridge runs the length of the tergum and there is only a very slight narrowing at the centre. In both *E. modestus* and *E. covertus* the articular ridge folds inwards forming a deep articular furrow and a marked narrowing at the centre. The articular furrow continues from the apical end to almost the basi-scutal angle and the articular margin forms a straight line except in worn specimens.

The scutum of *E. adelaidae* has an upward curving of the tergal corner of the basal margin. This feature may be observed externally in larger specimens, but is difficult to detect in smaller specimens in the field. The tergal corner of the basal margin of *E. modestus* and *E. covertus* is essentially flat.

The shell of *E. adelaidae* is similar to *E. modestus* except for a slight brown coloration. It never has the buff red colour with narrow contrasting ribs observed in *E. covertus*. Colour is not a good guide to distinguishing between *Elminius* species as they are subject to decoloration from wear and also from algal growth. The shell of *E. adelaidae* can appear almost black due to algal growth and golden brown in other specimens due to the developing gonads showing through the near translucent shell. In some specimens the brown coloration is very slight.

The shell of *E. modestus* is white, but this barnacle also suffers from decoloration due to algal growth and wear. The ribs on *E. covertus* can be worn away in older specimens. Care is required in distinguishing between *E. adelaidae* and *E. covertus* in such cases, because *E. adelaidae* sometimes has slight folds around the base which could be confused with the remnants of ribbing on *E. covertus*.

Stout pectinate setae are found on the posterior ramus of cirrus III of both *E. adelaidae* and *E. covertus*, but not *E. modestus*. The setae on both

TABLE 1. *Number of segments in rami of holotype and four other specimens of* Elminius adelaidae *sp. nov., anterior ramus first.*

Shell length (mm)	Cirrus					
	I	II	III	IV	V	VI
9.0 (holotype)	14, 7	9, 9	12, 11	22, 24	27, 28	30, 29
9.0	15, 7	9, 8	12, 11	20, 19	22, 22	24, 23
8.0	14, 8	9, 9	13, 11	25, 25	28, 24	29, 28
10.0	12, 6	8, 8	11, 10	24, 18	20, 19	22, 21
10.0	13, 7	10, 10	13, 12	26, 25	29, 25	30, 29

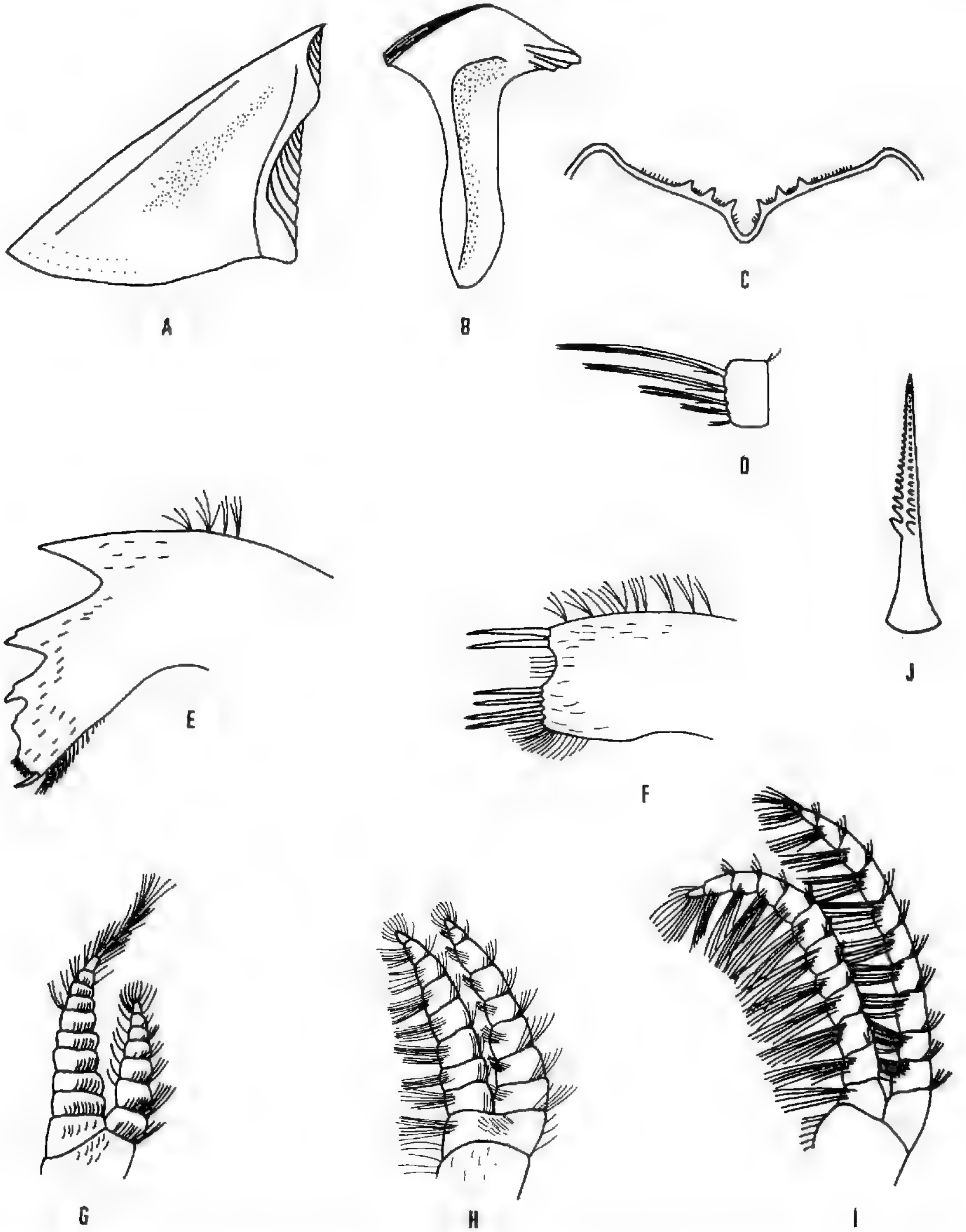

Fig. 2. *Elminius adelaidae* sp. nov. holotype. A: scutum; B: tergum; C: labrum; D: middle segment, posterior ramus, cirrus VI; E: mandible; F: maxillule; G–I: cirri I–III. J: pectinate seta from posterior ramus of cirrus III.

rami of cirrus III in *E. adelaidae* are extremely long compared to those found on cirrus III of *E. modestus* and *E. covertus*. The maxillule has two large spines above a notch with four large spines beneath the notch. *E. modestus* and *E. covertus*, however, have three large spines beneath the notch.

The labrum of *E. adelaidae* is similar to *E. modestus* and *E. covertus* in that there are three teeth on either side of the central notch. It differs in a distinct curve at the ends giving a "handle-bar" like appearance.

In gaping animals the tergoscutal flaps are white to cream with two dark brown spots (Fig. 1A). *E. covertus* has six pairs of dark spots on white tergoscutal flaps and *E. modestus* has one black spot on white tergoscutal flaps (Foster 1982, Fig. 1A, B).

Habitat: *E. adelaidae* is found in the high intertidal zone in sheltered waters where there is little wave action. It is highly abundant on pneumatophores, leaves and branches of *Avicennia marina* which are submerged at high tide. It is also found on rocks and artificial structures. *E. modestus* is usually found at mean tide level and below. It sometimes settles in the mangroves and there may be a small amount of overlap between the two species.

Distribution: The distribution of the three species in Australia has not been determined. In the Adelaide region, *E. covertus* does not occur and *E. adelaidae* is the main high shore species of *Elminius*.

Discussion

The description of *Elminius adelaidae* sp. nov. brings to four the number of extant species of *Elminius*. Of these *E. kingii* Gray, 1831 is restricted to South America and the remaining three are found in Australia. *E. modestus* is also found in New Zealand and was introduced from fouling on shipping into European waters (Flowerdew 1984). Only one extinct species, *E. chapronierei* from the lower Miocene, is recognised (Buckeridge 1983). On the basis of the setation of cirrus III, *E. adelaidae* is close to *E. covertus*, but the shell characteristics of *E. adelaidae* are more like those of *E. modestus*.

Foster's (1980, 1982) hypothesis that *E. modestus* is a New Zealand species has received some support from electrophoretic studies by Flowerdew (1984) which indicate a lack of genetic differentiation between specimens from New Zealand and Tasmania. *E. modestus* does not appear to be permanently established in Sydney (Foster 1982; Egan & Anderson 1985). In S. Aust. *E. modestus* corresponding to the description of Darwin (1854), Moore (1944 Fig. 1D) and Foster (1978 Fig. 57) is found and appears to be permanent and common. Until more information is obtained about *Elminius* in Australia, particularly the distribution and clarification of species, it should not be concluded definitely that *E. modestus* was introduced.

Acknowledgments

I would like to thank Dr A. J. Butler for reading the manuscript and for providing use of microscopes for the examination of specimens. My father helped to collect specimens of *E. covertus* in New South Wales.

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A NEW SPECIES OF TERTIARY CHITON (MOLLUSCA: POLYPLACOPHORA: ACANTHOCHITONIDAE) FROM SOUTH AUSTRALIA

*BY K. L. GOWLETT-HOLMES & B. J. MCHENRY**

Summary

A new species of Tertiary chiton, *Notoplax (N.) arenaria* sp. nov., is described from the Dry Creek Sands (Pliocene, Yatalan) from South Australia. The new species most closely resembles the extant *N. (N.) mayi,* but is distinguished from it by a more regularly grooved jugum and by the strong lateropleural rib on the median valves.

KEY WORDS: Chiton, Polyplacophora, Acanthochitonidae, South Australia, *Notoplax,* Tertiary, Pliocene, new species.

A NEW SPECIES OF TERTIARY CHITON (MOLLUSCA: POLYPLACOPHORA: ACANTHOCHITONIDAE) FROM SOUTH AUSTRALIA

By K. L. Gowlett-Holmes & B. J. McHenry*

Summary

Gowlett-Holmes, K. L. & McHenry, B. J. (1988) A new species of Tertiary chiton (Mollusca: Polyplacophora: Acanthochitonidae) from South Australia. *Trans. R. Soc. S. Aust.* 112(2), 81-82, 31 May 1988.

A new species of Tertiary chiton, *Notoplax (N.) arenaria* sp. nov., is described from the Dry Creek Sands (Pliocene, Yatalan) from South Australia. The new species most closely resembles the extant *N. (N.) mayi*, but is distinguished from it by a more regularly grooved jugum and by the strong lateropleural rib on the median valves.

Key Words: Chiton, Polyplacophora, Acanthochitonidae, South Australia, *Notoplax*, Tertiary, Pliocene, new species.

Introduction

A large number of Tertiary chiton species have been described from southern Australia, but very few are recorded from South Australia (Cotton & Godfrey 1940; Cotton & Weeding 1941; Cotton 1964). The last species description from South Australia was by Ashby (1940). During an examination of the fossil chiton collection of the South Australian Museum (SAM) we located two median valves of a species of *Notoplax* that differed from all known fossil and extant species of the genus. This new species is described here.

Notoplax (Notoplax) arenaria sp. nov.

FIG. 1

Holotype: SAM P12839, one median valve with slight chips to the insertion plates and sutural lamina, 4.75 × 5.6 mm, in excellent state of preservation, collected from 100.9 m (331 feet) Angas Home Bore, Parafield Gardens, Section 2259, Hundred of Yatala, County Adelaide, S. Aust. (34°47′06″S 138°36′26″E), collector unknown, 1940.

Paratype: SAM P27904, one worn median valve, sculpture eroded from jugum and part of pleural areas, insertion plates and sutural lamina broken and worn, 5.7 × 5.9 mm, with same collection data as holotype.

Diagnosis: Carinated. Jugum about 1/3 width of valve with regular grooves; valves beaked; prominent lateropleural rib; pustules oval, flat-topped. Slit formula ?/1/?.

Description of Holotype: Tegmentum about 50% of articulamentum. Jugum with regular grooves, ridges at edge of jugum breaking up into elongate pustules posteriorly; prominent beak (Fig. 1A). Prominent diagonal rib separates lateral and pleural areas, lateropleural areas including rib sculptured with irregular, oval, radiating, flat-topped pustules, smaller near beak, not differentiated on rib. Slit 1, ¼ width of articulamentum, in deep groove to edge of tegmentum. Insertion plates and sutural lamina well developed (Fig. 1B).

Etymology: From the Latin "arenarius" — relating to sand, sandy; from its type stratum, the Dry Creek Sands.

Variation: Although worn, the paratype (Fig. 1D) is like the holotype. The anterior and posterior valves are unknown

Stratigraphical occurrence: The specimens were retrieved from the Angas Home Bore at a depth of 100.9 m (331 ft), where the bore bottomed in "shell sands" which are consistent with a stratigraphic determination of Dry Creek Sands (Lindsay 1987).[1] The two valves of *N. (N.) arenaria* would therefore be Yatalan (Late Pliocene) in age.

Comparison with other species: N. (N.) arenaria was compared with other Tertiary and extant species of Acanthochitonidae in the collections of SAM and with extant species of *Notoplax* in the collections of the Australian Museum, Sydney (AM), the Museums of Victoria, Melbourne (NMV), the Western Australian Museum, Perth (WAM) and the Tasmanian Museum and Art Gallery, Hobart (TM). It most closely resembles the extant species *N. (N.) mayi* (Ashby, 1922) but can be readily distinguished from it by the regularly grooved jugum and the strong lateropleural rib. The new species can be easily distinguished from *N. (N.) adelaidae* (Ashby & Cotton, 1936), which is also from the Dry Creek Sands, by its much greater percentage of tegmentum to articulamentum, the straight posterior edge of

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[1] Lindsay, J. M. (1987) Identification and depositional environment of Dry Creek Sands, Angas Home Bore (1940), Parafield Gardens. *S. Aust. Dept. Mines & Energy Rept. Bk. No.* 87/96:1-6, fig. 1. Unpubl.

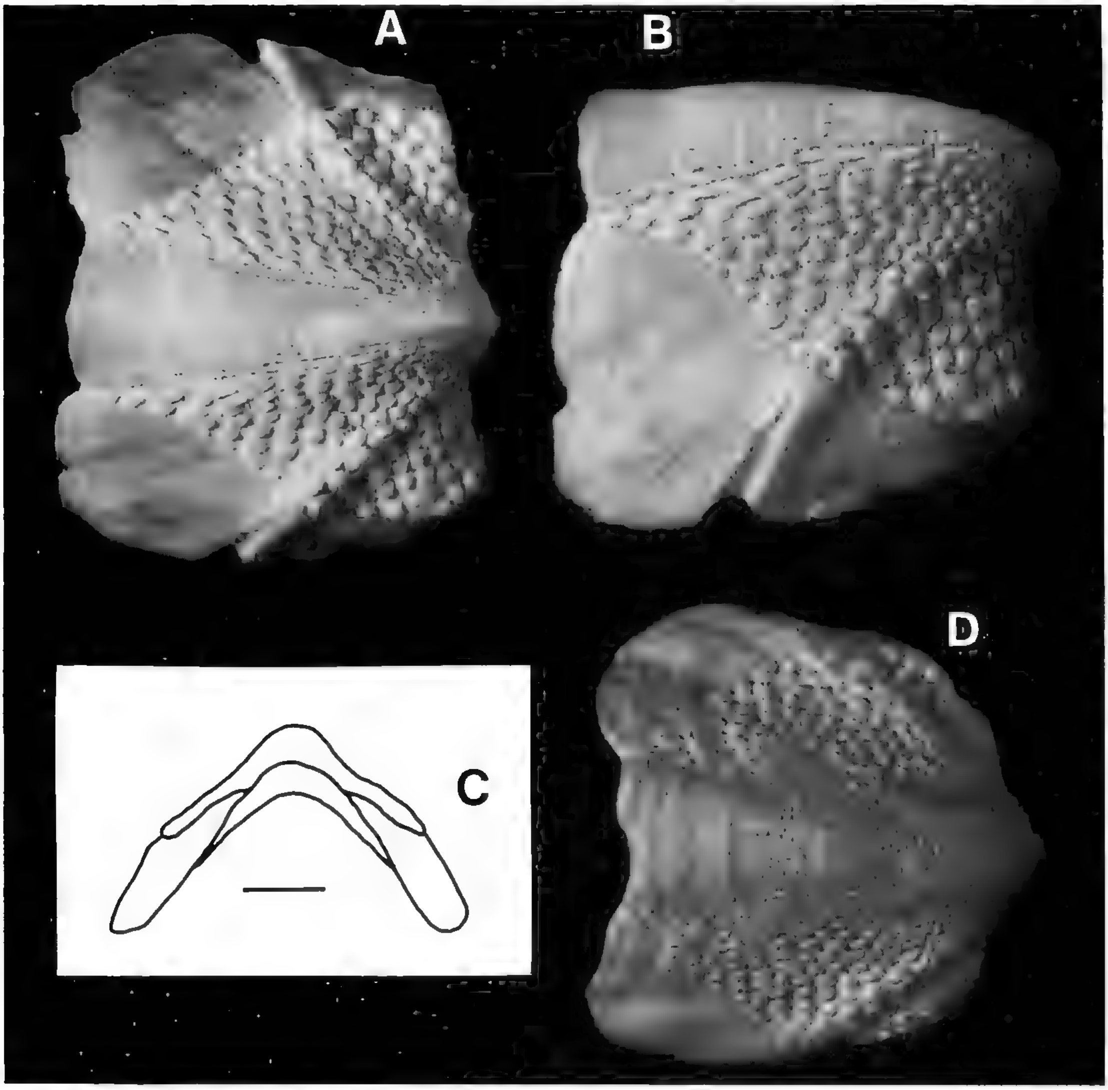

Fig. 1. *Notoplax (N.) arenaria* sp. nov. holotype (SAM P12839) A. top view, ×13; B. side view, ×14.3; C. anterior profile, scale bar = 1 mm; paratype (SAM P27904) D. top view, ×10.

the median valve, the lateropleural rib and the grooved jugum. It can be distinguished from other Tertiary and extant members of the Acanthochitonidae by the shape and arrangement of the pustules, the presence or position of the lateropleural rib, the form of the insertion plate slit and the jugal sculpture.

Acknowledgments

We thank the following curators and collection managers for providing data and specimens held by their respective institutions: Mr I. Loch (AM), Ms S. Boyd (NMV), Dr F. E. Wells (WAM) and Ms E. Turner (TM). The photographs were taken by Mrs J. Forrest.

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THE CRAB FAUNA OF WEST ISLAND, SOUTH AUSTRALIA: THEIR ABUNDANCE, DIET AND ROLE AS PREDATORS OF ABALONE

*BY A. G. J. MOWER & S. A. SHEPHERD**

Summary

Twenty-three species of crabs are recorded from West Island, South Australia. The vertical distribution and densities of sixteen species occurring on the boulder slope at Abalone Cove on the northern side of the Island, are described and the diets of the five most common species enumerated. Four of the species are mainly herbivorous but eat small amounts of animal matter and one species is omnivorous. Four of the species also ate small abalone in cage experiments and represent potential agents of abalone mortality.

KEY WORDS: crabs, abalone, diet, predation.

THE CRAB FAUNA OF WEST ISLAND, SOUTH AUSTRALIA: THEIR ABUNDANCE, DIET AND ROLE AS PREDATORS OF ABALONE

By A. G. J. Mower & S. A. Shepherd*

Summary

Mower, A. G. J. & Shepherd, S. A. (1988) The crab fauna of West Island, South Australia: their abundance, diet and role as predators of abalone. *Trans. R. Soc. S. Aust.* **112**(2), 83–86, 31 May 1988.

Twenty-three species of crabs are recorded from West Island, South Australia. The vertical distribution and densities of sixteen species occurring on the boulder slope at Abalone Cove on the northern side of the Island, are described and the diets of the five most common species enumerated. Four of the species are mainly herbivorous but eat small amounts of animal matter and one species is omnivorous. Four of the species also ate small abalone in cage experiments and represent potential agents of abalone mortality.

Key Words: crabs, abalone, diet, predation.

Introduction

The need to understand the recruitment process in abalone, necessary for the proper management of abalone fisheries has focused increasing attention on the ecology of juveniles and in particular of the agents of mortality. Dead abalone shells are frequently found damaged in different ways, but there is dispute whether this is caused by crabs, or is due to natural causes such as abrasion (Hines & Pearse 1982; Tegner & Butler 1985).

Studies on the ecology of juvenile *Haliotis laevigata* Donovan, and *Haliotis scalaris* Leach have been in progress at West Island, South Australia (35°36′25″S; 138°35′27″E) since 1983 (Shepherd & Turner 1985) but their predators are still largely unknown. Several crab families, which are represented at West Island, are known to attack and feed on molluscs, often inflicting shell damage (Skilleter & Anderson 1986; Vermeij 1977; Zisper & Vermeij 1978; Williams 1982).

This study describes the abundance and diet of the crab species present on a boulder slope at West Island the site of earlier studies, and gives the results of preliminary experiments to determine whether crabs eat abalone and the type of damage to the shell inflicted by them. An ancillary purpose was to accumulate information on a group of consumers, leading to a better understanding of the benthic food-web of the Island.

Materials and Methods

Twenty samples were taken at 1 m depth intervals from 1–5 m depths on the boulder slope of the study site on the northern slope of West Island (see Kangas & Shepherd 1984). A quadrat, 0.25 m^2 in area, was placed on the boulders and the area within the perimeter was searched systematically for crabs by removal of all boulders down to the sandy substratum. The sand below the boulders was then sifted by hand to collect any burrowing species.

Animals collected were identified to species and preserved in 70% alcohol. Subsequently the gastric mill was removed in the laboratory and the contents mounted on microscope slides in Karo, a light corn syrup. Only gastric mills subjectively estimated to be more than half full were examined in order to avoid biased estimates due to differential retention time of different prey items in the mill (Williams 1981).

Slides were placed on a grid and the material under each of 25 grid intersections was identified to the lowest taxonomic category possible. This method estimates the percentage composition of food items by volume (Berg 1979). Subsequently plant material was classified as green, brown or red macro-algae, filamentous algae (a polyphyletic group), geniculate corallines, comprising species in the genera *Jania*, *Haliptilon* and *Cheilosporum*, seagrass, comprising *Posidonia* or *Heterozostera*, and unidentifiable matter. Animal material was classified as sponge, foraminiferans, echinoderms, molluscs, crustaceans, and unidentifiable matter. The presence of sand grains was also recorded.

A series of "no choice" feeding experiments was conducted in plastic cages set on the sea-bed at West Island to determine whether crabs attacked abalone in the absence of other food, and to determine the nature of shell damage inflicted. In each cage 4–6 juvenile *H. scalaris* over a range of sizes were placed on boulders in the cage with a number (usually 4) of crabs of a given species. Controls with abalone but without crabs, were placed in an adjoining cage and all cages were recovered after intervals of 5–21 days. In addition observations were made on the period of activity of four species of crabs kept in aquaria.

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TABLE 1. *List of crab species at West Island, with their distribution and depth range. B* = boulder slope on northern shore of West Island. E = exposed shores of Island. Depth range in metres.

Family	Species
ANOMURANS	
Porcellanidae	— *Porcellana dispar* (Stimpson) B, 1–5
Lithodidae	— *Lomis hirta* (M. Edwards) B, 1–5
Paguridae	— *Paguristes frontalis* (M. Edwards) B, 3–5
	— *Paguristes sulcatus* (Baker) B, 1–5
	— *Paguristes brevirostrus* (Baker) B, 5.
	— *Pagurus* sp. 1 B, 5.
	— *Pagurus* sp. 2 B, 5.
Galatheidae	— *Galathea australiense* (Stimpson) B, 1–5.
BRACHYURANS	
Majidae	— *Huenia proteus* (de Haan) E, 10.
	Naxia aurita (Latrielle) B, 1–5; E, 13.
	— *Paratymolus latipes* (Baker) B, 2–4.
Goneplacidae	— *Litocheira bispinosa* (Kinahan) B, 3.
Hymenosomatidae	— *Halicarcinus ovatus* (Stimpson) B, 2–4.
Dromidae	*Petalomera lateralis* (Gray) B, 3.
Xanthidae	— *Pilumnus rufopunctatus* (Stimpson) B, 1–5
	— *Pilumnus fissifrons* (Stimpson) B, 1–5.
	Heteropilumnus fimbriatus (M. Edwards) B, 4
	— *Actaea peronii* (M. Edwards) B, 3–4.
	— *Actaea calculosa* (M. Edwards) B, 3.
	— *Megametope carinatus* (Baker) B, 1–5.
Grapsidae	— *Plagusia chabrus* (Linnaeus) B, 1–2.
	— *Brachynotus octodentatus* (M. Edwards) terrestrial
Portunidae	— *Nectocarcinus tuberculosus* (M. Edwards) B, 4–5.

Results

Twenty-three species of crabs, in 11 families, have been recorded in this and earlier collections at West Island (Table 1). Of these 20 were found on the boulder slope in this study. The vertical distribution of density of the six commonest species (density more than 0.1/m^2) on the boulder slope is shown in Fig. 1. The two species of *Pilumnus* were not readily distinguishable in the field and are plotted together in Fig. 1. *P. fissifrons* was much less common than *P. rufopunctatus*. *Porcellana dispar* escaped rapidly on disturbance and our sampling technique is therefore likely to have underestimated its density.

There are two very abundant species, *Lomis hirta* and the hermit crab *Paguristes sulcatus*, with densities of 10–15/m^2, and four moderately abundant species *Pilumnus rufopunctatus, Paguristes brevirostrus, Megametope carinatus* and *Paguristes frontalis*. The remaining species are quite rare with densities of less than 0.1/m^2.

Five of the six most common species were used for dietary analysis. The mean percentage composition of food in the gut of a sample of 15 of each of these species is given in Table 2. The percentage discarded for gut analysis, where the gastric mill was less than half full is also indicated.

Two species (*Paguristes sulcatus* and *Pilumnus rufopunctatus*) are almost wholly herbivorous, two species (*Lomis hirta* and *Paguristes frontalis*) are mainly herbivorous but take small amounts of animal matter, and one species, *Megametope carinatus* takes about equal amounts of plant and animal matter. Most collections were taken in morning dives, and it seems likely that the high incidence of empty gastric mills recorded by nocturnally active species (Table 2) is related to their nocturnal feeding and rapid fore-gut clearance (Table 3).

The results of "no choice" feeding experiments (Table 3) show that four out of five common species captured and ate small abalone mostly in the length range 15–32 mm. Two species of crab chipped the

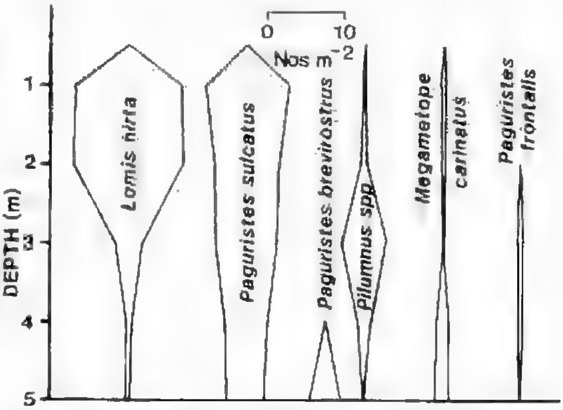

Fig. 1. Distribution of density of crabs on the boulder slope, in Abalone Cove, West Island.

TABLE 2. *Mean percentage composition of contents of gastric mill of five species of crabs. In each case sample size is 15.*

	Lomis hirta	*Paguristes sulcatus*	*Paguristes frontalis*	*Pilumnus rufopunctatus*	*Megametope carinatus*
Macro-algae					
green		2	3	6	—
brown	50	36	7	49	5
red (non-geniculate)	2	6	5	6	10
(geniculate corallines)	6	24	31	3	16
filamentous	9	14	13	16	2
seagrass	1	9	18	7	16
unidentified	5	4	3	1	—
TOTAL % ALGAE	73	95	80	88	49
sponge	—	1	1	—	—
foraminiferan	6	1	1	—	—
echinoderm	1	—	—	—	2
mollusc	5	1	1	5	12
crustacean	1	—	—	—	12
unidentified	7	2	12	1	23
TOTAL % ANIMAL	20	5	15	6	49
sand grains	7	—	5	6	2
% with gastric mill ⊕ half full	35	17	12	52	65

TABLE 3. *The size range of predaceous crabs and prey abalone, and the sizes of abalone, consumed and nature of shell damage inflicted and other details of "no choice" feeding experiments of crabs on abalone. Data on period of activity are from aquarium observations.*

Species	*Lomis hirta*	*Paguristes sulcatus*	*Paguristes frontalis*	*Pilumnus rufopunctatus*	*Megametope carinatus*
carapace width of crab (mm)	11–18	8–12*	13–17*	10–15	18–35
abalone presented (length range - mm)	11–53	6–40	10–49	9–35	15–40
abalone taken (length – mm)	22–27	28, 40	25, 32	—	15–19
damage inflicted	growing edge sometimes chipped	none	growing edge chipped	—	growing edge chipped
number of experiments	2	2	1	1	2
duration (days)	5, 13	5, 13	12	12	13, 21
time of activity	none kept	day time	day time	night time	night time

* inferred from size of shell occupied.

growing edge of the shell (Fig. 2) presumably during the process of capture. The controls showed no mortality of abalone and no chipped shells were observed on any individual.

Discussion

The factors influencing the vertical distribution of crabs are unclear and few comments can be made. *Lomis hirta* is morphologically strongly compressed in the dorso-ventral plane and clings tenaciously to the rock surface. It is thus well adapted to withstand strong water movements that occur in shallow water of 1-2 m depth where it is most abundant. It also has pinnate antennal appendages suggesting that it also can filter feed planktonic organisms. *Megametope* is a burrowing crab mostly found below the sand surface under boulders and this may account for its apparent preference for depths of 4-5 m where sand accumulates between and under boulders.

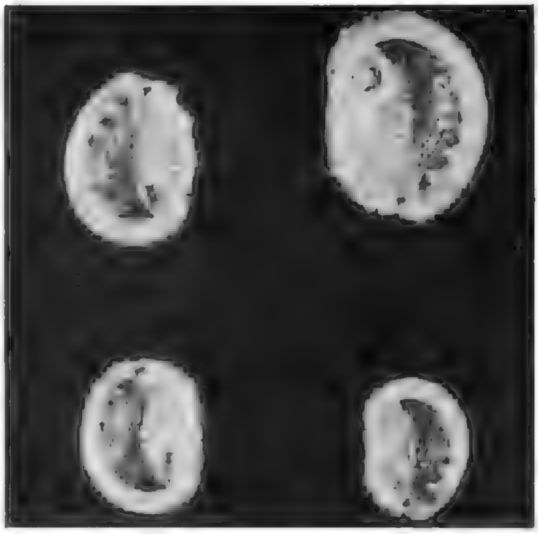

Fig. 2. Chipped shells of *Haliotis scalaris* eaten by crabs during cage experiments.

Despite the bias toward herbivory in most species, whose feeding was studied, the cage experiments show that all except *Pilumnus rufopunctatus* can capture abalone and that the only damage inflicted by these crab species is slight chipping of the growing edge of the shell. This kind of damage is similar to that inflicted on abalone by crab species of the genera *Gaetice* and *Charybdis* (Kojima 1981), *Loxorhyncus* and *Cancer* (Tegner & Butler 1985) and *Macropipus puber* (Clavier & Richard 1985).

"No choice" experiments do not indicate whether or how many abalone are actually taken by a potential predator. The incidence of dead juvenile abalone shells with chipped edges in the under-boulder habitat is low and only about 1-2/m^2 (Shepherd unpubl.) and this suggests that predation by these crabs is not high. This contrasts with the studies of Kojima (1981) and Tegner & Butler (1985) who reported that from one third to one half of the total mortality of young abalone was attributable to crab predation. Similarly Clavier & Richard (1985) considered crabs a principal predator of *Haliotis tuberculata*.

Acknowledgments

Messrs L. Gray, A. Bennett, V. Karo all gave assistance in the field. We are grateful to Dr P. Abrams for identifying *Paguristes brevirostrus* and to Dr D. J. G. Griffin for identifying earlier collections of crabs from West Island. We thank Mr R. K. Lewis for criticism of the manuscript.

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REDEFINITION OF *UPEROLEIA TALPA* TYLER, DAVIES & MARTIN, 1981 (ANURA: LEPTODACTYLIDAE: MYOBATRACHINAE)

BY M. DAVIES & A. A. MARTIN

Summary

BRIEF COMMUNICATION

REDEFINITION OF *UPEROLEIA TALPA* TYLER, DAVIES & MARTIN, 1981 (ANURA: LEPTODACTYLIDAE: MYOBATRACHINAE)

Uperoleia talpa was described from three individuals collected on a dry night south of Derby, W.A.[1] Subsequent collections in the area have provided additional material, and allowed biological and additional morphological, osteological and distributional data to be assembled. Here we report these data. Morphological measurements follow the methods of the original description,[1] and are expressed as mean ± standard deviation with ranges in parentheses.

Calls of three individuals were recorded at a site 22 km S of Derby on 14.ii.80, using a Sony TC-510-2 tape recorder and a Beyer M88 dynamic microphone, at a tape speed of 19 cm/sec. Wet-bulb air temperatures measured close to the calling sites of males ranged between 25.6–26.0°C. Calls were analysed by means of a sound spectrograph (Kay Model 6061-B Sona-Graph), with the overall response curve maintained in the FL-1 position. One call of each male was analysed.

Material examined is deposited in the South Australian Museum, Adelaide (SAM), the Western Australian Museum, Perth (WAM), and the University of Adelaide osteological collection (UAZ).

Uperoleia talpa Tyler, Davies & Martin, 1981[1]

Glauertia mjobergi: Main 1965[2] p. 66; Barker & Grigg 1977,[3] p. 199.

Uperoleia talpa Tyler, Davies & Martin, 1981,[1] p. 52.

Uperoleia talpa: Tyler 1982,[4] p. 87. Cogger, Cameron & Cogger 1983,[5] p. 34; Tyler, Smith & Johnstone 1984,[6] p. 102; Tyler 1985,[7] p. 408; Cogger 1986,[8] p. 87; Tyler 1987,[9] p. 232.

Diagnosis: A large species (♂♂ 26–38 mm S-V, ♀♀ 32–36 mm S-V) lacking maxillary teeth; toes fringed with moderate webbing; metatarsal tubercles very large; frontoparietal fontanelle widely exposed; carpus of six elements; anteromedial processes of anterior hyale of hyoid slender, short; no ilial crest; advertisement call of about 130 msec duration, with some 40 pulses produced at a pulse repetition rate of about 315 pulses/sec.

Material examined: 49 ♂♂ and 9 ♀♀ were examined: SAM R28792–94, WAM R94430, 10–18 km S Derby; SAM R28795, 22–41 km S Derby; SAM R28808, 41 km S Derby; SAM R31733, 28 km S Derby; SAM R28809–38, WAM R94431–34, 28 km S Derby; SAM R28796–801, WAM R94436–38, 8 km NE Broome; SAM R28802–7, WAM R94439–40, 106 km E Broome.

External morphology: Large species (males 26–38 mm, females 32–36 mm S-V) with short snout, usually truncated (4/5 of specimens) or slightly rounded when viewed from above. Eye to naris distance greater than internarial span (E-N/IN 1.20 ± .17 [1.00–1.56]). Fingers short with lateral fringes in 2/5 of specimens, absent in remainder. Subarticular tubercles prominent in about ½ specimens, moderately prominent in others. Palmar tubercle at base of thumb never prominent; that on heel of hand, prominent in 3/5 of specimens but poorly developed in remainder. Hind limbs very short (TL/S-V 0.31 ± .02 [0.25–0.35]). Toes long, broadly fringed in all specimens, moderately webbed in about 7/8 of specimens, basally webbed in remainder. Subarticular tubercles conical, metatarsal tubercles extremely prominent. Inner metatarsal tubercle oriented along long axis of first toe; outer metatarsal tubercle angled slightly to long axis of foot.

Dorsal surface with strongly defined dermal glands (in contrast to specimens in type series). About 1/5 of specimens with only moderately developed parotoid glands; 4/5 with strongly developed, and occasionally hypertrophied, glands. Inguinal and coccygeal gland development as in parotoid glands. Submandibular gland poorly developed in about 1/6 of specimens, moderately developed in 1/6, well developed in remainder. Dorsal surface smooth in ⅔ of specimens, moderately rugose in about 2/9, rugose in remainder.

Ventral surface granular in about ⅓ of specimens; smooth in remainder.

Dorsum weakly patterned in about ¼ of specimens, moderately marked in remainder. Ventral surface unpigmented.

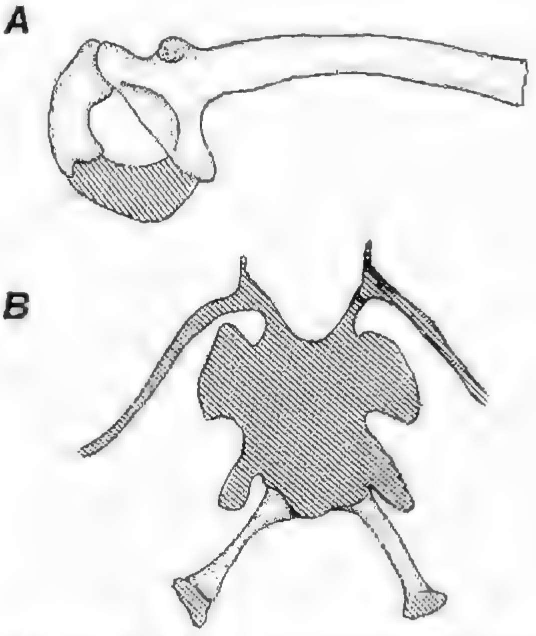

Fig. 1. (A) Lateral view of the pelvis; and, (B) ventral view of the hyoid of *Uperoleia talpa*.

Osteology: Material examined: UAZ A591–4, A598–600, B864, 28 km S Derby; UAZ A595a, b, 53 km E Derby on Gibb River Rd; UAZ A602, 8 km NE Broome; UAZ A865–6, 10 km S Derby.

Variation occurs in posteromedial separation of nasals. Nasals widely separated medially in some, less so in others. Anterior edges of nasals strongly crescentic in some specimens, barely so in others.

Anterior extremities of frontoparietals vary in position: barely reaching posterior extremities of sphenethmoid, terminating at levels of anterior extremity of frontoparietal fontanelle, or reaching anteriorly to anterior edges of sphenethmoid. Orbital edges of frontoparietals straight, gently angled medially.

Zygomatic ramus of squamosal tiny and bifid in many specimens. Pars facialis of maxillary shallow to moderately deep with strongly developed monticuline preorbital process. Condition of palatines varies — bones always reduced laterally, but in many specimens not extending beyond lateral extremities of nasals.

Cultriform process of parasphenoid moderately slender, varies in length. In one specimen (UAZ A602) it is dagger-blade shaped. Well-developed pterygoid process of palatal shelf of maxillary. Anterior ramus of pterygoid moderately expanded, in moderately-long contact with pterygoid process of maxilla. Epiotic eminences of crista parotica incompletely ossified posteriorly. Vomerine fragments at edge of choanae in UAZ A602.

No ilial crest. Dorsal prominence well developed, monticuline; dorsal protuberance laterally situated on prominence (Fig. 1A).

Hyoid plate longer than wide. Anteromedial processes of anterior hyale slender, moderately long. Alary processes of hyoid plate not pedunculate. Posterolateral processes broad, moderately long. Posterior cornua ossified (Fig. 1B).

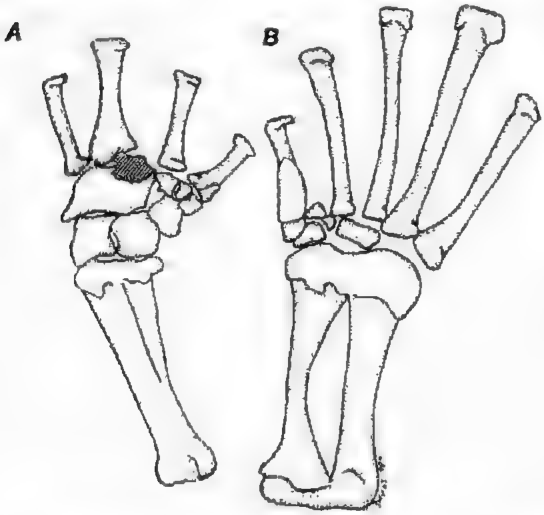

Fig. 2. (A) Palmar view of the carpus; and, (B) plantar view of the tarsus of *Uperoleia talpa*.

Carpus of six elements. Moderate degree of torsion. O. radiale and O. ulnare present; O. radiale is larger. Both articulate with O. radioulnare proximally, and with each other on proximomedial border. Distally, both articulate with large transversely elongated O. centrale postaxiale. O. radiale articulates with O. centrale preaxiale.

O. centrale postaxiale articulates distally with bones of O. metacarpii III, IV and V. Very small flange extends proximally from lateroproximal corner. Palmar sesamoid situated ventromedially (Fig. 2).

O. centrale preaxiale articulates laterally with O. radiale, distally with O. centrale postaxiale, and with carpal elements of O. distale carpale 2 and 3, laterally with basal prepollical element.

Three distal tarsal elements present. Lateral element largest, lying at base of O. metatarsus III and extending laterally to articulate with medioproximal side of base of O. metatarsus II. Medial element lies at base of O. metatarsus I and also articulates with O. centrale prehallucis.

Distal prehallical element very long, slender and bullet-shaped, extending for about ⅓ length of O. metatarsus I (Fig. 2).

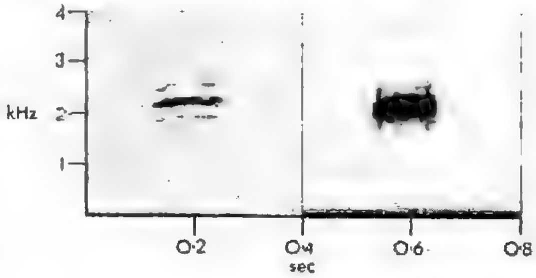

Fig. 3. Audiospectrograms of the advertisement call of a male of *Uperoleia talpa* from 22 km S of Derby, W.A., 14.ii.80. Left trace, 45 H_z bandpass; right trace, 300 H_z bandpass. Wet-bulb air temperature: 25.6°C.

Advertisement call: A "creak" 130 msec (mean: n = 3) in duration (range 125–135), with a dominant frequency of 2450 H_z (2200–2900). The call consists of 41 (40–42) pulses repeated at a rate of 315 (311–320) pulses/sec (Fig. 3).

Comparison with other species: Uperoleia talpa is a large edentate species with a widely exposed frontoparietal fontanelle and moderately webbed toes. These features are shared with *U. russelli, U. orientalis* and *U. borealis. U. talpa* is distinguished from *U. orientalis* by the absence of a midvertebral stripe in the former. *U. borealis* lacks

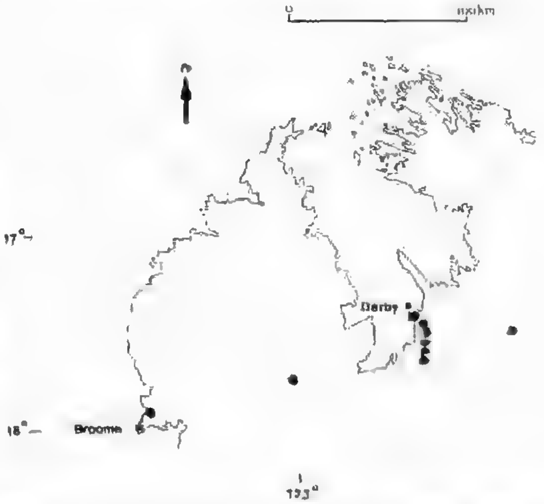

Fig. 4. Distribution of *Uperoleia talpa* in the Kimberley Division of Western Australia.

the back patterning characteristic of *U. talpa* and is distinguished further by call[1] (pulse rate one third that of *U. talpa*). *U. russelli* has pigmented inguinal and postfemoral patches; whereas, in *U. talpa*, pigment is lacking.

Breeding biology: Uperoleia talpa is sympatric with *U. mjobergi* and *U. aspera* at sites between 12 and 42 km S of Derby in W.A. The three species are spatially separated with respect to calling site.[10] *U. mjobergi* calls at the edge of or in shallow temporary waters, whereas *U. talpa* calls from dry vegetated places a considerable distance (up to 10 metres) from water. *U. aspera* calls from the areas between these sites. In March 1980, breeding activity followed torrential rainfall.

Glandular secretions: Uperoleia talpa is unique amongst *Uperoleia* in releasing copious quantities of white frothy secretion from the parotoid glands in response to tactile stimuli such as those received when being picked up. The secretion is toxic to other frogs placed in the same container as the *U. talpa*.[9,10]

Distribution: Uperoleia talpa is confined to the southwestern portion of the Kimberley Division of Western Australia. The distribution of the species is shown in Fig. 4.

Field work was supported by a grant to M. J. Tyler by the Utah Foundation. We thank M. J. Tyler and G. F. Watson for field companionship.

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NEOBATRACHUS PZCTUS (ANURA: LEPTODACTYLIDAE) FROM THE MIOCENE/PLIOCENE BOUNDARY OF SOUTH AUSTRALIA

BY *MICHAEL J. TYLER*

Summary

BRIEF COMMUNICATION

NEOBATRACHUS PICTUS (ANURA: LEPTODACTYLIDAE) FROM THE MIOCENE/PLIOCENE BOUNDARY OF SOUTH AUSTRALIA

The fossil record of frogs in Australia hitherto has been based upon Holocene, Late Pleistocene and Mid-Miocene material, principally from Western Australia, South Australia and Queensland.[1] Here I report an important additional specimen from South Australia.

The specimen (South Australian Museum P27928) is the right ilium of the extant leptodactylid species *Neobatrachus pictus* Peters. It was collected by Mr N. Pledge at Corra-Lynn Cave at Curramulka, Yorke Peninsula, South Australia. The specimen (Fig. 1) is complete and its identity is indicated by the narrow shaft, obliquely situated dorsal protuberance and high dorsal acetabular expansion.

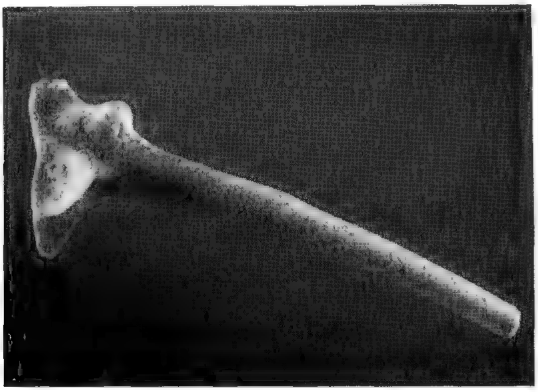

Fig. 1. Right ilium of *Neobatrachus pictus* (SAM P 27928).

The Curramulka fauna is considered to be on the boundary between the Late Miocene and Early Pliocene.[2]The record therefore is significant in bridging one of the major gaps in the existing fossil record.

Only two species of frogs now occur on the Yorke Peninsula. These are *Limnodynastes tasmaniensis* Gunther[4] which is distributed widely in southeastern Australia, and *N. pictus* (previously reported from the southern end of the peninsula as that species[5-6] or, erroneously, as *N. centralis*[3-4]).

It is becoming apparent that extant species of Australian frogs occur as early as the Middle Miocene. At least some fossil ilia of that age cannot be distinguished from their modern counterparts. If these observations are supported by studies of other Tertiary frogs, anuran skeletal morphology, as exemplified by the ilium, will have been shown to be extremely conservative.

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STUDIES ON SOUTHERN AUSTRALIAN ABALONE (GENUS HALIOTIS) 1X. GROWTH OF H. SCALARIS

BY S. A. SHEPARD, A. G. J. MOWER & K. HILL

Summary

BRIEF COMMUNICATION

STUDIES ON SOUTHERN AUSTRALIAN ABALONE (GENUS *HALIOTIS*) IX. GROWTH OF *H. SCALARIS*

The non-commercial abalone *Haliotis scalaris* Leach is a common species occurring in a cryptic habitat under rocks in southern Australian coastal waters.[1] As part of long-term studies on the recruitment and survival of abalone[2] in this habitat at West Island, South Australia (35° 37'S; 138° 35'E) we describe here the growth rate of *H. scalaris* during the first four years of life. The earlier note[3] described the spawning cycle, recruitment and juvenile growth in the first year only of this species at West Island.

An underwater hand lens[2] was used to search for newly settled *H. scalaris* on a crustose coralline substratum on and under boulders mostly 20 × 30 cm diameter at the study site (extending over a distance of about 60 m) where previous studies were made.[3] Sampling was stratified spatially at 4 and 5 m depths in five sections of the site and twenty samples, each covering 0.25 m^2, were taken at each visit. Sampling consisted of measuring and recording the size of all abalone within a quadrat frame 0.25 m^2 in area. Diving time was about five hours per visit except that, on the October 1986 and December 1986–January 1987 visits, about 35 hours in all were spent searching for abalone.

The MIX interactive computer program[4] was used to separate modes of multimodal distributions and fit Gaussian component distributions with maximum likelihood techniques. Probability values exceeding 0.05 indicate statistically satisfactory fits. Some individuals were also tagged with small plastic tags fixed to the shell with superglue to verify the growth rate.

Length frequency distributions from under-boulder censuses from December 1984–January 1987 are given in Fig. 1; those obtained during 1983 and 1984 have been published previously.[3] There was a strong recruitment (i.e. numbers of individuals 1-5 mm long recorded) in 1983, a very weak recruitment in 1984 (only detected as individuals grew into larger size classes), a weak settlement in 1985 and a stronger one in 1986. The modes of length frequency distributions (Fig. 1) are plotted over time in Fig. 2, and the progression of the modes is taken to indicate the growth rate.

A linear regression by the least squares method was fitted to the modal means for all years combined, each modal mean being weighted by the reciprocal of its standard error. The regression equation of best fit is

$$L = 0.00854 + 0.0373A \ (R^2 = 0.98)$$

where L = length in mm and A = age in days. The standard error of the slope is 0.0009 and of the constant is 0.520. The mean growth rate of the successive cohorts (derived from the equation) is 1.13 mm per month (S.E. = 0.03 mm). The X- intercept (1 January) is a theoretical rather than a biologically realistic mean birth date. Earlier studies[3] suggest that settlement of the species occurs predominantly from January to June. If this is so, the growth rate in the first few months after settlement must be faster than that indicated above.

The mean growth rate of four tagged individuals (plotted in Fig. 2) is 1.12 mm per month (S.E. = 0.10 mm) which is not significantly different from the growth rate inferred from modal progressions. This growth rate is slower than that of *H. laevigata* in the same habitat,[5] but similar to numerous other species of abalone whose early growth has been examined.[6,7,8,9]

We are grateful to Jean Turner, P. S. Clarkson and C. H. Deane for diving assistance. Funds supporting the study came from Fishing Industry Research Trust Account (FIRTA).

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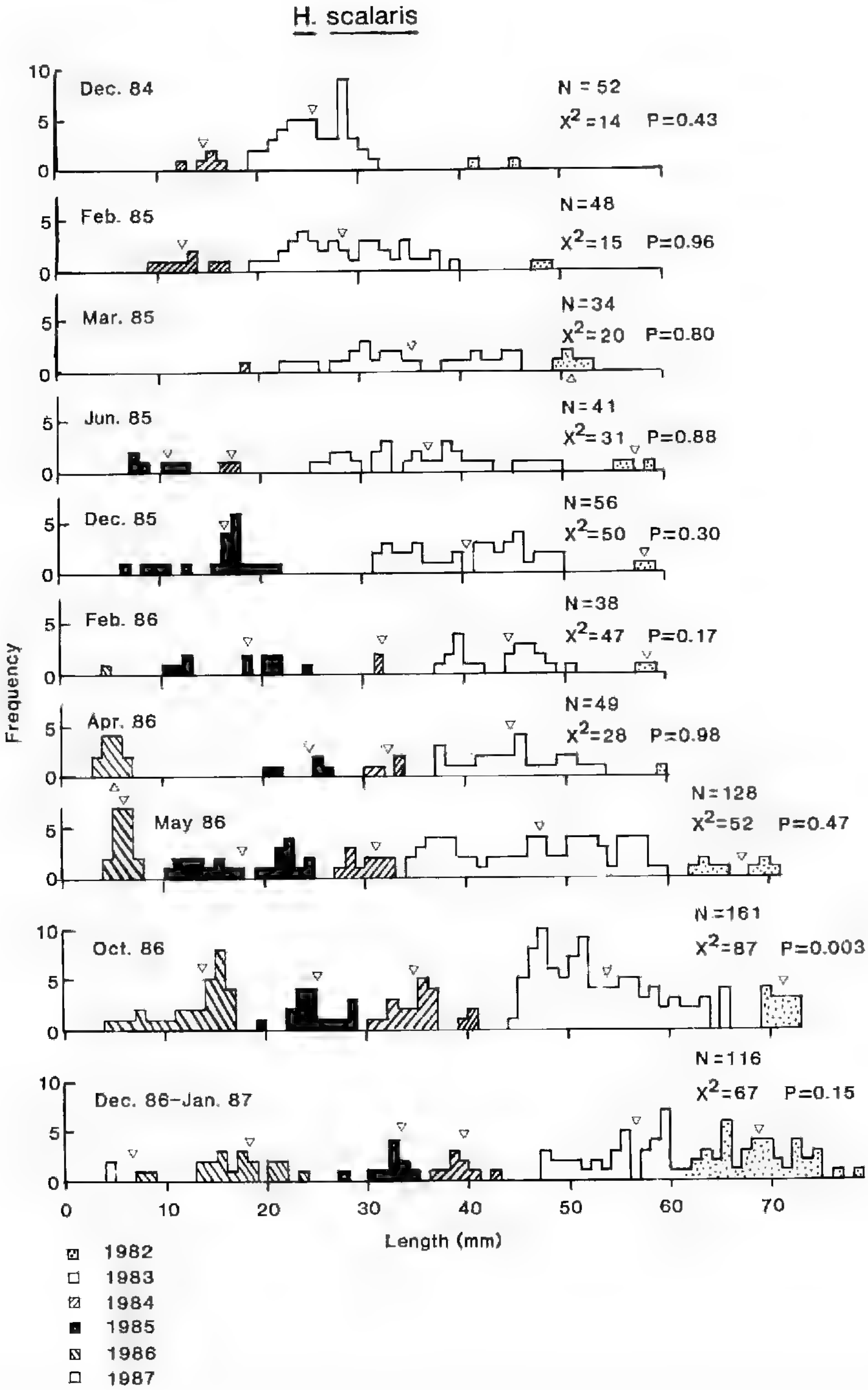

Fig. 1. Length frequency distributions of *H. scalaris* at West I. from December 1984 to January 1987. Triangles represent the position of the modes of the fitted Gaussian distributions. Annual cohorts are distinctively shaded.

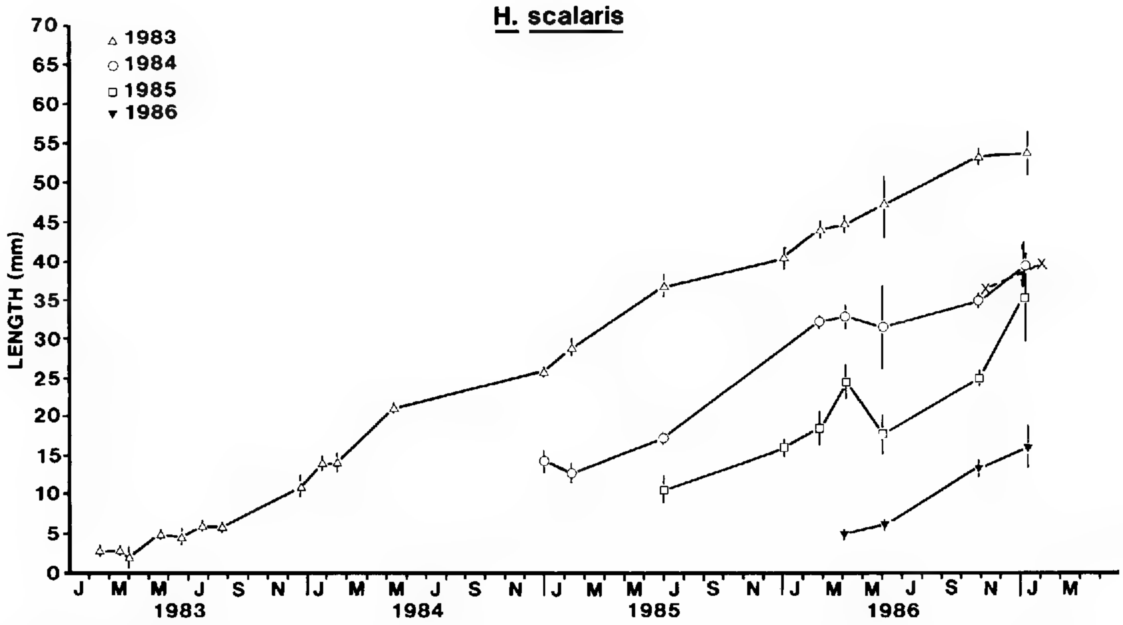

Fig. 2. Plots of modes (and standard errors) of annual cohorts from 1983 to 1986. The mean growth of tagged individuals is shown (x....x).

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30 NOVEMBER, 1988

Transactions of the
Royal Society of South Australia
Incorporated

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TRANSACTIONS OF THE

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

VOL. 112, PART 3

MOTILE MACROEPIFAUNA OF THE SEAGRASSES, *AMPHZBOLIS* AND *POSZDONZA*, AND UNVEGETATED SANDY SUBSTRATA IN HOLDFAST BAY, SOUTH AUSTRALIA

*BY V. N. SERGEEV, S. M. CLARKE & S. A. SHEPARD**

Summary

The motile macroepifauna was examined in stands of *Amphibolis antarctica,* in mixed stands of *Posidonia angustifolia* and *Posidonia sinuosa,* and in nearby unvegetated sand at two sites in Holdfast Bay, South Australia. In all, 178 species including 49 species of molluscs and 114 species of crustaceans were recorded in the three habitats. There were significantly more species at both sites, and significantly more individuals at one site, in vegetated than unvegetated substrata. Seagrass biomass was significantly and positively correlated with the number of species and number of individuals at the shallow site, but not at the deeper one. Seagrass biomass appears to be only one of a number of factors determining the structure of the macroepifaunal assemblage. Cluster analyses of samples show that the faunas of each habitat are distinct. Of the 25 most common species, 11 were significantly associated with *Amphibolis,* eight with *Posidonia,* and six were associated with vegetated as compared with unvegetated substrata, with which five were associated. Only harpacticoid copepods of the genus *Amphiascopsis* were non-selective. The habitat preferences of species appear to be a complex result of individual requirements for food and shelter.

KEY WORDS: macroepifauna, seagrasses, molluscs, crustaceans, *Posidonia, Amphibolis,* South Australia.

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SERGEEV, V. N., CLARKE, S. M. & SHEPHERD, S. A. (1988) Motile macroepifauna of seagrasses, *Amphibolis* and *Posidonia*, and unvegetated sandy substrata in Holdfast Bay, South Australia. *Trans. R. Soc. S. Aust.* **112**, 97–108, 30 November, 1988.

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KEY WORDS: macroepifauna, seagrasses, molluscs, crustaceans, *Posidonia*, *Amphibolis*, South Australia.

Introduction

Seagrasses are a conspicuous element in temperate Australian coastal waters (Larkum 1977; Womersley 1984) and especially important in the South Australian Gulfs where they form extensive meadows (Shepherd & Sprigg 1976; Shepherd 1983; Thomas & Clarke 1988) and might be expected to provide a large fraction of the total productivity (Mann 1982). Seagrasses also provide habitat, shelter and food for many mobile invertebrates which in turn are used as food by fish and other secondary consumers (Kikuchi 1974; Robertson 1980; Pollard 1984 and reviews by Virnstein 1987; Howard *et al.* 1988; Bell & Pollard 1988). Invertebrates are thus an important link in the trophic network in coastal seagrass communities. Because the seagrass beds in Holdfast Bay, South Australia have become seriously degraded (see Clarke 1987, and review by Shepherd *et al.* 1988) the consequences of such loss on higher trophic levels needs to be assessed.

This study was of a pilot nature and set out to describe the motile macroepifauna of two major seagrasses and unvegetated substrata, and so document the faunistic changes that might be expected to result from the decline of seagrasses in Holdfast Bay. The seagrasses were *Posidonia angustifolia* Cambridge & Kuo and *P. sinuosa* Cambridge & Kuo, which occur in mixed stands, and *Amphibolis antarctica* (Labillardiere) Sonder & Ascherson ex Ascherson. The unvegetated substrata were blowouts, which occur widely in these seagrass beds (Fig. 1 a). *P. angustifolia* and *P. sinuosa* are similar to each other morphologically, both having long narrow blades arising from a rhizome, and can be readily distinguished only by examination of the buried sheath or (microscopically) of the epidermal cells (Cambridge & Kuo 1979). *A. antarctica* is architecturally more complex with a tough cylindrical stem supporting an array of tufted leaves.

We examined the species composition and abundance of all taxa retained in a 1 × 0.5 mm mesh in vegetated areas over a range of seagrass biomass values and in unvegetated sandy areas in order to assess the importance of the structure and biomass of these seagrasses to the macroepifauna. In each case epifaunal, but not infaunal, taxa associated with the substratum were sampled.

Because the macroepifauna is highly mobile and might be expected to select an optimal habitat, based on seagrass architecture and density, and because survival may differ between habitats and within habitats according to seagrass density, differences in epifaunal species composition and abundance should disclose the net outcome of these two processes, i.e. habitat preferences and differential survival.

An important collateral aim of the study was to obtain a taxonomic reference collection of macroinvertebrate taxa associated with seagrass and unvegetated substrata in Holdfast Bay for use in later studies. Voucher specimens are lodged in the South Australian Museum. Except for the study of Watson *et al.* (1984) on *Heterozostera* this has not

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previously been attempted for southern Australian seagrasses.

Materials and Methods

Study Sites

Sites were selected in Holdfast Bay, S. Aust., where serious seagrass recession has occurred through expansion of blowouts and the effects of sewage sludge effluent (see Shepherd *et al.* 1988). One study area (Blowouts S1 and S2) was located 1.4 km off Henley Beach (34°55.5'S, 138°30'E) at 6–7 m depth (Fig. 2) where extensive mixed stands of *Posidonia angustifolia* and *P. sinuosa*, and smaller patches of *Amphibolis antarctica* surround blowouts. The second study area (Blowout S3), examined at a later date, was 2.6 km off Brighton (35°01'S, 138°31'E) at 10–11 m depth where *P. angustifolia* is dominant and *A. antarctica* occurs only in small patches. The former area was chosen because it was considered to be representative of seagrass habitats in Holdfast Bay; this judgement was based on extensive sampling during comprehensive studies of seagrass-sediment dynamics of Holdfast Bay (Clarke 1987; Thomas & Clarke 1988). The latter area was near the maximum depth of seagrass and was chosen to maximise contrast with the former, and so test the applicability of the earlier results to a deeper seagrass habitat.

Fig. 1. (a) Aerial photograph at Brighton in Holdfast Bay showing blowouts in seagrass beds. Bar scale 500m. (b) Diver sampling unvegetated substratum in a blowout. (c) Oblique view of *Amphibolis* bed. (d) Oblique view of *Posidonia* bed.

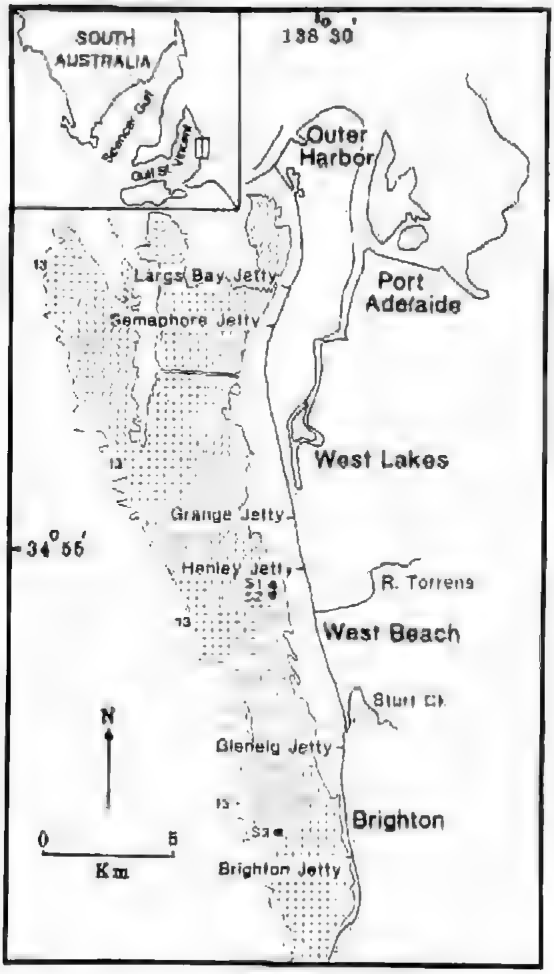

Fig. 2. Holdfast Bay, South Australia showing study sites and seagrass distribution.

A 25 × 25 cm quadrat frame attached to the open end of a plankton net of mesh size 1 × 0.5 mm and enclosing a volume of 40 litres was used for sampling. The net was secured to the quadrat by a lace and unfolded only when the quadrat was rapidly thrust downwards to the seabed during the sampling operation (Fig. 1 b, c, d). All samples, both in vegetated and unvegetated areas, were taken about 5m from the seagrass-sand boundary of the blowout being investigated, in order to avoid possible 'edge effects'.

In the seagrass samples, the seagrass was cut off at sand level with shears operated from outside the net. After the sample was taken, the net was released from the quadrat, the surficial sediment was manually disturbed to a depth of 1–2 cm in order to expel sheltering animals into the water column, the opening tied shut, and the net and contents sealed in a plastic bag. The technique is similar to that described by Ledoyer (1962) and used by Scipione & Fresi (1984), Virnstein *et al.* (1984) and others.

At the Henley Beach site six replicate samples were taken in each of three habitats (unvegetated sand, *Posidonia* and *Amphibolis*) at two blowouts (S1, S2) giving 36 samples in all. At Brighton eight replicates were taken in the same three habitats at one blowout (S3) giving 24 samples.

Samples, including the surficial sediment and any detritus, were preserved in 10% formalin and seawater and later hand-sorted to remove all animals. The seagrass in each sample was weighed after removal of excess water, and animals were identified to the lowest possible taxon and species' abundances per quadrat tabulated. Sampling was done at about noon, in March 1985 at S1 and S2 and in November 1985 at S3.

Only the motile macroepifauna is considered here. Bryozoans, foraminiferans, hydroids and polychaetes, and meiofaunal species not adequately retained by the mesh, are excluded.

Analyses

Data for the two sites cannot be compared directly due to differences in depth and time of sampling and in locality, and are analysed separately.

A cluster analysis of species' abundances per quadrat was performed on the data from each site. After a log (N + 1) transformation of the data the Euclidean distance measure of similarity and the group average sorting strategy were used to achieve clustering of quadrat data (see Clifford & Stephenson 1985; Field *et al.* 1982).

Data on number of species and number of individuals were examined by analysis of variance (ANOVA). Where the variances are heterogeneous, as disclosed by a Cochran C-test, data were transformed to achieve homogeneity. A Student – Newman – Keuls (SNK) test was then used to detect significant differences between individual means. Cluster analyses, ANOVAs and least squares regressions were performed with the Biostat computer package (R. A. Pimental & J. D. Smith 1985. Sigma Soft Placentia, California).

Results

Community Totals

In all, 7124 individuals divided among 178 species were obtained in the two vegetated habitats (*Amphibolis* and *Posidonia*) and in unvegetated sand. There were 49 species of molluscs, 114 species of crustaceans (59 amphipods, 19 isopods, 13 decapods, five mysids, ten copepods and eight ostracods), seven species of pycnogonids and eight species of echinoderms. The species with authorities are listed in Table 1.

Analyses of variance show that the number of species differs significantly between seagrass habitat and unvegetated sand at both sites (Tables 2, 3). At the Henley Beach site there is no significant difference (P>0.05) between the two blowouts (S1, S2). There are significantly fewer species in unvegetated sand than in seagrass at both sites, but no significant difference in number of species between the two seagrasses (Table 3). Overall, there are fewer species of molluscs than of arthropods in seagrass, except that at Brighton there is little difference in the number of species of mollusc between unvegetated sand and *Posidonia* (Fig. 3).

The two sites do not give a consistent picture in the variation in number of individuals per sample in relation to habitat. At Henley Beach there is no significant (P>0.05) difference between any habitat, but at Brighton there are significantly fewer individuals in *Posidonia* and sand than in *Amphibolis*. (Table 3).

Next we examined by regression analysis the role of seagrass biomass as a factor influencing the number of species and of individuals per sample. Significant linear regressions relating number of species and individuals with *Posidonia* and *Amphibolis* biomass respectively are given in Table 4 for Henley Beach. Here the number of species in *Posidonia* and both number of species and individuals in *Amphibolis* are significantly related to biomass; at Brighton there are no significant regressions.

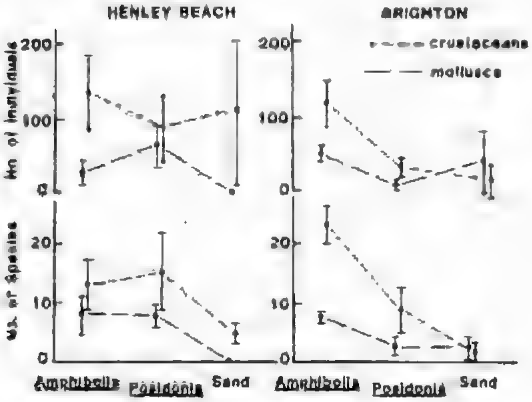

Fig. 3. Mean number of individuals and species of crustaceans and molluscs per sample in three habitats, (*Amphibolis, Posidonia* and unvegetated sand) at Henley Beach and Brighton. Vertical bars are standard errors.

Habitat differences

Dendrograms of sample classifications using species abundances as attributes (Fig. 4) show that, with minor exceptions, the vegetated habitats, *Posidonia* and *Amphibolis*, and unvegetated sand separate out at relative similarities of less than 42%, indicating faunistic coherence within, and substantial dissimilarity between, habitats. At Henley Beach, the epifaunas of *Posidonia* and *Amphibolis* are relatively distinct and more similar to each other than either is to sand, whereas at Brighton there is greater similarity between the fauna of unvegetated sand and *Posidonia*. In fact one *Posidonia* sample was more similar to sand samples than to other *Posidonia* samples, due to the absence of the harpacticoid *Porcellidium* sp which was generally common in seagrasses but rare in sand (Table 5).

Pie diagrams (Fig. 4) show the mean relative abundances of molluscs and arthropods for each habitat; they indicate strong dominance by a few species with a very large number of rare species. The 25 most common species (i.e. those with mean relative abundance per habitat of >5%) differ significantly in their absolute abundances between the three habitats, and are categorised according to their apparent preferences (Table 4). Eleven of the 25 species are more abundant in *Amphibolis*, two species are more abundant in *Posidonia*, and six species are more abundant in both seagrasses without distinction between them. Only the harpacticoid *Amphiascopsis* spp are indifferent to habitat; but this has little significance since several taxa may be included.

There are very marked differences between the faunas of the two sites, Henley Beach and Brighton. Fourteen of the 25 most common species, and 76% of all species occur only at one site.

Unvegetated blowouts have a characteristic fauna which differs between the two sites. At Henley Beach the amphipod *Guernia* cf *gelane* and the ostracod *Cypridinodes galatheae* are dominant, and at Brighton the minute gastropod *Lissotesta contabulata*, the harpacticoid *Amphiascopsis* spp, the mysid *Leptomysis australis*, the tanaid *Leptochelia ignota* and the sea-star *Allostichaster polyplax* are co-dominant (Fig. 4).

Discussion

Despite the very limited sampling program that could be carried out in this study, some comparison can still be made with the species richness of seagrass epifauna elsewhere. Virnstein *et al.* (1984) have assembled comparative data on species abundances of amphipods, isopods and decapods in

TABLE 1. *List of species with authorities obtained in the study.*

Phylum MOLLUSCA	
Class GASTROPODA	
Trochidae	*Badepyrus pupoides* (Adams)
	Thalotia conica (Gray)
	Cantharidus irisodontes (Quoy & Gaimard)
	Cantharidus bellulus (Dunker)
	Cantharidus apicinus (Menke)
	Nanula sp.
	Calliostoma sp.
	Calliostoma legrandi (Tenison Woods)
	Calliostoma hedleyi Pritchard & Gatliff
	Callistele calliston (Verco)
	Ethminolia elveri Cotton & Godfrey
Fissurellidae	*Macroschisma tasmaniae* Sowerby
	Notoacmea flammea (Quoy & Gaimard)
Liotiidae	*Argalista* sp.
	Lissotesta contabulata Tate
Patellidae	*Patella (Scutellastra) peronii* Blainville
Phasianellidae	*Phasianella australis* (Gmelin)
Turritellidae	*Gazameda iredalei* Finlay
Epitoniidae	*Acutiscala minora* Iredale
Calyptraeidae	*Calyptraea calyptraeformis* (Lamarck)
Melanellidae	*Curveulima indiscreta* (Tate)
Potamididae	*Batillaria bivaricata* Ludbrook
	Batillaria diemenensis (Quoy & Gaimard)
Cymatiidae	*Cymatiella gaimardi* Iredale
Vermetidae	*Tenagodus weldii* Tenison Woods
Columbellidae	*Mitrella acuminata* (Menke)
Olividae	*Oliva australis* Duclos
Fasciolariidae	*Microcolus dunkeri* (Jonas)
Pyrenidae	*Macrozafra atkinsoni* (Tenison Woods)
Nassariidae	*Niotha pyrrhus* (Menke)
Triphoridae	*Hedleytriphora scitula* (A. Adams)
Muricidae	*Bedeva paivae* (Crosse)
	Lepsiella flindersi (Adams & Angas)
Buccinidae	*Cominella eburnea* (Reeve)
Triphoridae	*Obesula albovittata* (Hedley)
Pyramidellidae	*Congulina* sp.
	Pyrgiscus sp.
	Chemnitzia mariae (Tenison Woods)
	Odostomia sp.
Scaphandridae	*Acteocina fusiformis* (A. Adams)
Class BIVALVIA	
Glycymeridae	*Glycymeris radians* (Lamarck)
Mytilidae	*Musculus paulucciae* Crosse
	Trichomusculus penetectus (Verco)
Pteriidae	*Electroma georgiana* (Quoy & Gaimard)
Veneridae	*Tawera lagopus* (Lamarck)
Psammobiidae	*Gari brazieri* Tate
Class AMPHINEURA	
Ischnochitonidae	*Stenochiton cymodocealis* Ashby
	Stenochiton pilsbryanus Bednall
Class CEPHALOPODA	
Idiosepiidae	*Idiosepius notoides* Berry
Phylum CRUSTACEA	
Amphipoda	
Corophiidae	*Corophium* sp.1
	Corophium sp.2
	Corophium sp.3
	Corophium sp.4
	Ericthonius sp.
Ochlesidae	*Ochlesis eridunda* Barnard
Cypriodeinae	*Austropheonoides mundoe* Barnard
	Cyproidea ornata Haswell
	Naeapheonoides mullaya Barnard

Caprellidae	*Caprella scaura* (Templeton)
	Caprella danilevskii (Czerniavskii)
	Paraproto spinosa (Haswell)
Corophilidae	*Cerapus abdictus* (Templeton)
Prophliantinae	*Guernea* c.f. *gelane* Barnard
Liljeborgiidae	*Liljeborgia* sp.
Phoxocephalidae	*Brolgus tattersalli* (Barnard)
	Cunmurra itickerus Barnard
	Matong matong Barnard
	Birubius sp.1
	Birubius sp.2
	Birubius wirakus Barnard
	Birubius c.f. *chintoo* Barnard
	Booranus wangoorus Barnard
Haustoridae	*Urohaustorius* sp.
	Urothoides sp.
Dexaminidae	*Paradexamine goomai* Barnard
	Paradexamine c.f. *guarallia* Barnard
	Paradexamine thadalee Barnard
	Paradexamine c.f. *windarra* Barnard
	Paradexamine frinsdorfi Sheard
	Paradexamine moorhousei Sheard
	Paradexamine sp.
	Atylus homochir Haswell
Lysianassidae	*Amaryllis macrophthalma* Haswell
	Tryphosella orana Barnard
	Tryphosella spp.
	Parawaldeckia spp.
	Parawaldeckia stebbingi (Thomson)
	Parawaldeckia yamba Barnard
Gammaridae	*Maera viridis* Haswell
	Ceradocus sp.
	Mallacoota carteta Barnard
	Mallacoota subcarinata Haswell
Ampithoidae	*Cymadusa variata* Sheard
	Cymadusa filosa Savigny
Leucothoidae	*Leucothoe commensalis* Haswell
	Leucothoe sp.
Amphilochidae	*Gitanopsis* sp.
Aoridae	*Aora typica* Kroyer
Atylidae	*Atylus* sp.
Eusiridae	*Tethygeneia megalophthalma* (Haswell)
	Tethygeneia sp.
Phliantidae	sp.1
Podoceridae	*Podocerus* sp.
Stenothoidae	*Ausatelson kolle* Barnard
	Ausatelson ule Barnard
Serolidae	*Serolis levidorata* Harrison & Poore
	Serolina delavia Poore
Isopoda	
Sphaeromatidae	sp.1
	Exosphaeroma sp.1
	Exosphaeroma sp.2
	Dynamenella sp.
	Dynamenella parva (Baker)
	Pseudocerceis c.f. *trilobata* Baker
	Haswelia emarginata Haswell
	Cymodoce coronata Haswell
Cymothoidae	*Cirolana* sp.
	n.gen. n.sp. (see Baker 1926, p. 279, Pl. XLVII)
Anthuridae	*Paranthura punctata* (Stimpson)
	Accalathura sp.
	Paranthura sp.
	n.gen. n.sp.
Janiridae	sp.1
Jaeropsidae	*Jaeropsis* sp.
Arcturidae	*Neastacilla* sp.
	Neastacilla deducta (Hall)

Idoteidae	*Crabyzos longicaudatus* (S. Bate)
Tanaidacea	
Tanaidae	*Leptochelia ignota* (Chilton)
Decapoda	
Hymenosomatidae	*Halicarcinus ovatus* (Stimpson)
Crangonidae	*Pontophilus intermedius* (Fulton & Grant)
Pandalidae	*Parapandalius leptorhynchus* (Stimpson)
	Crangon sp.
Hippolytidae	*Hippolyte* sp.
	Hippolyte tenuirostris (S. Bate)
	Hyppolyte australiensis (Stimpson)
	Latreutes compressus (Stimpson)
	Latreutes sp.
Processidae	*Processa* sp.
Paguridae	*Paguristes* sp.
Penaeidae	*Peneus* sp.
Majidae	*Naxia aries* (Guerin)
Mysidacea	
Mysidae	*Australomysis acuta* (Tattersall)
	Australomysis incisa G.O. Sars
	Afromysis australiensis (Tattersall)
	Gastrosaccus indicus (Hansen)
	Leptomysis australiensis (Tattersall)
Class COPEPODA	Calanoida
Pseudodioptomidae	sp.1
Harpacticoida	
Porcellidiidae	*Porcellidium* sp.
	Amphiascopsis spp.
Harpacticidae	n.sp.
Laophontidae	sp.1
Cumacea	
Bodotriidae	*Cyclapsis* sp.
	Leptocuma sp.
	Sympodomma bakeri Hale
Dastyliidae	*Anchicolurus waitei* (Hale)
Nannastacidae	*Cumella laeve* Calman
Class OSTRACODA	
Nebaliacea	*Paranebalia longipes* (Sars)
Myodocopida	*Cypridinodes* c.f. *galathea* Poulsen
	Alteratochelata c.f. *lizardensis* Kornicker
	Vargula sp.
Cylindroleberididae	sp.1
	Lowoleberis sp.
Podocopida	*Xestoleberis* sp.
	Neonesidae sp.
Phylum CHELICERATA	
Class PYCNOGONIDA	
Ammotheidae	*Ascorhynchus longicollis* (Haswell)
	Achelia sp.1
	Achelia sp. nov.
Callipallenidae	*Callipallene* sp.
	Callipallene emaciata (Dohrn)
	Pseudopallene sp.
	Propallene sp. nov.
Phylum ECHINODERMATA	
Class ECHINOIDEA	
Temnopleuridae	*Amblypneustes ovum* (Lamarck)
Class CRINOIDEA	
Aporometridae	*Aporometra wilsoni* (Bell)
Class ASTEROIDEA	
Asteriidae	*Uniophora granifera* (Lamarck)
	Allostichaster polyplax (Muller & Troschel)
Class OPHIUROIDEA	
Ophionereididae	*Ophionereis schayeri* Muller & Troschel

	Ophiopeza assimilis Bell
	Ophiocomina australis H. L. Clark
Ophiacanthidae	*Ophiacantha alternata* A. M. Clark

TABLE 2. *Analyses of variance testing differences in number of species and individuals per sample at Henley Beach and Brighton sites. *** P<0.001; n.s. P> 0.05.*

HENLEY BEACH

	No. of species				No. of individuals	
(a)	d.f.	MS	F	(b)	MS	F
Location(L)	1	0.78	1.84 n.s.		6346.8	1.11 n.s.
Habitat(H)	2	4.39	10.36 ***		4176.9	0.73 n.s.
L × H	2	19.95	47.05 ***		11348.4	1.99 n.s.
Error	30	0.42			5718.0	

BRIGHTON

	No. of species			No. of individuals	
	d.f.	MS	F	MS	F
Habitat	2	1493	128 ***	44332	42.4 ***
Error	21	12		1045	

TABLE 3. *Mean number of species and individuals per sample in three habitats at the Henley Beach and Brighton sites. Standard errors in brackets. 'a' indicates no significant (P>0.05) difference by SNK test.*

	HENLEY BEACH		BRIGHTON
Species	Blowout S1	Blowout S2	Blowout S3
Amphibolis	23.0 (3.0) a	21.3 (1.3) a	30.5 (1.1)
Posidonia	29.2 (3.4) a	22.8 (3.6) a	11.5 (1.5)
sand	6.5 (1.0)	5.5 (0.6)	4.0 (1.0)
Individuals			
Amphibolis	151.2 (29.9) a	168.2 (18.3) a	170.1(10.5)
Posidonia	178.8 (30.0) a	136.0 (25.6) a	35.2 (5.7) a
sand	166.0 (42.7) a	81.7 (33.3) a	47.8 (16.0) a

TABLE 4. *Regression equations of number of species (S) and number of individuals (I) per sample against wet weight (W) in grams of* Posidonia *and* Amphibolis *in samples at Henley Beach. (* P<0.05; ** P< 0.01; n.s. P>0.05). In each regression sample size is 12.*

		Equation	R^2
Species	*Posidonia*	$S = 10.6 + 0.35\ W$	0.39*
	Amphibolis	$S = 17.2 + 0.03\ W$	0.08 n.s.
Individuals	*Posidonia*	$I = 3.9 + 3.5\ W$	0.62**
	Amphibolis	$I = 44.5 + 0.76\ W$	0.46*

seagrasses at various latitudes. Judged against this compilation, the mean number of species recorded in vegetated substrata per site for amphipods (36 species) and isopods (10 species) is higher, and that of decapods (8.5 species) is lower compared with other locations at about the same latitude (35°). Similar comparisons for molluscs are not available because of lack of uniformity in method of collecting in different places. However, Ledoyer (1966) recorded similar numbers of molluscan species in seagrass to those given here. Overall, the species richness of the epifauna in these seagrasses in Holdfast Bay is comparable with that of the Mediterranean *Posidonia oceanica* (Ledoyer 1966) which is notably rich in species (see Virnstein *et al.* 1984). The number of species of macroepifauna in *Heterozostera* in much shallower water in Victoria (Watson *et al.* 1984) is much lower than that recorded in this study.

The faunistic coherence of habitats and the significant differences in abundance of common species between habitats suggest that there are strong associations between many epifaunal species and habitat. Two causes of these associations – species' requirements for food and for shelter – are of recognized importance.

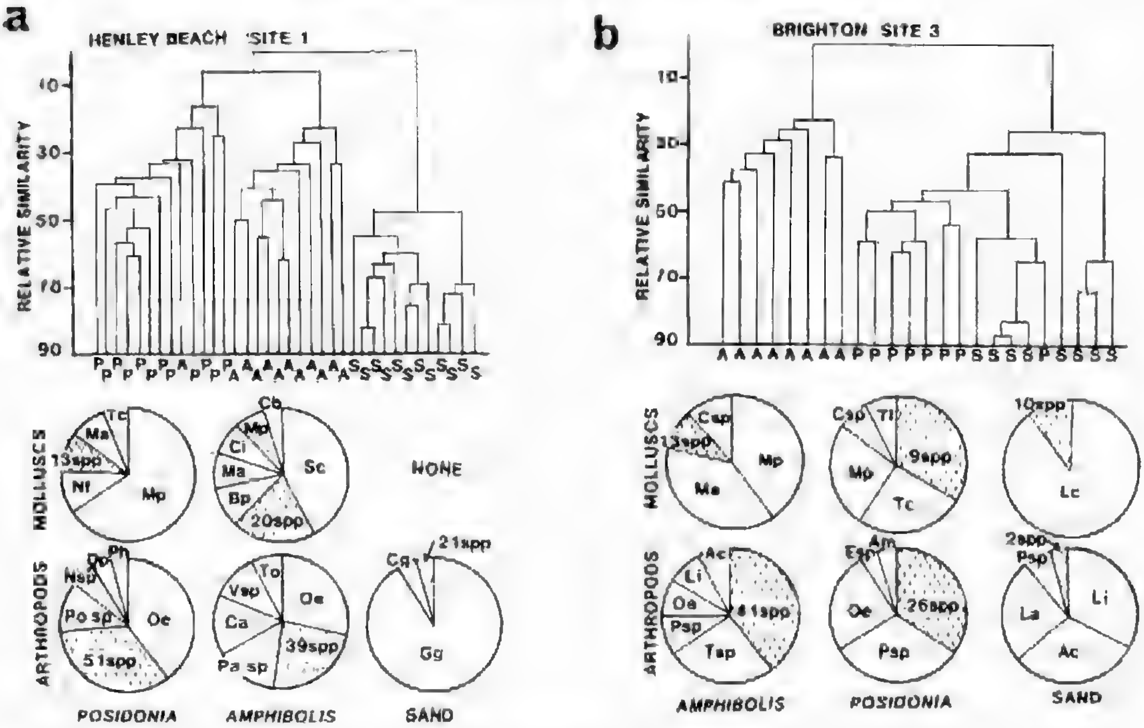

Fig. 4. Dendrograms of sample classifications for (a) Henley Beach and (b) Brighton sites, and pie diagrams of relative mean abundances of most common molluscs and arthropods in three habitats, *Amphibolis*, *Posidonia* and unvegetated sand. The key to species' abbreviations is given in Table 5.

The food requirements of species are apparent for many molluscs e.g. archaeogastropods which graze on macro- or micro-algae on seagrass blades, and mesogastropods and neogastropods which are variously detritivores, carnivores or suspension feeders (Ludbrook & Gowlett-Holmes 1988). A few species are host-specific, such as the two species of *Stenochiton* (*S. pilsbryanus* on *Posidonia* and *S. cymodoceulis* on *Amphibolis*), or have strict microhabitat requirements such as *Musculus paulucciae*, which occurs in the basal interstices between seagrass blades

Similarly, many amphipods, isopods and decapods feed on seagrass epiphytes or detritus (Zimmerman *et al.* 1979; Howard 1982, 1984; Watson *et al.* 1984), and pycnogonids and some decapods are predators of smaller invertebrates (Howard 1984; Staples[1]. These species are presumably linked to seagrass habitats where their food is more abundant.

The requirement for shelter in which plant architecture, biomass, surface area and density have each been emphasized (see Homziak *et al.* 1982; Stoner 1982, 1983; Lewis 1984; review by Orth *et al.* 1984; Virnstein & Howard 1987 a, b), may also contribute to the observed association between species and habitat. However our data do not allow (nor was the purpose of this study) to distinguish between the requirements for food and shelter or assess the relative importance of each. The existence of simple linear relations between measures of plant abundance and numbers of species or individuals is consistent with hypotheses of requirements for either food or shelter. But such relations may often be obscured by the existence of threshold effects or other complicating biological or physical factors (Orth *et al.* 1984). The shallower Henley Beach site shows linear relations in three out of four cases but the deeper Brighton site shows none. The likely presence at the Brighton site of organic matter in surface sediments, as suggested by the large number of detrital feeding organisms (e.g. *Lissotesta* and *Leptomysis*) in the samples from unvegetated sand, could blur such relations even if they existed. However the differences between the two sites could also be due to other factors related to depth, time of year, or simply a function of the sites themselves.

Patches of bare sand in blowouts are continuing to expand in Holdfast Bay from numerous

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[1] Staples D. A. Sea spiders or Pycnogonids. Unpublished ms.

TABLE 5. *Mean abundances per sample of the 25 most common species in* Amphibolis *(A),* Posidonia *(P) and unvegetated sand (S) at Henley Beach (H) and Brighton (B). Data for Henley Beach are for Sites 1 and 2 combined. No reference to a habitat indicates zero abundance. Probability values are from t tests. (*$P<0.05$; **$P<0.01$; ***$P>0.001$). Species are listed in four ecological groups according to apparent habitat preferences. Abbreviations of species are those given in Fig. 4.*

Species	*Abbreviation*
Amphibolis preferring	
MOLLUSCA	
Cantharidus irisodontes A 2.3, P 0.3** (H,B)	Ci
Cantharidus bellulus A 1.4 (H,B)	Cb
Bedeva paivae A 2.8 (H,B)	Bp
Cingulina sp A 4.6, S 0.5* (B)	C sp
Stenochiton cymodocealis A 13 (H)	Sc
CRUSTACEA	
Cerapus abdictus A 13.8, P1.3* (H,B)	Ca
Tryphosella orana A 12.2, P 0.5* (H)	To
Parawaldeckia sp A 22.9 (H)	Psp
Tethygeneia sp A 11.6, P 0.8** (H,B)	Tsp
Leptochelia ignota A 5.5, P 0.5, S 1.2 A–S* A P* (H,B)	Li
Vargula sp A 17.7 (H)	Vsp
Posidonia preferring	
MOLLUSCA	
Notoacmaea flammea P 9.5 (H)	Nf
CRUSTACEA	
Neonesidea sp P 4.8, A 0.7* (H)	Nsp
Preferring vegetated substrata (V) (combining data for Amphibolis *and* Posidonia*) to unvegetated sand (S)*	
MOLLUSCA	
Thalotia conica V 3.8 (H,B)	Tc
Macrozafra atkinsoni V 6.4, S 0.2** (H,B)	Ma
Musculus paulucciae V 17.8 (H,B)	Mp
CRUSTACEA	
Erichthonius sp V 2.40 (B)	Esp
Ochlesis eridunda V 25.7, S 0.3*** (H,B)	Oe
Porcellidium sp V 8.1, S 0.4* (H,B)	Psp
Sand - preferring	
MOLLUSCA	
Lissotesta contabulata S 32.1 (B)	Lc
CRUSTACEA	
Guernia cf gelane P 1.1, S 93.9** (H)	Gg
Leptomysis australiensis S 2.3 (B)	La
Cypridinodes cf galatheae A 0.5, P 2.5, S 7.3, P–S** A–S** (H)	Cg
ECHINODERMATA	
Allostichaster polyplax P 0.7, S 11.8* (H)	
Non–selective	
CRUSTACEA	
Amphiascopsis spp A 7.9, P 1.1, S 2.9 ns (B)	Ac

man-related and other causes (Clarke & Thomas in press). Immediate effects of seagrass loss on the epifauna are probably reflected in the differences we observed between the complex epifaunal assemblage in seagrasses and the quite different sand-dwelling assemblage. Longer term effects due to loss of organic production are likely to entail widespread and serious declines in numbers of individuals and species of the epifauna that is trophically dependent on seagrass, its epiphytes or its detritus, and of fish and other secondary consumers that in turn depend for food on the epifauna.

Acknowledgments

We thank C. H. Deane, A. Dalgetty and N. Holmes for assistance in the field and office. Drs N. Ludbrook (molluscs), A. N. Baker (ophiuroids), G. C. B. Poore (crustaceans), D. Staples (pycnogonids), S. J. Hall and C. Bartley (ostracods), and R. Hamond (harpacticoids) each gave valued taxonomic advice or determinations within their specialties. Dr A. J. Butler and an anonymous referee constructively criticised the manuscript. Funds for the study were provided by the Commonwealth Department of Employment and Industrial Relations and the South Australian Department of Labour (Community Employment Programme).

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A NEW SPECIES OF URACANTHUS (COLEOPTERA: CERAMBYCIDAE): A PEST ON ORNAMENTAL CYPRESSES IN THE ADELAIDE REGION

*BY S. A. RONDONUWU**† *& A. D. AUSTIN**

Summary

A new species of cerambycid beetle from South Australia is described, based on both sexes of the adult and all immature stages. *Uracanthus cupressianus* sp. nov. causes damage to cypresses, *Cupressus* spp., planted as ornamental trees in parks and gardens around Adelaide. Notes on *Uracanthus* are provided, and the relationships and biology of *U. cupressianus* sp. nov. are discussed.

KEY WORDS: Coleoptera, Cerambycidae, *Uracanthus cupressianus* sp. nov., *Cupressus* spp.

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Summary

RONDONUWU, S. A. & AUSTIN, A. D. (1988) A new species of *Uracanthus* (Coleoptera: Cerambycidae): a pest on ornamental cypresses in the Adelaide Region. *Trans. R. Soc. S. Aust.* 112([illegible]), 109–117, 30 November, 1988.

A new species of cerambycid beetle from South Australia is described, based on both sexes of the adult and all immature stages. *Uracanthus cupressianus* sp. nov. causes damage to cypresses, *Cupressus* spp., planted as ornamental trees in parks and gardens around Adelaide. Notes on *Uracanthus* are provided, and the relationships and biology of *U. cupressianus* sp. nov. are discussed.

KEY WORDS: Coleoptera, Cerambycidae, *Uracanthus cupressianus* sp. nov., *Cupressus* spp.

Introduction

In Australia the Family Cerambycidae is represented by almost 1000 described species (McKeown 1947), many of which have been recorded as causing damage to native trees grown for timber, wind-breaks or as ornamentals. However, the taxonomy of the family in this country has received virtually no attention in the last 30 years, even though the group is of significant importance to the ecology of trees and shrubs in natural habitats and in commercial situations (Linsley 1959).

Recently one of us (SAR) completed an extensive project on the biology and ecology of a species of *Uracanthus* which causes substantial damage to ornamental cypresses, particularly *Cupressus sempervirens* L. (Cupressaceae) in the Adelaide region. The members of this Australian genus were described prior to 1950 and are dealt with in the works of Lea (1916, 1917), McKeown (1938, 1940, 1942, 1947, 1948) and Duffy (1963). The only key to species is that presented in Lea (1916), which covers 22 of the 37 known species. In this work our species runs to either *U. acutus* Blackburn or *U. discicollis* Lea, but is quite different from these species in a number of characters (see below). To ensure that we had an undescribed species we borrowed all available holotypes, and examined the *Uracanthus* holdings in the South Australian Museum, Australian National Insect Collection and the Waite Institute Insect Collection (see Table 1). Our comparisons using this material showed that the species we had reared from branches of *C. sempervirens* in the Adelaide region was substantially different in many important characters to all other species and, accordingly, should be considered as new.

In this paper we describe the species, discuss its intrageneric relationships, and provide brief notes on its biology. A detailed account of the ecology, behaviour and interaction with the main host tree will be presented elsewhere. Although we examined other species in the genus (Table 1), we cannot provide a comprehensive key because of unresolved intraspecific variability in some taxa. However, we indicate where these problems lie and what characters may prove useful in resolving them.

Methods

Larval stages were obtained from infested twigs of *C. sempervirens* collected from Adelaide suburbs during 1986. They were either fixed and preserved in 80% alcohol or reared through to adults in the laboratory. Male genitalia and cuticular structures from larvae were dissected out, soaked in 10% KOH (4–6 hrs), placed in 10% acetic acid (15 mins), dehydrated, and either permanently mounted on slides in Berlese's fluid or temporarily mounted in glycerol. Adult reproductive systems were drawn from freshly killed specimens dissected under Ringer's solution. Descriptions of the larval stages were compiled from freshly killed specimens examined under 80% alcohol, except for sculpturing and pilosity characters which were examined by firstly drying specimens on filter paper.

The morphological terms used follow Duffy (1953, 1957, 1960, 1963), Torre-Bueno (1962), Eady (1968) and Harris (1979). Abbreviations for institutions are: ANIC, Australian National Insect Collection, CSIRO, Canberra; AM, Australian Museum, Sydney; BMNH, British Museum (Natural History), London; MV, Museum of Victoria, Melbourne; NRS, Natural History Museum, Stockholm; SAM, South Australian Museum, Adelaide; HMO, Hope Museum, Oxford;

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WAM, Western Australian Museum, Perth; WARI, Waite Agricultural Research Institute, Adelaide.

Genus *Uracanthus* Hope

A complete bibliography to the genus is provided by McKeown (1947).

Comments

The Australian Uracanthini is in urgent need of revision. There are seven genera, none of which is well characterized: the most recent works by Lea, McKeown only provide descriptions of new species. A key to some genera is given by Lea (1916) and a more extensive generic key is presented by Rondonuwu (1988[1]). *Uracanthus* is closest to *Scolecobrothus* Hope, differing only in the latter having 12-segmented antennae, segments 11 and 12 fully articulated, and the distal nine segments dentate or serrate along one side. In *Uracanthus* the antennae are 11-segmented. Segment 11 is sometimes divided by a suture but the two parts are never articulated, and the distal nine segments are cylindrical or subcylindrical.

We found a number of characters to be more variable than indicated in Lea's and McKeown's work, undoubtedly because they based their species' descriptions on very few specimens. Shape of elytral apices, surface sculpturing, pilosity and body size varied in many species and, although these characters will remain important in delimiting species, their range of variation will need to be documented in any future revisionary work. Characters we found useful at the species level were the structure of the male genitalia, the proximity of the eyes on the ventral head and the shape and length of the antennae. Such characters may help resolve the problem surrounding the *U. triangularis* Hope complex, which includes three varieties (Var. A, B and C) designated by Lea (1916) on the basis of differences in pilosity.

For nearly all known species of *Uracanthus* only descriptions of the adult stage are given, usually of the male. Duffy (1963) is the only author who has provided any information on immature stages, and then only for the final instar larva of three species, viz. *U. triangularis*, *U. cryptophagus* Olliff. and *U. pallens* Hope. We present here a description of all life-history stages for the new species and have used Duffy (1953, 1957, 1960, 1963) as a guide in trying to limit the description of non-adult stages to characters of specific value only.

Uracanthus cupressianus sp. nov.
FIGS 1–20

Holotype: ♂, SAM, Glenelg, South Australia, reared ex *Cupressus sempervirens*, 5.x.1986, S. Rondonuwu. Paratypes: adults - 27 ♂, 26 ♀, genitalia of 5 ♂ in glycerine capsules, same data as holotype except for some with different collecting dates; 3 ♂, 3 ♀, SAM; 21 ♂, 20 ♀, 5 ♂ genitalia preparations, WARI; 3 ♂, 3 ♀, ANIC.

Adult Male

Size (holotype). Length 13.8 mm, width across anterior part of elytra 3.1 mm (also see Table 2).

Colour. Generally reddish brown; head, proximal antennal segments, pronotum and femora usually darker than elytra; almost entire body covered with dense even pilosity of short hairs giving golden sheen appearance over surface.

Head. Lower face (from lower eye to tip of closed mandibles) about as long as wide, lateral margins converging ventrally only slightly; clypeus flat or slightly convex, sparsely punctate, sparsely pilose, dorsal margin triangular, bounded by deep sutures; medial impressed line deep and glabrous, extending posteriorly to point just behind eyes; antennal sockets raised well above surface of frons on high cone-like protuberances which are moderately narrow at apex; frons and dorsal parts of genae coarsely punctate but punctures mostly hidden by pilosity; lateral and ventral part of head mostly glabrous; lateral part sparsely punctate, ventral headpart with very coarse transverse striae; eyes coarsely facetted, broadly separated in ventral aspect by about half width of head (measured across posterior margin); antennae (Fig. 1) shorter than body, 11-segmented, sometimes segment 11 divided by feeble suture (i.e. appearing 2-segmented), segments 3-11 extremely narrow and elongate, evenly cylindrical, apex of segments 5-10 produced only slightly on outer side.

Thorax. Pronotum (Fig. 9) longer than width across posterior margin (5.0:4.3), posterior margin wider than anterior margin (4.3:3.3) so that in dorsal view lateral margins converge anteriorly; lateral pronotum with broadly pointed hump just posterior to midline; pronotum with two very broad longitudinal bands of dense pilosity dorsally and narrower pilose band above coxae, dorsomedial longitudinal line narrow to moderately broad and glabrous, lateral surface mostly glabrous, ventral surface sparsely and evenly pilose; dorsal and lateral part of pronotum with uneven transverse strigose-punctate sculpturing, mostly hidden by pilosity;

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[1] Rondonuwu, S. A. (1988) "Biology and Ecology of Cypress Twig Borer, *Uracanthus cupressiana* sp.n (Cerambycidae)". Unpublished Ph.D Thesis, University of Adelaide.

TABLE 1: *Species of* Uracanthus *known from Australia* (* = holotype examined; x = holotype missing; + = species known from South Australia)

Species	Holotype & depository	Depositories of other material examined
Uracanthus acutus Blackburn (*)	♂ BMNH	SAM, ANIC, WARI
U. albatus Lea (*)	♂ SAM	WARI, SAM
U. ater Lea (*)	♂ SAM	SAM, ANIC
U. bivitta Newman (*,+)	♀ BMNH	SAM, ANIC, WARI
U. corrugicollis Lea (*,+)	♂ SAM	SAM, ANIC
U. cryptophagus Ollif. (*)	♀ AM	SAM, ANIC
U. cupressianus sp.nov. (*,+)	♂ SAM	ANIC, WARI
U. dentiapicalis McKeown (*)	♂ WAM	—
U. discicollis Lea (*,+)	♂ SAM	SAM, ANIC, WARI
U. dubius Lea (*,+)	♂ SAM	SAM, ANIC
U. froggatti Blackburn (*)	♂ BMNH	SAM, ANIC
U. fuscocinereus White (*)	♀ BMNH	WARI, ANIC
U. fuscostriatus McKeown (*)	♂ WAM	ANIC
U. fuscus Lea (*,+)	♂ SAM	SAM, ANIC
U. gigas Lea (x)	♂ BMNH	SAM, ANIC
U. glabrilineatus Lea	♂ SAM	SAM
U. inermis Aurivillius (*)	♀ NRS	—
U. insignis Lea (*)	♀ SAM	SAM, ANIC
U. lateroalbus Lea (*)	♂ SAM	SAM, ANIC
U. leai McKeown (*)	♂ SAM	SAM
U. longicornis Lea (*)	♂ SAM	SAM
U. loranthi Lea (*)	♂ MV	SAM, ANIC
U. maleficus Lea (*)	♂ SAM	SAM, ANIC
U. marginellus Hope (*,+)	♂ HMO	SAM, ANIC
U. minatus Pascoe (*)	♀ BMNH	—
U. multilineatus McKeown (*)	♂ WAM	ANIC
U. pallens Hope (*)	♂ HMO	SAM, ANIC
U. parallelus Lea (*)	♂ MV	ANIC
U. parvus Lea (*)	♂ SAM	ANIC
U. pertenuis Lea (*,+)	♂ SAM	SAM, ANIC
U. regalis McKeown (*)	♂ AM	ANIC
U. simulans Pascoe (*,+)	♂ BMNH	SAM, ANIC
U. strigosus Pascoe (*,–)	♂ BMNH	SAM, ANIC
U. suturalis Lea	♂ SAM	SAM, ANIC
U. triangularis Hope	♀ HMO	SAM, ANIC, WARI
U. triangularis var. A Lea (*)	♂ SAM	SAM, ANIC
U. triangularis var. B Lea (*,+)	♂ SAM	SAM, ANIC
U. triangularis var. C Lea (*,+)	♀ SAM	SAM, ANIC
U. ropicus Lea (*)	♂ SAM	SAM, ANIC
U. ventralis Lea (*)	♂ SAM	SAM, ANIC

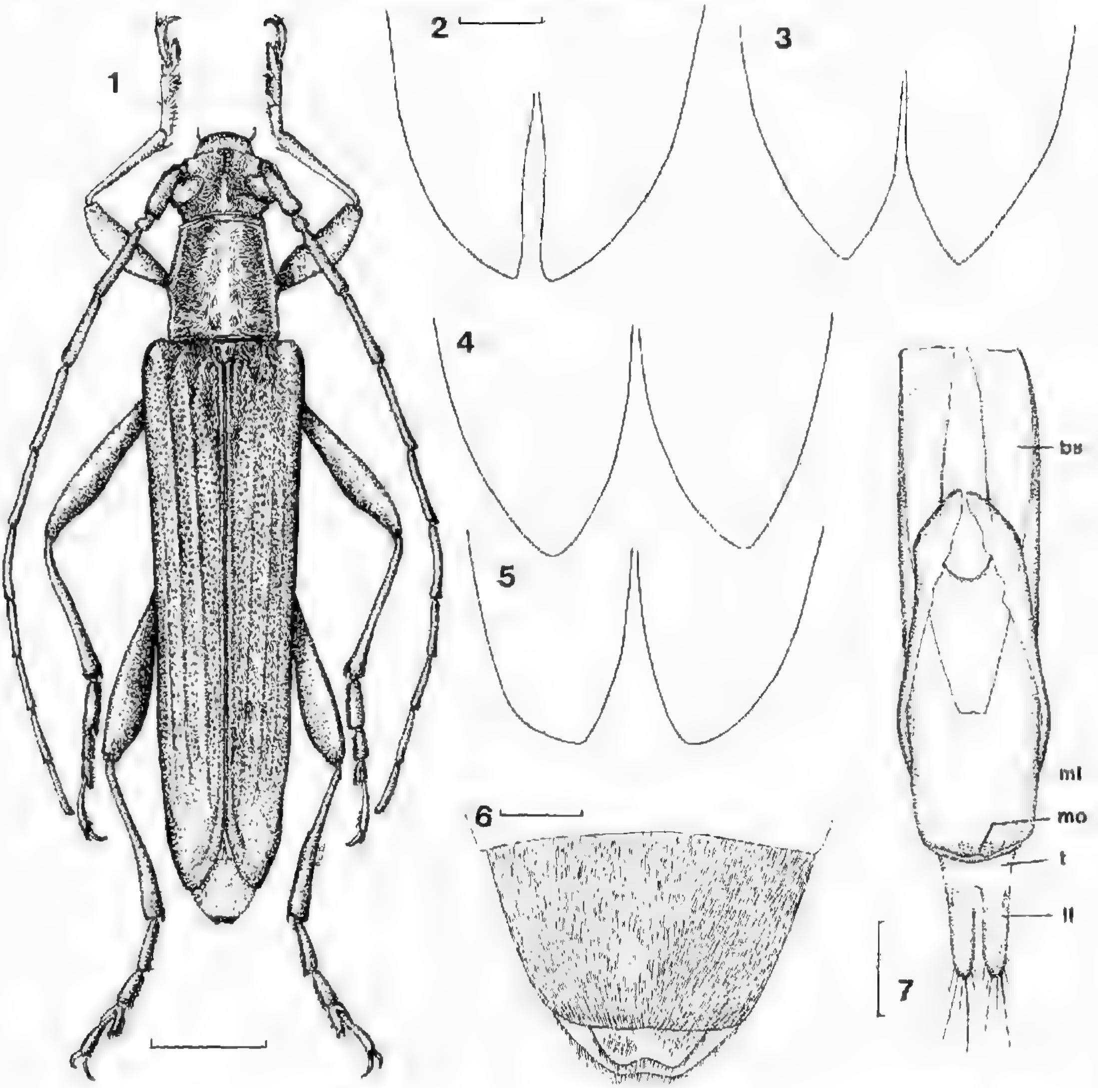
dorsal part of pronotum with one pair (sometimes two pairs) of small shallow glabrous depressions, dorsomedial longitudinal line slightly depressed; scutellum pointed posteriorly, smooth, virtually glabrous.

Elytra. Much wider than prothorax measured across anterior margin, width decreasing posteriorly; apices broadly pointed either symmetrically or asymmetrically (Figs 4, 5); anterior corners glabrous; surface of each elytron with four feeble raised longitudinal lines (Fig. 1), punctate all over but punctures partly hidden by dense even pilosity.

Legs. Moderately stout; femora expanded in distal two-thirds, widest approximately one-third from distal end, lateral surfaces transversely strigose-punctate and almost without pilosity; tibiae slightly bowed, hind tibiae more so than fore and mid tibiae; first segment of hind tarsus 1.54–1.56 times longer than second; first segment of fore and mid tarsi 1.5 times or less longer than second.

Abdomen. Ventral surface with uniform pilosity, moderately dense; S7 broadly truncate posteriorly, sometimes slightly emarginate medially; T7 broadly rounded posteriorly and slightly emarginate medially; T8 (if visible) much narrower than T7 and deeply emarginate medially (Fig. 6).

Genitalia and Reproductive System. Genitalia (Fig. 7) with lateral lobes of tegmen cylindrical, apices rounded with several short and several long setae; basal piece thin and folded but becoming flat and wider at tip; median lobe parallel-sided, becoming narrower at apex; lateral margin of median orifice



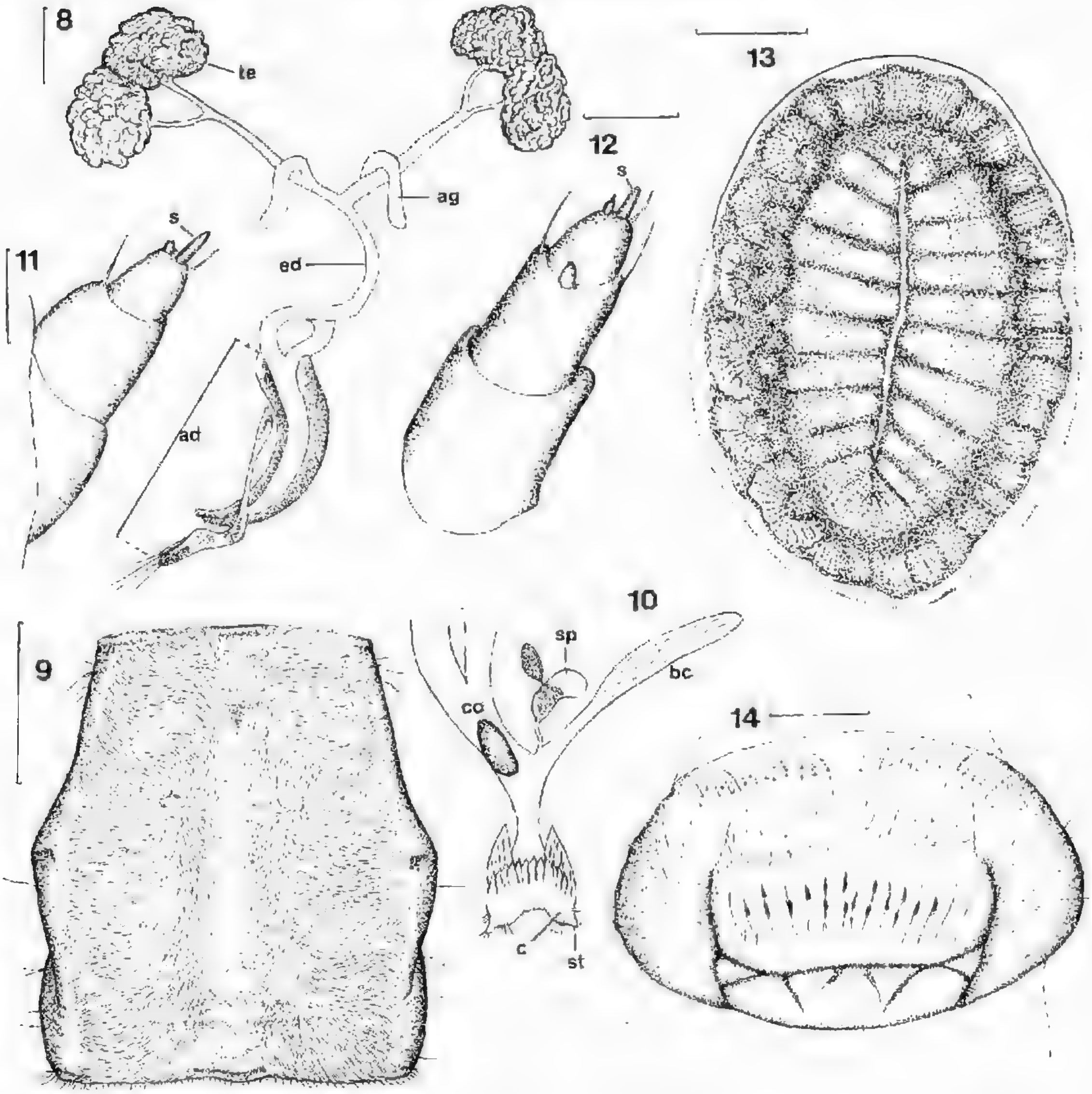
FIGS 1-7. *Uracanthus cupressianus* sp. nov. 1, adult male paratype; 2 and 3, adult female, paratypes, variation in the apices of the elytra; 4 and 5, adult male, paratypes, variation in the apices of the elytra; 6, adult male, paratype, distal segments of the abdomen, ventral view; 7, adult male genitalia (aedeagus), paratype. Scales: Fig. 1 = 2 mm; Figs 2–6 = 0.5 mm; Fig. 7 = 250 μm. bs = basal strut; ll = lateral lobe; ml = medial lobe; mo = medial orifice; t = tegmen.

narrowed apically, rounded, slightly notched medially; dorsal lobe as wide as ventral lobe; basal struts short and truncate anteriorly; internal sac with a knot behind aedeagus; arrangement of glands and ducts as in Fig. 8.

Adult Female

As for male except as follows:

Size. (see Table 2); pronotum slightly broader in posterior half, with broader more diffuse glabrous medial longitudinal line; elytra slightly more parallel-sided, apices either symmetrical or asymmetrical (Figs 2, 3); terminal segments of abdomen with long golden hairs, T8 retracted into the genital chamber; ovipositor very short, bearing pair of styli at distal edge; styli bearing 2–4 long fine hairs interspersed with short tactile hairs; coxites medially and dorsolaterally bearing 6–8 long hairs interspersed with short tactile hairs; structure of distal reproductive system as in Fig. 10.



FIGS 8-14. *Uracanthus cupressianus* sp. nov. 8, adult male reproductive system; 9, adult male, paratype, dorsal pronotum; 10, adult female, ovipositor and distal portion of the reproductive system showing an egg in the common oviduct; 11, larval instar I, paratype, antenna; 12, larval instar VII, paratype, antenna; 13, larval instar VII, paratype, abdominal spiracle; 14, larval instar VII, paratype, pronotum. Scales: Figs 8 and 10 = 0.5 mm; Fig. 9 = 1 mm; Fig. 11 = 25 µm; Fig. 12 = 50 µm; Fig. 13 = 250 µm; Fig. 14 = 0.5 mm. ad = aedeagus; ag = accessory gland; bc = bursa copulatrix; c = coxite; co = common oviduct; ed = ejaculator duct; sp = spermatheca; st = stylus; te = testis; s = supplementary process.

Immature Stages

Egg: Length 1.5 mm width 0.6 mm; ovoid with one end slightly tapering and bearing a group of spicules, opposite end strongly tapering, truncate, with spicules that are roundly inclined; chorion light to dark grey and coarsely reticulate.

Larval Instar I: Length (Table 2); antennae hyaline, segment 3 with 1 distal peg and larger supplementary process (Fig. 11); mandibles and pronotum not strongly sclerotized, spiracles very small; abdominal segment 10 without caudal process and bearing few fine hyaline setae (Fig. 20).

TABLE 2. *Size of various life-history stages of* Uracanthus cupressianus *sp. nov. For stages LI to Pupa the width was measured across the pronotum and for adults it was measured across the widest part of the elytra.*

STAGE	LENGTH (mm)			WIDTH (mm)			
	$\bar{x}$	S.D.	RANGE	$\bar{x}$	S.D.	RANGE	n
LI	2.46	0.24	2.1–2.6	0.61	0.03	0.5–0.7	26
LII	3.36	0.55	2.2–3.8	0.66	0.22	0.6–0.8	10
LIII	5.60	1.66	4.3–8.6	0.89	0.26	0.7–1.2	25
LIV	10.49	1.92	7.8–15.2	1.52	0.28	1.2–2.2	25
LV	13.74	1.44	10.3–16.0	1.98	0.16	1.8–2.5	25
LVI	18.73	2.10	15.5–22.2	2.44	0.27	2.1–3.0	25
LVII	23.16	2.66	19.0–31.0	3.27	0.42	2.7–4.4	25
Prepupa	13.44	4.74	12.0–20.0	3.27	0.56	2.5–3.9	25
Pupa	16.83	1.44	13.5–19.0	2.42	0.16	2.2–2.7	15
Adult ♂	14.86	0.93	12.5–16.6	2.89	0.23	2.5–3.1	28
Adult ♀	17.65	1.42	14.4–19.6	3.54	0.44	2.7–4.7	26

Larval Instars II–IV: Length (Table 2); similar to instar I but differing in being progressively larger and more sclerotized and developing 3 small caudal tubercles on segment 10 (Fig. 19) which progressively become more sclerotized.

Larval Instars V and VI: Length (Table 2); generally similar to instar VII but smaller and with some of the morphological characters described for instar VII being difficult to see, particularly for instar V.

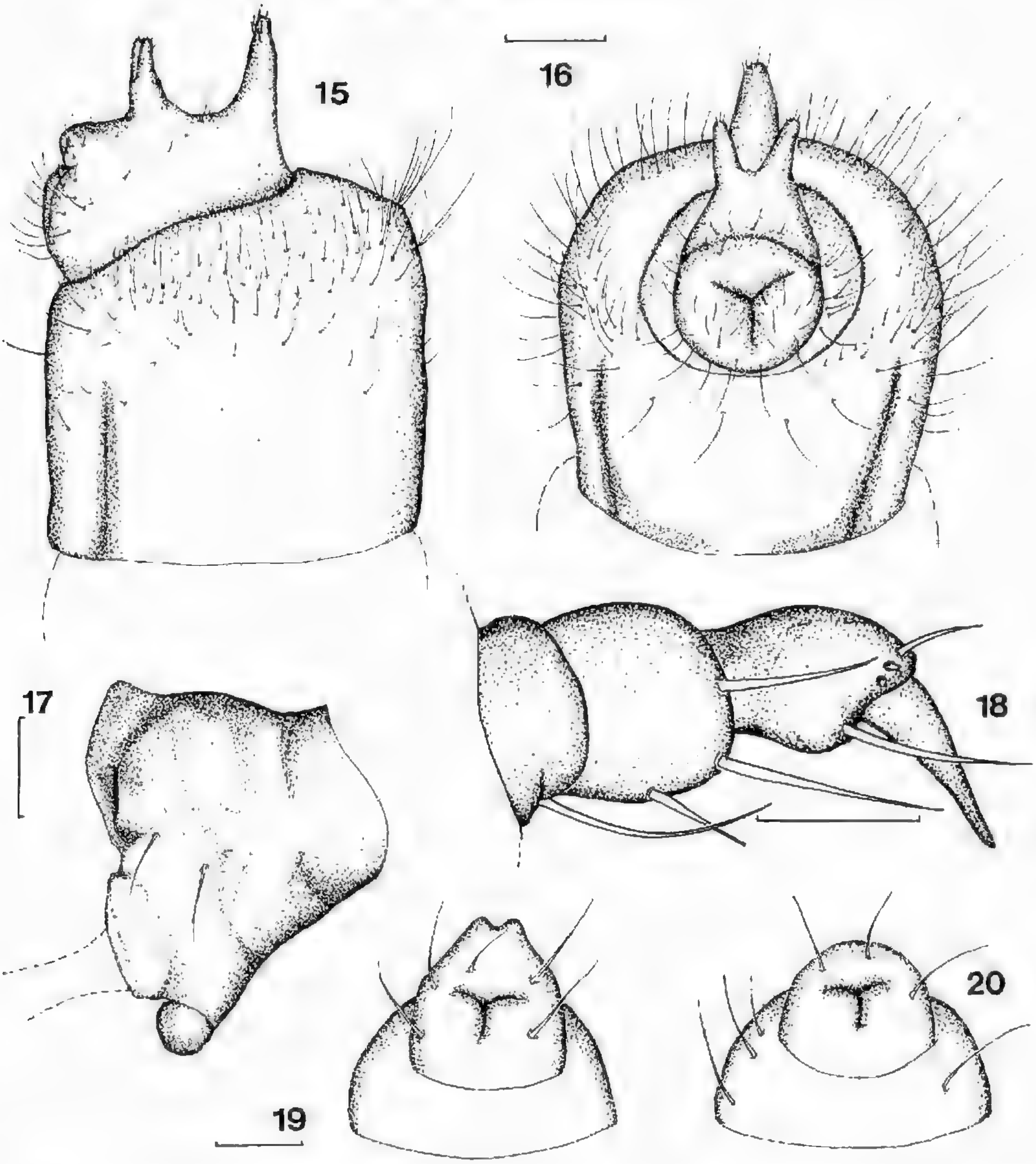
Larval Instar VII: Size (see Table 2); body elongate and subcylindrical, yellow to white in colour; pronotum with brown and pink patches; mouth bright red-brown; mandibles dark red-brown.
Head. Virtually parallel-sided; epistoma indistinct, with four epistomal setae; frons coarsely punctate, weakly sclerotized, bearing about 12 setae; median suture well defined, frontal suture indistinct; hypostoma strigate, bearing 5 long setae anteriorly near gular sutures; gular sutures raised and curved; gular region raised, hairless and weakly sclerotized; antennal segments strongly sclerotized, segments 2 and 3 bearing pegs, segment 3 with larger supplementary process (Fig. 12); clypeus membranous, trapezoidal, narrow, hairless; labrum circular and fringed anteriorly with long thick setae; mandibles short and stout, upper corner turned inwards and pointed, inner surface concave, outer surface with two long setae basally (Fig. 17).

Prothorax: Pronotum oval (Fig. 14), sometimes subrectangular, only slightly wider than posterior segments if at all, well sclerotized, posteromedial plate finely longitudinally striate with associated pigmented punctures, sparsely setose or glabrous, anterior half and lateral margins with long setae; prosternum sparsely setose, coarsely punctate, lightly sclerotized; eusternum semicircular, sparsely setose, finely punctate, sternellum very sparsely setose, with 6–10 fine setae.

Meso- and Metathorax: Mesotergum bearing x-shaped suture; metatergum with irregular suture; both these tergites with long reddish-brown setae laterally; mesosternum and metasternum bearing irregular transverse furrow.

Legs: Small; coxa strongly transverse; trochanter narrower with one long seta; femur as wide as trochanter, with three setae; tibiotarsus broad but narrower and longer than femur, with 3–4 setae; unguiculus not particularly elongate, about as long as tibiotarsus (Fig. 18).

Abdomen: First two dorsal ampullae bearing 4–5 transverse impressions delimited by one pair of lateral furrows and a median longitudinal furrow, remaining ampullae with indistinct tranverse impression; first four ampullae densely setose laterally, remaining three very sparsely setose; first five ventral ampullae with just one tranverse impression, last two ampullae with 2–3 impressions; first four epipleura not protuberant, bearing roundish pleural disc, 5th–7th epipleura slightly protuberant, each with single thick long seta and a few fine setae; 8th epipleuron not protuberant, with small round pleural disc; 9th epipleuron rounded posteriorly with numerous long thick reddish-brown setae; terminal segment (segment 10) usually bearing three short well sclerotized processes above anus, each process bearing a few short setae (Figs. 15, 16), sometimes with additional smaller lateral processes, or with main lateral processes wanting so only one large medial process is present; spiracles complex (Fig. 13), well sclerotized, red-brown.



FIGS 15–20. *Uracanthus cupressianus* sp. nov. 15, larval instar VII, paratype, distal segments of the abdomen, lateral view; 16, larval instar VII, paratype, distal segments of the abdomen, posteroventral view; 17, larval instar VII, paratype, mandible; 18, larval instar VII, paratype, metathoracic leg; 19, larval instar II, paratype, distal segments of the abdomen, posteroventral view; 20, larval instar I, paratype, distal segments of the abdomen, posteroventral view. Scales: Figs 15 and 16 = 0,5 mm; Fig 17 = 200 µm; Figs 18–20 = 100 µm (same scale for Figs 19 and 20).

Sexual dimorphism: Dissected male instar VII larvae differ from females by having two prominent reddish-yellow testicular follicles located ventrolaterally in abdominal segment 5. They can also be distinguished by having stouter and larger mouth parts. The ovaries in the females are hard to distinguish but can sometimes be seen as thread-like diffuse structures embedded in fat bodies.

Prepupa: There is a progressive contraction of the body during the prepupal period, which is initiated soon after larval instar VII has stopped feeding. The segmentation is very distinctive due to deep intersegmental infolds, which develop as a result of this contraction. The body colour changes to dull white or yellow, it becomes shorter (see Table 2), the thorax becomes thicker and the head turns ventrally. Numerous fat bodies are visible through the semi-transparent body wall.

Pupa: Size (Table 2); morphology generally the same as that described for other Cerambycinae (Duffy 1953); apparently with few unique distinguishing characteristics.

Other material examined: Immature stages - large number of eggs, larval instars I-VII and pupae, same data as adult paratypes, stored in 70% alcohol, WARI.

Comments

The adult of *Uracanthus cupressianus* is distinct from all described congeners. In general appearance it is most similar to *U. acutus* but differs from this species in the pronotum being more transversely strigate and pilose dorsally, the apices of elytra being less acutely pointed, and the elytra having four feeble longitudinal lines. *U. acutus* has the pronotum almost hairless and only weakly transversely strigate, the apices of the elytra acutely spinose, and the surface of elytra coarsely punctate and lacking longitudinal lines.

U. cupressianus also bears a superficial resemblance to *U. longicornis* Lea, *U. loranthi* Lea and *U. discicollis* Lea, but these species differ in several important characters. *U. longicornis* has the eyes almost touching ventrally, the pronotum very strongly transversely strigate and unevenly pilose, the antennae more robust and longer than the body, and the apices of the elytra narrowly rounded with an inner acute spine. *U. loranthi* has the pronotum irregularly transversely strigate-nodulate, with four longitudinal pilose bands dorsally, and the apices of the elytra broadly and diagonally truncate. *U. discicollis* has the surface of the pronotum completely smooth with much longer pilosity, the antennae longer than the body, and the elytra with dense inner longitudinal bands of dense long pilosity, but lacking longitudinal raised lines.

Of the three species of *Uracanthus* for which the final instar larva is known (Duffy 1963), *U. cupressianus* is most similar to *U. pallens*, particularly in the shape and arrangement of the posterior abdominal processes. These species differ, however, in the shape and pilosity of the pronotum, while the other two species, *U. triangularis* and *U. cryptophagous*, differ from *U. cupressianus* in having smaller multilobed posterior abdominal processes.

Biology

U. cupressianus causes substantial damage to branches of introduced cypresses, *Cupressus* spp., particularly *C. sempervirens*, which are planted as ornamental trees in parks and gardens throughout the Adelaide region and in South Australian country towns. This insect also may be responsible for the sporadic damage seen on cypresses in Victoria and New South Wales. The larval stages tunnel up and down branches, quickly turning them brown and killing them. In some Adelaide suburbs up to 70% of all trees are damaged by the feeding activity of the larvae. The native host trees of *U. cupressianus* are thought to be *Callitris* spp. (Cupressaceae).

Adult beetles emerge in spring, mate and females lay eggs soon after at night on the bark of trees. The first instar larvae burrow into the sapwood and begin feeding and tunnelling. The larvae continue to grow and moult, with each branch usually accommodating only one larva. Small holes to the outside are occasionally produced to allow for the ejection of frass and possibly for the aeration of tunnels. Final instar larvae construct a chamber at one end of the main tunnel where pupation occurs. The life cycle of most individuals is biennial and includes a larval-pupal diapause, although some individuals take as little as one year to complete their development. The larva (III–V) of *U. cupressianus* is parasitized by a braconid wasp (Helconinae: Cenocoeliini, genus and species indet.) and is preyed upon by a clerid beetle (recorded only in the larval stage), but these species never cause much mortality. The physiological condition of the host tree is probably a more important factor in regulating population numbers, a phenomenon which will be discussed in detail by one of us (SAR) at a later date.

Acknowledgments

We thank Dr Eric Matthews (SAM), Dr Terry Houston (WAM), Mr Ken Walker (MV), Mr Geoff Holloway (AM), Mr Chris O'Toole (HMO), Mr Les Jessop (BMNH) and Dr Per Lindskog (NRS) for loan of type material; Mr Paul Dangerfield for drawing the figures, and Drs Roger Laughlin and Jenny Gardner for reading drafts of the manuscript. This work was supported by a Colombo Plan Award from the Australian Government to SAR.

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NEW ROTIFERS (ROTIFERA) FROM TASMANIA

BY W. KOSTE[*]*, R. J. SHIEL*[+] *& L. W. TAN*[++]

Summary

One hundred Tasmanian aquatic habitats were surveyed for Rotifera in spring 1987. Of 168 taxa identified, 59 were first records for Tasmania, 21 new to Australia and four (*Trichotria buchneri* sp. nov., *T. pseudocurta* sp. nov., *Lecane herzigi* sp. nov. and *Notommata tyieri* sp. nov.) new to science. New taxa are described and figured, several of the new records also are figured, and brief ecological information is given.

KEY WORDS: Rotifera, new species, new records, Tasmania, zoogeography.

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Summary

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One hundred Tasmanian aquatic habitats were surveyed for Rotifera in spring 1987. Of 168 taxa identified, 59 were first records for Tasmania, 21 new to Australia and four (*Trichotria buchneri* sp. nov., *T. pseudocurta* sp. nov., *Lecane herzigi* sp. nov. and *Notommata tyleri* sp. nov.) new to science. New taxa are described and figured, several of the new records also are figured, and brief ecological information is given.

Key Words: Rotifera, new species, new records, Tasmania, zoogeography.

Introduction

In our first surveys of Tasmanian waters for rotifers (Koste & Shiel 1986), the predominantly humic, acid waters examined contained species assemblages more closely related to those of tropical northern Australia than to the southern fauna (Shiel & Koste 1986), with a small but distinctive endemic component (Koste & Shiel 1987a).

To investigate the apparent abundance of "pantropical" taxa at 42–43°S, and to add to our data on rotifer species diversity and seasonality, a further survey was made in Sept.-Oct. 1987. Most of the 100 habitats visited in the earlier surveys were resampled, and several acid dune lakes on the west coast were included.

This paper reports on the results of the 1987 survey, in particular the Rotifera new to Australia, with relevant ecological details. Full distribution and ecological data are included by family in a continuing revision of the Australian Rotifera (e.g. Koste & Shiel 1987b). Microfauna other than Rotifera will be reported elsewhere on completion of the sampling surveys.

Materials and Methods

Habitats sampled were as reported earlier (Koste & Shiel 1986), with the addition of six sites in the dune lake area north of Strahan on the west coast (Fig. 1). The only change to sampling methods reported previously was the use of a 13 l perspex trap for quantitative collections from some sites.

In the laboratory, subsamples were scanned sequentially in a perspex counting tray using a Zeiss SV-8 stereo microscope. The first 300–400 individual organisms encountered were identified and scored, and the remainder of the tray checked for additional species. A Zeiss Research compound microscope was used to identify selected mounted individuals (or trophi preparations after clearing with sodium hypochlorite), and photomicrographs taken.

Fig. 1. Additional sampling sites in 1987 survey (see Koste & Shiel (1986) for survey sites). Inset: sites referred to in text (a = L. Garcia sites; b. L. Pedder; c. Arthur's Lake.

Selected specimens were prepared for scanning electron microscopy (SEM) according to Amsellem & Clement (1979), and photographed at various magnifications in a Phillips SEM 505. Statistical methods used are described in Hellawell (1978).

Results

Ranges of water quality recorded were as follows: water temperature 4.0–24.0°C; pH 3.1–8.5; conductivity (K_{18}) 9.0-39,100 $\mu S\ cm^{-1}$; turbidity 0.5-160 Hach nephelometric turbidity units (NTU). As in the earlier surveys, most sites sampled had dark, tea-coloured humic waters (78% < pH 7.0) and were low in electrolytes (44% < 100, 46% 100-1000, 10% > 1000 $\mu S\ cm^{-1}$). With the

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exception of one highly turbid stock dam near Karanja (Strathgordon road), turbidities were very low (<10 NTU with the majority <1.0).

One hundred and sixty-eight rotifer species were identified from the 1987 sample series; 59 of these are new records for Tasmania (Table 1), bringing to 249 the known Tasmanian taxa; 21 are new to Australia (total now 644), including four new taxa described here.

Systematics

Notholca squamula (Müller)

FIG. 2

Brachionus squamula Müller, 1786, p. 334, Fig. 47:4-7.

The typical form of this halophile occurs in southern Victoria and Tasmania (Koste & Shiel 1987b). A population (sample 1996) differing from the f. typ. in size and anterior lorica morphology was collected from Boggy Creek, near St Helens.
Measurements: Lorica (length × width) 200×146 μm; anterior median spines 33 μm; submedian spines 18 μm; lateral spines 9-10 μm.
Ecology: 15°C, pH 8.5, K_{18} 13.94 mS cm^{-1}, turbidity 0.5 NTU. Shallow water, entry of creek into estuary, approx. 175m from sea. Emergent macrophytes. The Boggy Creek plankton was simple, dominated by nauplii of an unidentified cyclopoid copepod, with minor components a calanoid, *Gladioferens spinosus*, and another halophile rotifer, *Colurella adriatica*.

Fig. 2. *Notholca squamula* Müller) from St Helens. Lorica, ventral. Scale bar 100 μm.

Remarks: The St Helens specimens exceed the global range of 120-190×96-144 μm (Koste 1978) and are considerably larger than the 132×100 μm *N. squamula* recorded from western Victoria. The anterior margin also is distinctive; whereas the mainland form (and *N. squamula* elsewhere) has lateral occipital spines approximately half the length of the median spine pair, with much shorter submedian spines, the Boggy Creek form has submedian spines exceeding the range of 8-12 μm reported by Koste (1978), and the lateral spines are much shorter. It is likely that these morphological differences are an ecotypic response to estuarine habit.

Subsamples of the St Helens material are lodged with the Koste collection (FRG), the Shiel plankton collection (MDFRC), and a representative series of individuals mounted on a microslide (V.4105) with the South Australian Museum (SAM).

Trichotria buchneri sp. nov.

FIGS 3-5

Material: 16 females in formalin, sample No. 2050.
Holotype: Loricate female on microslide, sample 2050. Coll. 02.x.87, R. J. Shiel, SAM V.4106.
Paratypes: Date and place of collection as for holotype. Two slides in the Collection Rotatoria, Limn. Ecology, Senckenberg Museum, Frankfurt/M. No. 7340 and 7341; one slide SAM V.4107; one slide and one SEM stub Shiel Coll. (MDFRC).
Type locality: Roadside pool west of corner of Lake Rd and Garcia Rd, Lake Garcia, Strahan (42°09'S, 145°19'E).
Description: Rigid lorica (Fig. 5a) of nearly triangular cross-section (Figs 3c, 5b); median keel on dorsal plate, ending in long caudal spine (Figs 3a, b; 5a, c); anterior dorsal margin with deep rounded aperture (Fig. 5d) projecting laterally to pointed, sinuate cusps (Figs 3b, 5d); ventral plate domed medially, with large postero-ventral semicircular foot opening (Fig. 3d); anterior ventral margin with curved aperture between two blunt triangular projections (Figs 3d, 5d); foot two segmented, strongly loricate (Figs 3d, e); toes long, rigid, with acute points; head with rectangular plates (Fig. 3f) which form a pyramidal projection in the contracted state (Figs 5a, b, d); dorsal plate surface with long rows of minute denticles (Fig. 5e); lateral antenna on cuticular papilla; dorsal antenna not visible in contracted state.
Measurements: Lorica length 160-182 μm; width to 115 μm; height to 84 μm; proximal foot segment 24 μm; distal foot segment 15 μm; toes 50 μm.
Ecology: From 0.75 m depth, open water between emergent reeds, over organic silt on sand; dark

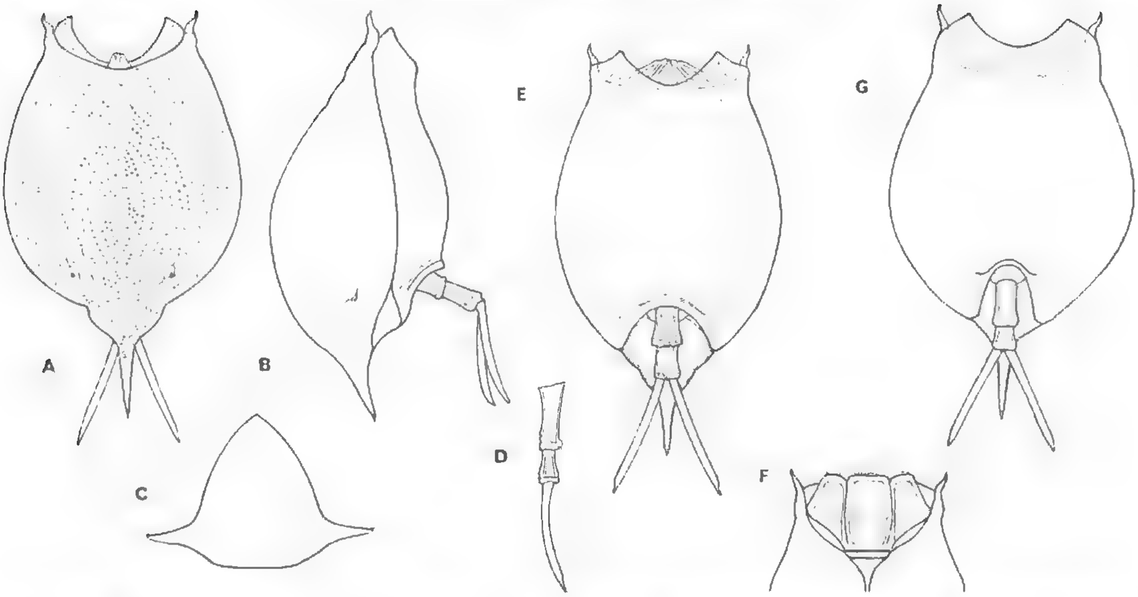

Fig. 3. *Trichotria buchneri* sp. nov. A. dorsal; B. lateral; C. cross-section; D. foot and toe, lateral; E. ventral; F. head, extended; G. ventral, head fully contracted.

Fig. 4. *Trichotria buchneri* sp. nov. Photomicrograph, dorsal.

humic water, 17.0°C, pH 3.1, 80.6 μS cm^{-1}. The most abundant plankter in this collection was a calanoid, *Calamoecia tasmanica* (Smith), however the rotifer assemblage accompanying *T. buchneri* was the most diverse yet recorded from Tasmania: 35 spp. in at least 20 genera, with *Keratella procurva* (Thorpe) the most abundant.

Remarks: The new species apparently is related to the *T. tetractis* group, however their cross section is hexagonal (Fig. 6c), there are two keels, the foot segments are strongly pustulated, with dorsal hooks on the second, and the foot is three-segmented. Paired hooks on the second segment of *T. tetractis caudata* (Lucks, 1812) are shown in Fig. 6. The reflexed caudal spine can be seen in Fig 6, which also shows the more terminal position of the foot groove, ventrally placed in the sp. nov.

Etymology: Dedicated to Professor Hans Buchner, Zoological Institute, Seidlstrasse, University of Munich, in recognition of his investigations of heterogony in rotifers.

Trichotria pseudocurta sp. nov.
FIGS 7–8

Material: 3 loricate females, sample No. 2024, coll. 27.ix.87, R. J. Shiel.

Holotype: Designated by illustration (Fig. 9). All specimens treated for trophi analysis. Trophi preparation in *Trichotria* section, Koste Coll. (FRG).

Type locality: L. Pedder, from Serpentine Dam boat ramp (42°46'S,145°59'E) west of Strathgordon (Fig. 1).

Description: Lorica U-shaped in outline, both surfaces punctate/stippled; short, acute lateral

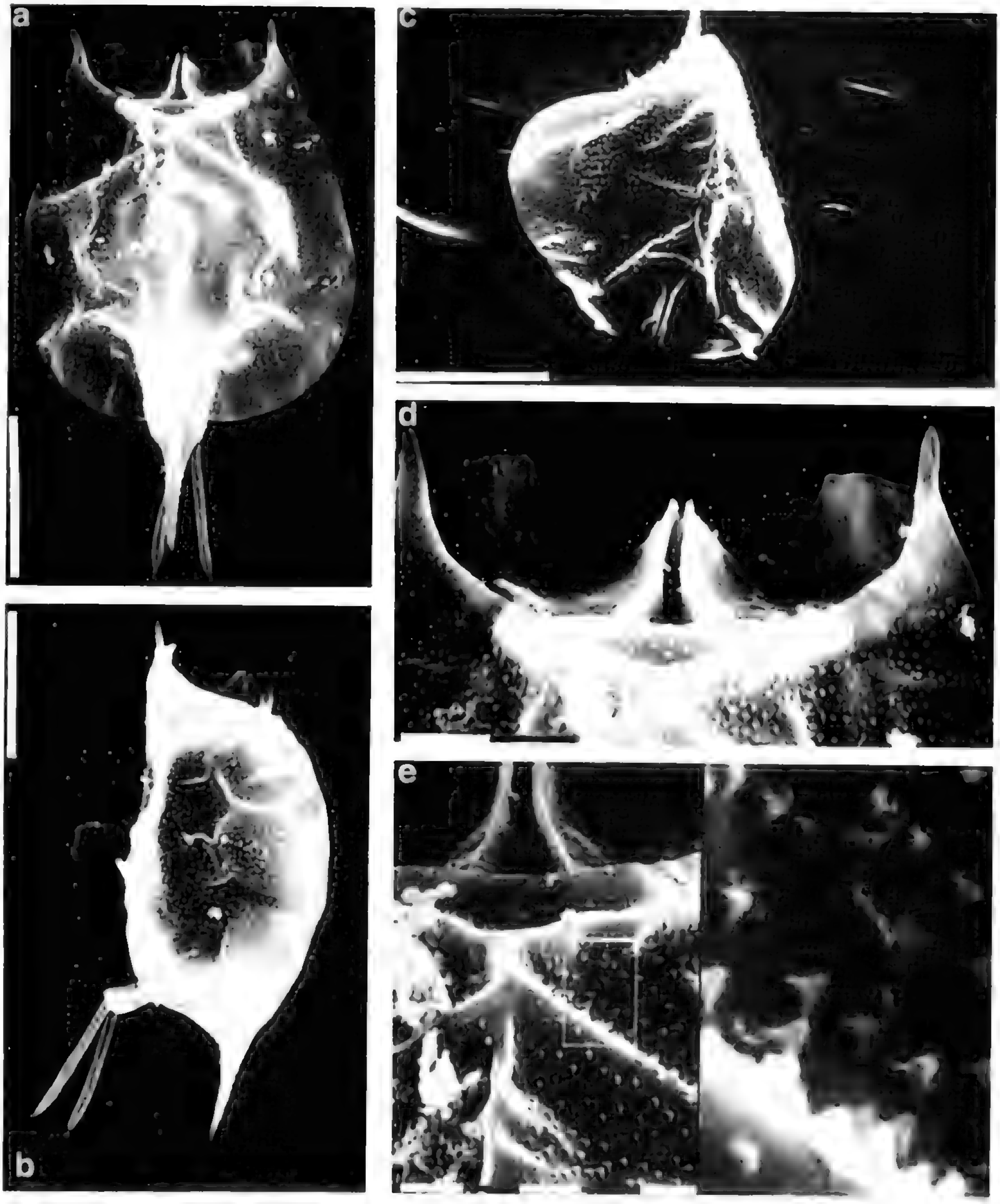

Fig. 5. *Trichotria buchneri* sp. nov. Scanning-electron micrographs a. lorica, dorsal; b. lorica of a second individual, lateral; c. anterior elevation of third individual; d. plates of contracted head of specimen in a; e. dorsal lorica denticulation of same individual, magnified at right. Scale bars a–c 50 μm, d 10 μm, e 5 μm.

spines at anterior margin; dorsal plate with twin keels commencing on either side of median notch in anterior margin, running posteriorly to fuse to single keel before posterior margin; ventral plate with twin ribs terminating at raised ridge at anterior margin of oval foot opening; foot 3-segmented,

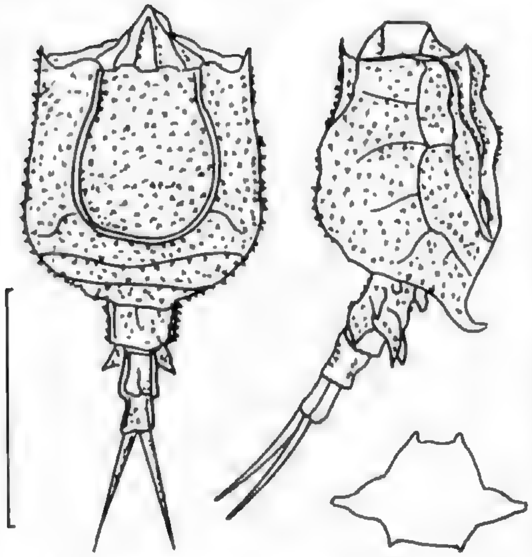

Fig. 6. *Tricholeria tetractis caudata* (Lucks). Dorsal, lateral and cross-section. Redrawn from Wulfert (1967). Scale bar 100 μm.

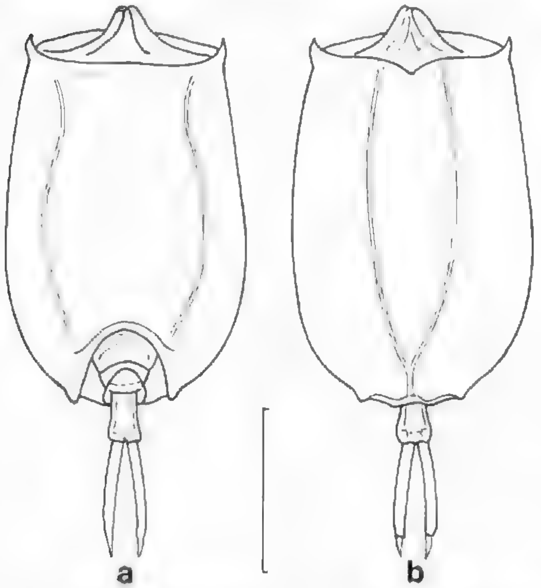

Fig. 7. *Trichotria pseudocurta* sp. nov. a. dorsal; b. ventral. Scale bar 50 μm.

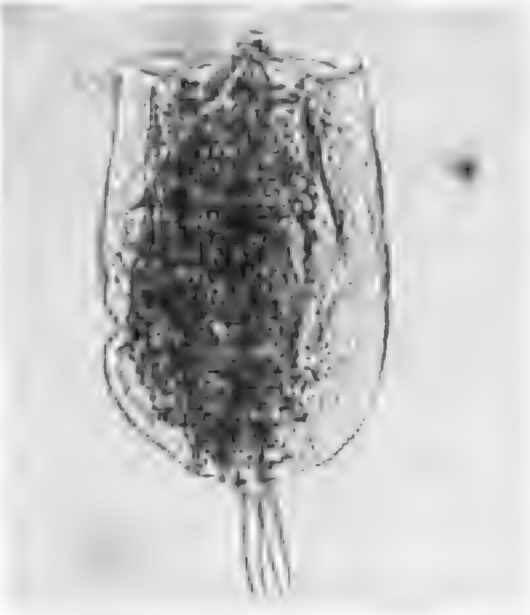

Fig. 8. *Trichotria pseudocurta* sp. nov. Photomicrograph, dorsal.

lacks spines on segments; toes with short claws.

Measurements: Lorica length 125 μm; width 74 μm; toes (incl. claws) 36 μm.

Ecology: Collected from 1 m depth over gravel, vicinity of emergent reeds; water dark brown, humic. 21°C, pH 5.2, 32.6 μS cm^{-1}, 0.5 NTU. Rotifers dominated the Lake Pedder plankton at this site, with *Keratella cochlearis* (Gosse) and *K. australis* (Berzins) most abundant of ten species identified. Microcrustacean plankters were *Calamoecia australis* (Searle) and *Bosmina meridionalis* Sars.

Remarks: This small species resembles a Volga River species, *T. curta* (Skorikov, 1914), which has a lorica length of 80-110 μm, toes 30-40 μm (Rudescu 1960), however the latter lacks the frontal corner cusps and has more angular lorica morphology.

Squatinella cf. *leydigi* (Zacharias)
FIG. 9

Stephanops leydigi Zacharias, 1886:255, Fig. 9:1, 2.
Squatinella leydigi (Zacharias) after Voigt (1957).

In sample 2050, from a small, humic roadside pool near L. Garcia, north of Strahan (Fig. 1), were several *S. leydigi* resembling the f. *longiseta* described by Pourriot (1971) from Europe. The typical form is not known from Australasia.

Measurements: body 210-235 μm; dorsal spine 270-378 μm; toe length to 37 μm.

Ecology: ca. 0.75 m depth, dark, humic water over silt. 17°C, pH 3.1, 80.6 μS cm^{-1}, 0.5 NTU.

Remarks: In view of the exclusion of "form" under article 16 of the International Code of Zoological Nomenclature (Ride *et al.* 1985), and the considerable variation within *Squatinella* (Koste 1988), this taxon must await more detailed treatment. It is likely that specific status is warranted.

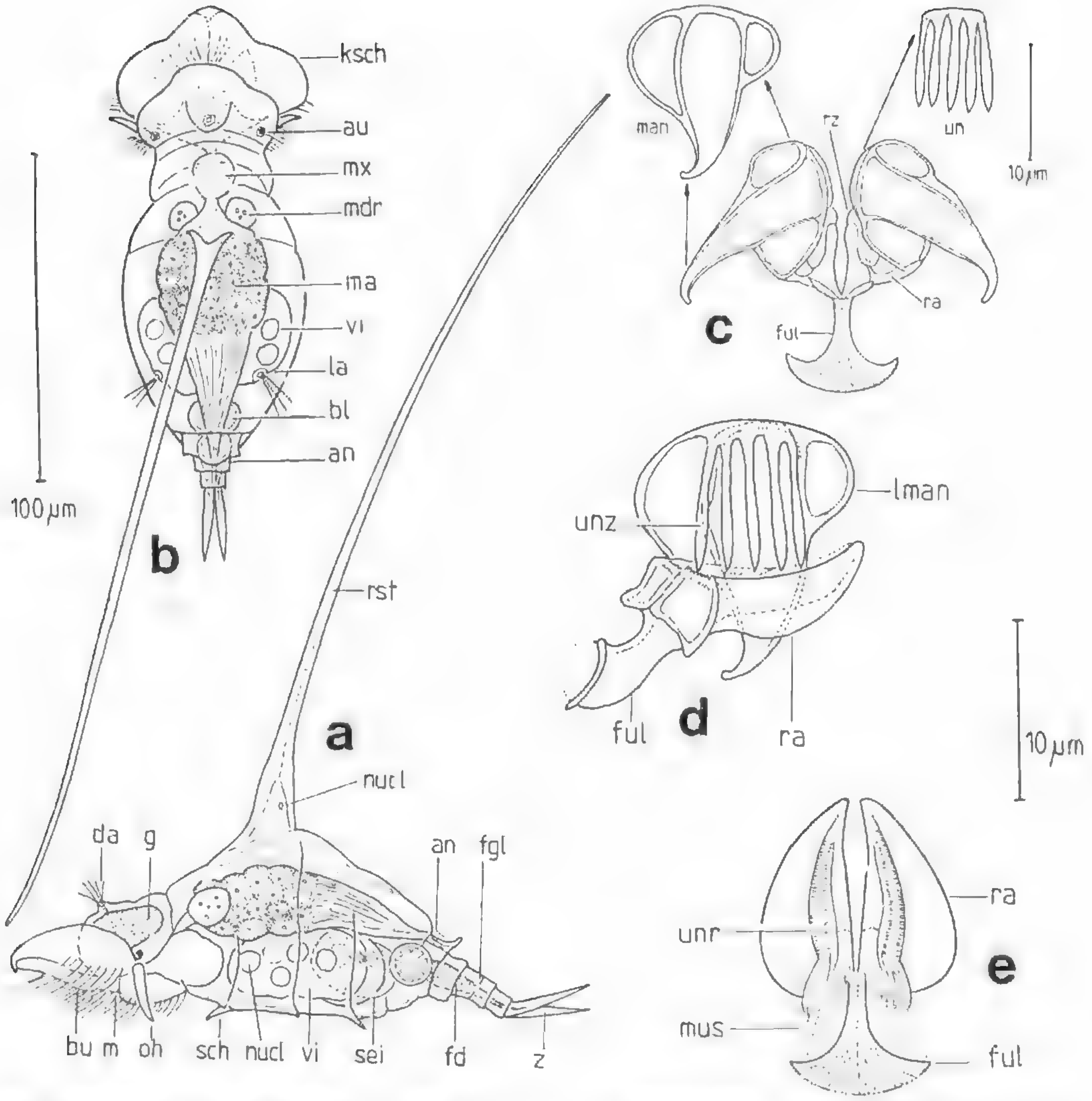

Fig. 9. *Squatinella* cf. *leydigi* (Zacharias). **a.** lateral (an = anus; bu = buccal field; da - dorsal antenna; fd = foot gland; fgl = foot segment; g = subcerebral ganglion; m = mouth; nucl = nucleii; oh = "ear"; rst - dorsal spine; sei - subitaneous egg; z - tow);
b. dorsal (an = anus; au = eye; bl = bladder; ksch - head-shield; la = lateral antenna; ma - stomach; mdr - gastric gland; mx = mastax; vi = vitellarium);
c. trophi (f = fulcrum; ma = manubrium; ra = râmus; rz = ramus tooth; un = uncus);
d. trophi, lateral (ful = fulcrum; lman = left manubrium; ra = ramus; unz = unci teeth);
e. trophi, ventral (ful = fulcrum; mus = musculature; ra = ramus; unr = unci ridge).

Lecane (Monostyla) subulata (Harring & Myers)
FIG. 10

Monostyla subulata Harring & Myers, 1926:410, Fig. 45:3, 4.
Lecane (M.) subulata (Harring & Myers) after Voigt (1957).

Also in sample 2050 were two specimens of this small acidobiont lecanid, known previously from wet *Sphagnum* in Europe and North America. They were within the size range given by Koste (1978:243). Full description and ecology will appear in Koste & Shiel (in press).

Measurements: Total length to 100 µm; lorica to 68 µm long, 65 µm wide; toe to 27 µm; claw to 10 µm.
Ecology: ca. 0.75 m depth, open water between emergent reeds, over organic silt. 17°C, pH 3.1, 80.6 µS cm $^{-1}$, 0.5 NTU.

Lecane (Lecane) rotundata (Olofsson)

FIG. 11

Cathypna rotundata Olofsson, 1918:593, Fig. 53.
Cathypna Hudson & Gosse (1886) = *Lecane* Nitzsch (1827) by priority.

Collected in a net tow (sample 2027) from L. Pedder, 17 km east of Strathgordon (Fig. 1), this is a surprising record of a species previously known from northern Canada, coastal waters of Novaya Zemla, Spitsbergen, Swedish Lappland and Hokkaido (Koste 1978). Full description and ecology will appear in Koste & Shiel (in press).
Measurements: Dorsal plate 90×105 µm; ventral plate 106×66 µm; toes 31 µm; claws 6 µm.
Ecology: From ca. 2 m deep, dark humic water, no visible vegetation, over rocky/gravel substratum. 14.3°C, pH 6.1, 33.0 µS cm^{-1}. Possibly an incursion dislodged from submerged vegetation by strong wind-induced wave action at the time of collection.

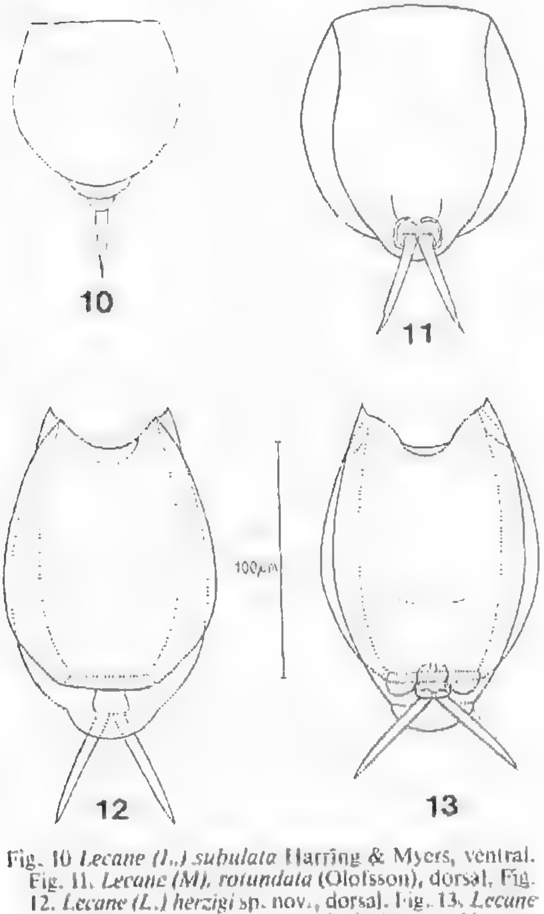

Fig. 10 *Lecane (L.) subulata* Harring & Myers, ventral. Fig. 11. *Lecane (M). rotundata* (Olofsson), dorsal. Fig. 12. *Lecane (L.) herzigi* sp. nov., dorsal. Fig. 13. *Lecane* (s. str) *herzigi* sp. nov., ventral. Scale bar 100 µm.

Lecane (L.) herzigi sp. nov.

FIGS 12–14

Material: 52 loricate females in formalin, sample Nos 2049, 2050.
Holotype: Loricate female on microslide, sample 2050. Coll. 02.x.87, R. J. Shiel. SAM V.4108.
Paratypes: Date and place of collection as for holotype; three slides in the Collection Rotatoria, Limn. Ecology, Senckenberg Museum, Frankfurt/M. No. 7360–62; one slide SAM V.4109; one slide Shiel Coll. MDFRC.
Type locality: Roadside pool west of corner of Lake Rd and Garcia Rd, Lake Garcia, Strahan (42°09'S,145°19'E). Also present in Lake Garcia, ca. 1 km east of the pool.
Description: Lorica outline ovate, widest medially; head aperture margins with deep rounded sinuses, ventral deeper than dorsal; pointed cusps at external angles of head aperture short, incurving; dorsal plate ovate, broadly truncate posteriorly; ventral plate slightly narrower than dorsal, with posterior segment a broadly rounded lobe commencing at second foot segment; deep lateral sulci; coxal plates small; toes straight, acutely pointed, without claws.
Measurements: Dorsal plate 96×74 µm; ventral plate 177×70 µm; width of anterior points 41 µm; toes 38–39 µm.
Ecology: From 0.75 m depth, open water between emergent reeds, over fine organic material/sand. Water very dark, humic. 17.0 °C, pH 3.1–4.3, 80.6–98.3 µS cm^{-1}, 0.5 NTU.
Etymology: Dedicated to Dr Alois Herzig, Biologische Station des Burgenlandes, Illmitz, Neusiedlersee, Austria, in recognition of his work on Rotifera.
Remarks: The new species resembles *L. (L.) mitis* Harring & Myers, 1926, from New Jersey, but differs in the shape of the anterior margins of the lorica and caudal part of the ventral plate, which is not clearly separated into a distinct lobe as in *L. herzigi*.

Notommata tyleri sp. nov.

FIG. 15

Material: 17 females in formalin, sample No. 1987.
Holotype: Part-contracted female on microslide, sample 1987. Coll. 22.ix.87, R. J. Shiel. SAM V.4110.
Paratypes: Date and place of collection as for holotype; one slide SAM V.4111; one slide Shiel Coll. MDFRC (*Notommata* # 1987).
Type locality: Arthur's Lake (41°59'S/146°55'E) (Fig. 1). From shallow water (<1 m) at boat ramp on western margin off Miena-Poatina Rd.
Description: Very small species, body short and stout; greatest width <½ body length (non-ovigerous, Fig. 15b) to slightly more than ½ (with

Fig. 14. *Lecane herzigi* sp. nov.. Photomicrograph, ventral.

subitaneous egg); integument soft, flexible, but outline constant; head and corona typical for genus, with slight constriction of body ca. ⅓ length (Fig. 15b); body dilated distally to rounded rump with median, indistinctly segmented lobulate foot bearing two short toes (Fig. 15b); toes conical, tapering from broad base to recurved, acute tips (Fig. 15c) (only tips visible in contracted state); dorsal and lateral antennae small, papilliform; mastax (Fig. 15e–g) modified virgate type (cf. Koste & Shiel 1987b); rami strongly convex on outer margins no inner denticulation; fulcrum slender, straight, dilated distally; manubria slender, curved, with distinctive handle-like median structure (Fig. 15g, h); internal organs normal, vitellarium conspicuous; foot glands elongate, club-shaped.
Measurements: Total length 120–139 μm; incus 19μm; toes 12–16 μm, subitaneous egg 30–45 × 50–65 μm.
Ecology: Collected from open water over gravel, no emergent vegetation, 8.0°C, pH 7.7, 17.4 μS cm^{-1}, 0.5 NTU. Dominant plankters were rotifers (10 spp.), with most abundant taxa *Polyarthra vulgaris* Carlin and *Gastropus minor* (Rousselet). Dominant microcrustacean was *Boeckella rubra* (Smith).
Etymology: Dedicated to Dr Peter Tyler, Department of Botany, University of Tasmania, in recognition of his continuing contributions to Tasmanian limnology.
Remarks: Nearly all specimens were contracted in the preservative, however analysis of the trophi showed elements resembling those of *N. trypeta* Harring & Myers (1922:602, Fig. 50:5–8), with differences in the rami and manubria. *N. tyleri* sp. nov. is slightly smaller than *N. trypeta* (150 μm) with larger mastax and longer toes (16 μm and 9 μm respectively in *N. trypeta*) Harring & Myers noted that *N. trypeta* appeared to be an obligate parasite of Cyanophycean *Gomphosphaeria*. The animals in our sample were all free-living, and no Cyanophyceae were present. We consider differences in trophi structure and habit to indicate a distinct species.

This animal belongs to a group which could be delineated from *Notommata* and defined as a new genus. It would include *Pleurotrocha (Notommata) vernalis* Wulfert, 1935, *P. (N.) chalicodis* Myers, 1933, *P. robusta* (Glascott, 1893), *Notommata thitasa* Harring & Myers, 1922, and *N. trypeta* Harring & Myers, 1922.

Trichocerca weberi Jennings
FIGS 16–17

T. weberi Jennings, 1903:309–10, Pl. 1, Figs 12–14, Pl.XIII, Figs 116–7)

In a formalin-preserved sample, coll. L. Garcia, 25.ix.87, P.A. Tyler, Botany Department, University of Tasmania, (Subsample no. 2049a, Shiel Coll. MDFRC), were several females of a *Trichocera* resembling *T. weberi* Jennings, described from North America. There were appreciable differences in body and trophi measurements.
Measurements: Lorica length 140–148 μm (vs 112–120 μm for *T. weberi*); trophi 47 μm (vs. 42 μm); left toe 60 μm (vs. 40 μm); right toe 50 μm (vs. 30–36 μm); height 47 μm (vs. 45 μm). Ranges in Koste (1978) are: lorica length 95–133 μm; trophi 52 μm; left toe 30–45 μm; right toe to 42 μm; height to 50 μm; anterior cusp to 12 μm).
Remarks: The larger dimensions than the size ranges reported by Koste (1978) are notable, but in the absence of more detailed work on this species, indeed on *Trichocerca* generally, we consider this form may represent ecotypic variation. *T. weberi* is known from Qld (Russell 1961) and a billabong in Vic. (Shiel unpubl.), also from N.Z. (Jennings 1903).

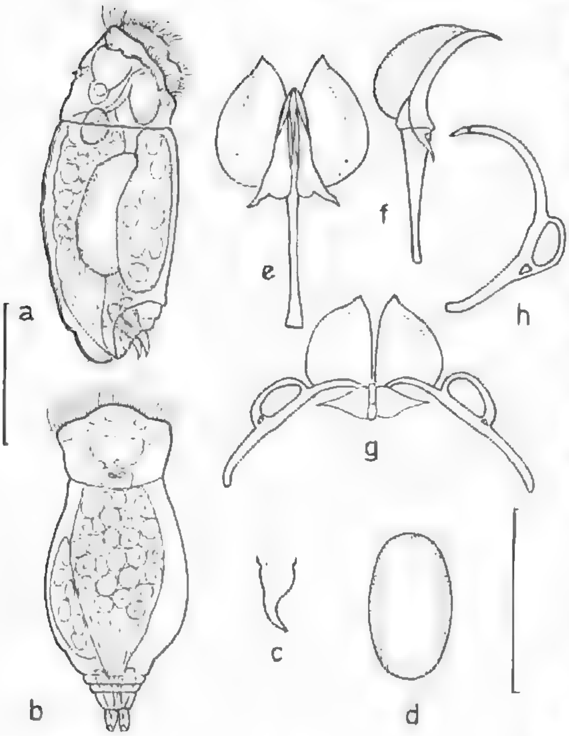

Fig. 15. *Notommata tyleri* sp. nov. a. lateral, semi-contracted; b. dorsal; c. toe, lateral; d. subitaneous egg; e. incus; f. incus, lateral; g. trophi, ventral view; h. manubrium, lateral. Scale bar left 50 μm (a-d), right 10 μm (e-h).

Discussion

Community composition

As in the earlier surveys, there was marked heterogeneity of resident rotifer communities within and between habitat categories (cf. Table 1). From 1-32 rotifer species occurred in each locality (mean = 9.95), with a distinct ranking of species richness according to general habitat type. This did not follow the same sequence as the earlier surveys, where permanent natural lakes had the most diverse rotifer communities (i.e. highest H' index) > rivers flowing from them > permanent stock dams > marshes > streams > vegetated roadside pools > stock dams > ditches.

In the 1987 survey very low species numbers were present in several of the Central Plateau lakes. In Lake St Clair, for example, only two rotifer species were recorded (H' = 0.29), whereas 16 species were present at the same site in Dec. 1985 (H' = 3,15). Extreme wind turbulence at the time of collection is a likely cause for the apparent decline; the rotifers may have been deeper and away from the shoreline, thus avoiding turbulence and abrasion from fine suspensoids.

In all other habitat categories, species diversity was higher than previously recorded, with rivers carrying the widest range of species (H' = 2.8; mean no. of taxa 11.5). Marshes and vegetated roadside pools had comparable communities (H' = 2.7; 11.9 and 9.8 spp. respectively), followed by stock dams (H' = 2.4; 10.3 spp.) > natural lakes (H' = 2.2; 10.3 spp.) > streams (H' = 2.0; 6.5 spp.) > impoundments (H' = 1.9; 7.7 spp.). Where a higher mean species number for the site category accompanies a lower diversity (e.g. impoundments vs. streams), the index used (Shannon-Weaver) (see Hellawell 1978 for comparative indices) has taken into account the relative numbers of individuals. In impoundments, the rotifer community tended to be numerically dominated by one or two species, whereas in streams a more even distribution was apparent. Overall, higher species numbers collected from the same sites by the same methods suggest a seasonal effect, considered later.

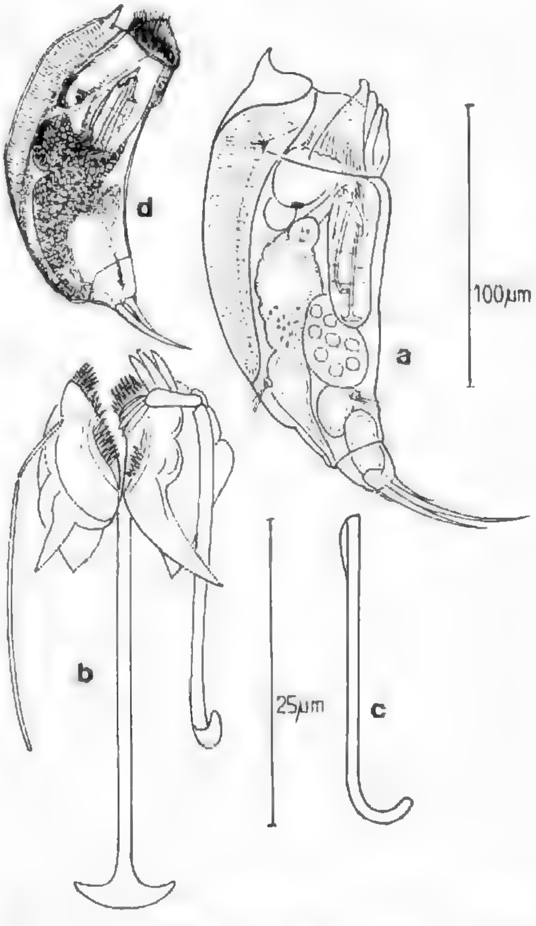

Fig. 16. a-c *Trichocerca weberi* Jennings. a. lateral; b. trophi; c. left manubrium; d. *T. weberi* from Jennings (1903).

Fig. 17. *Trichocerca weberi*, lateral, photomicrograph.

We should note here that in many of these habitat categories rotifers were not dominant in numbers or biomass. In most sites, community dominants were nauplii of the calanoid copepod *Calamoecia tasmanica*, or testate amoebae (e.g. *Difflugia* and *Arcella* spp.) These assemblages will be the subject of a detailed report at a later date (Shiel & Tan in prep.).

The new sites in the dune lake area were unexpectedly rich in species, including many of the new records given in Table 1. Site 2050, a permanent humic roadside pool near Lake Garcia, contained 32 taxa (H' = 3.9), both the highest number of species and H' index we had recorded from a Tasmanian collection. Lake Garcia (site 2049) at that time (02.x.87) contained 25 rotifer species (H' = 2.96), with only seven species common to the two sites. A subsample collected from lake Garcia 25.ix.87, a week before our visit to the same locality, was provided later by Dr P. A. Tyler (Botany Department University of Tasmania). It contained 35 taxa (H' = 4.4), including eight new records (claimed by Dr Tyler to represent "superior methods"!). Remarkably, less than ⅓ of these species (11) were present in our sample the following week. While inter-site community dissimilarity was a feature of earlier surveys, it was unexpected to find >40% similarity between intra-site samples collected a week apart. This possibly reflects a combination of intra-site patchiness of the microfauna and temporal species replacement, both of which are unstudied in Tasmanian waters, and indeed, are poorly known from mainland waters (e.g. Ganf *et al.* 1983, Shiel *et al.* 1987). More intensive study of the species-rich dune lake series clearly is warranted, particularly in view of the probable age, permanence and isolation of these lakes.

Within-habitat patchiness was evident in a series of samples from the northern shores of Lake Pedder (Fig. 1): 10 rotifer spp. occurred in a tow from the Serpentine Dam arm (western end, west of Strathgordon), with *Keratella australis* the dominant (83%). 4.5 km east of Strathgordon, *Conochilus hippocrepis* comprised 81% of the five taxa present, while at the eastern end of the lake, ca. 12 km away, *K. cochlearis* (33%) dominated the 12 taxa recorded, eight of which were not present at the opposite end of the lake.

Given the size of the impoundment, it is not unexpected that its filling submerged a range of waters with diverse planktonic and littoral microfauna. It is, nevertheless, remarkable that in a continuous and presumably mixed water mass, such distinct plankton communities are maintained. The dendritic morphology of Lake Pedder may be a contributing factor, permitting some spatial separation of mixing currents.

In general, high inter-site community dissimilarity held across the 100 localities surveyed, with only a few closely-situated morphologically or chemically similar habitats sharing more than 25% of their rotifer species. Table 2, for example, compares similarity indices of eight arbitrarily selected sites. Shared species tended to be those most widely distributed in the 1987 survey: *Keratella slacki* (44%), *Lecane flexilis* (40%), *K. australis* (38%), *Brachionus angularis* (32%), *K. cochlearis*/*Trichocerca similis* (29%), *Polyarthra dolichoptera* (26%), *Filinia longiseta*/*K. procurva* (24%) and *L. lunaris* (23%). All except *L. flexilis* and *B. angularis* were also the most widely distributed species in earlier surveys; all are widely tolerant endemic or cosmopolitan rotifers, pancontinental on the mainland. Other rotifer species in Tasmania are patchily distributed: 45 of the new records in Table 1 (76%) were collected from single habitats.

Seasonality

Two of our surveys were made in autumn, two in spring. Summer and winter surveys are desirable before more specific comments on seasonality of the Tasmanian rotifer fauna are possible. Nevertheless, different "most abundant" taxa and changes

TABLE 1. *Rotifera recorded from Tasmania for the first time. An asterisk (*) indicates a new record for Australia. Occurrence is shown by + = rare (one locality), ++ = limited distribution (>10% of localities). Habitat is given by S = stock dam, P = pond or small roadside pool, L = lake or large impoundment, R = river or stream (flowing). Known distribution on the mainland is given by state.*

Bdelloidea				
1.	*Habrotrocha angusticollis* (Murray)	+	L	NSW, NT; Qld
2.	*Otostephanus* Milne sp.			
3.	*Philodina megalotrocha* Ehrenberg	++	S	Qld
4.	*Rotaria tridens* Montet*	+	L	
Monogononta				
5.	*Asplanchna girodi* (De Guerne)	+	S	Qld, Vic
6.	*Brachionus quadridentatus ancylognathus* (Schmarda)	+	S	Vic
7.	*Cephalodella auriculata* (Müller)	+	S	Vic
8.	*C. gracilis* (Ehrenberg)	+	P	Vic
9.	*C. megalocephala* (Glascott)	+	R	NSW
10.	*C. sterea* (Gosse)	+	P	NT
11.	*C. tinca* Wulfert	+	S	Vic
12.	*Conochilus hippocrepis* (Schrank)	++	L	Qld, Vic
13.	*Dicranophorus epicharis* Harring & Myers	++	R/L	NT
14.	*D. lütkeni* (Bergendal)	+	P	Vic
15.	*Eothinia elongata* (Ehrenberg)	+	S	Vic
16.	*Euchlanis triquetra* (Gosse)	+	L	NT
17.	*Filinia longiseta limnetica* (Zacharias)	+	L	NSW, SA, Vic
18.	*Gastropus minor* (Rousselet)	++	L	NT; Qld
19.	*Heterolepadella heterostyla* (Murray)	+	P	NSW
20.	*Lecane (M.) elachis* Harring & Myers	+	P	NT
21.	*L. (M.) opias* Harring & Myers*	+	P	
22.	*L. (M.) subulata* (Harring & Myers)*	+	P	
23.	*L. (L.) doryssa* Harring	++	P	NT
24.	*L. (L.) herzigi* sp. nov.*	+	L	
25.	*L. (L.) mira* (Murray)	+	R	Qld
26.	*L. (L.) rotundata* (Olofsson)*	+	L	
27.	*Lindia ecela* Myers*	+	P	
28.	*Macrochaetus collinsi* (Gosse)	+	L	Qld
29.	*Monommata actices* Myers	+	P	NT
30.	*M. aequalis* (Ehrenberg)	+	L	Qld
31.	*M. longiseta* (Müller)	+	R	NSW; Qld, Vic
32.	*M. maculata* Harring & Myers	+	P	Qld
33.	*M. phoxa* Myers*	+	P	
34.	*M. viridis* Myers*	+	P	
35.	*Notommata cerberus* (Gosse)	+	P	NSW, Qld, Vic
36.	*N. cerberus longinus* Wulfert*	+	R	
37.	*N. pseudocerberus* De Beauchamp*	++	R	
38.	*N. tyleri* sp. nov.*	+	L	
39.	*Ploesoma truncatum* (Levander)*	+	L	
40.	*Proalinopsis caudatus* (Gosse)	+	L	NSW; WA
41.	*P. staurus* Harring & Myers*	+	P	
42.	*Ptygura pilula* (Cubitt)	+	P	NSW, NT
43.	*Resticula nyssa* Harring & Myers*	+	L	
44.	*Rhinoglena frontalis* (Ehrenberg)	+	S	
45.	*Squatinella cf. leydigi* (Zacharias)*	+	P	
46.	*Synchaeta grandis* Zacharias	+	S	NSW, Vic, WA
47.	*S. tackowitziana* Lucks	+	P	SA, Vic
48.	*Testudinella ahlstromi* Hauer*	++	L/P/R	
49.	*T. incisa* (Ternetz)	+	L	Qld
50.	*Trichocerca bidens* (Lucks)	++	L/P/S	Vic
51.	*T. braziliensis* (Murray)*	+	P	
52.	*T. dixon-nuttalli* (Jennings)	+	L	Qld
53.	*T. rosea* (Stenroos)*	++	P/R	
54.	*T. scipio* (Gosse)*	+	P	
55.	*T. similis grandis* (Hauer)	++	S	NSW, SA, Vic
56.	*T. weberi* (Jennings)	+	L	Qld, Vic
57.	*Trichotria buchneri* sp. nov*	++	L/P	
58.	*T. pseudocurta* sp. nov.*	+	L	
59.	*T. tetractis similis* (Stenroos)	++	L/P/R	

TABLE 2. *Sörenson indices for eight representative rotifer communities (0 - no species shared: 1 = all species shared).*

							1977 Stream
						0	1991 Stock Dam
					10	0	2001 R'side Pool
				.28	.13	.21	2002 R'side Pool
			06	.19	.26	.19	2027 Lake Pedder
		.04	.22	.09	.04	.14	2049 Lake Garcia
	.21	.07	.12	.05	.05	.20	2050 Dune Pool
0	.13	0	.06	.29	.09	.14	2066 R'side Pool
2050	2049	2027	2002	2001	1991	1977	

in species dominants within habitats are indicative of seasonal community responses. Prominent is the appearance of *Lecane flexilis*, which was neither common nor abundant in the three earlier surveys, but was relatively widespread (43 sites) and numerically abundant in many localities in 1987, and is clearly of spring occurrence.

General trends of species replacement were similar in large permanent lakes and smaller water bodies more prone to seasonal extremes, e.g. stock dams, although the species composition differed in each case. In Lake Pedder, for example, the sequence of rotifer community dominants and their proportions over the four surveys were: (1980, 4 spp., $H' = 1.49$) *K. cochlearis* (62%) > *Trichocerca similis* (20%) > *Pompholyx complanata* (12%); (1984, 8 spp., $H' = 1.89$) *Filinia pejleri* (37%) > *K. cochlearis* (37%) > *Conochilus dossuarius* (21%); (1985, 8 spp., $H' = 0.82$) *K. cochlearis* (86%) > *C. dossuarius* (10%) > *Hexarthra mira* (3%); (1987, 10 spp., $H' = 2.19$) *K. australis* (46%) > *K. cochlearis* (22%) > *C. dossuarius* (16%). Dominants in a stock dam, e.g. Wallaces, Southport (not sampled in the first survey) were: (1984, 10 spp., $H' = 2.92$) *Brachionus angularis* (31%) > *K. tropica* (16%) > *F. pejleri* (13%); (1985, 4 spp., $H' = 1.84$) *B. angularis* (46%) > *F. longiseta* (30%) > *K. slacki* (19%); (1987, 6 spp., $H' = 1.40$) *K. slacki* (65%) > *Polyarthra dolichoptera* (23%) > *B. angularis* (7%).

Zoogeography

Each field survey has added considerably to the known Tasmanian rotifer fauna; 62 spp. in 1980/84, 120 in 1985, 59 in 1987. Predictably, the proportion of first records for the island has declined: 75%..47%..35% as each survey has collected a greater proportion of known species.

To date, 12 new rotifer taxa have been described from Tasmania, with one subsequently recorded from the southeast of S.A. (Koste & Shiel 1986). This represents only 4% endemicity relative to ca. 12% on the mainland, but notably approx. 20% (49 species) of the extant Tasmanian fauna is not recorded from the mainland. Of those remaining species listed in Table 1 which are known from the mainland, 16 (44%) are recorded only from northern N.S.W., N.T. or Qld.

Too many gaps exist in the sampling record to allow more than speculation on the apparent disjunct distribution of many rotifers previously considered tropical taxa. The classification of these species as "pantropical" by reviewers (e.g. Koste 1978) indicates only that they have been collected mainly in the tropics. Interesting anomalies occur; e.g. a distinctively tropical component of the rotifer fauna was recorded downstream of heated outflows from nuclear power plants on the Loire River (Lair 1980), seen as a response to human interference.

The significant "tropical" component in the Tasmanian rotifer fauna may represent relict populations from an earlier period, or opportunist species occupying suitable habitats. Either alternative depends on the moderate environmental conditions of much of Tasmania's "lakeland".

A longitudinal sample series east of the continental divide would determine if the distributions are real, or simply those of collectors! Although some of our mainland samples have been collected from Cape York, at 11°S, and some in this series below 43°S, our most intensive surveys have been west of the continental divide, where alkaline, highly turbid waters bear little resemblance to those of Tasmania.

Acid humic waters certainly occur at higher altitudes along the divide, but little is known of their aquatic microfauna. These waters, or lower altitude sheltered waters east of the divide, may provide refuges for taxa hitherto considered "tropical", and explain the apparent disjunct distributions.

Acknowledgments

The Australian Biological Resources Study supported Tasmanian fieldwork (RJS/LWT) and graphic costs (WK). Dr P. A. Tyler (Hobart) provided material, suggested that the west coast acid lakes might have "a few" rotifers, provided maps thereto, and freely gave lodgings and hospitality. Numerous property owners willingly provided access to stock dams. The Deutschen Forschungsgemeinschaft provided long-term loan of microscope facilities to WK. Facilities of the Botany Department, University of Adelaide, and Murray-Darling Freshwater Research Centre were used in MS preparation. Dr Derek Duckhouse, Department of Zoology, University of Adelaide, and an anonymous referee commented critically on a draft MS. All the above are thanked for their assistance.

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CONTRIBUTIONS TO THE TAXONOMY OF STIGMODERA (CASTIARINA) (COLEOPTERA: BUPRESTIDAE)

BY S. BARKER*

Summary

Three new synonyms of *Stigmodera (Castiarina)* are recognised (valid name is given last): *acuta* Deuquet = *delicatula* Kerremans; *tripartita* Kerremans = *deserti* Blackburn = *atricollis* Saunders. *S. mimus* Saunders is resurrected from synonymy. Ten new species of *Stigmodera (Castiarina)* are described: *S. ashburtonensis* sp. nov., *S. deliciosa* sp. nov., *S. distantia* sp. nov., *S. macquillani* sp. nov., *S. mayoiana* sp. nov., *S. murchisonensis* sp. nov., *S. sedlaceki* sp. nov., *S. tepperi* sp. nov., *S. watkinsi* sp. nov. and *S. williamsi* sp. nov.

KEY WORDS: New species, *Stigmodera (Castiarina),* Coleoptera, Buprestidae

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Three new synonyms of *Stigmodera (Castiarina)* are recognised (valid name is given last): *acuta* Deuquet = *delicatula* Kerremans; *tripartita* Kerremans = *deserti* Blackburn = *atricollis* Saunders. *S. mimus* Saunders is resurrected from synonymy. Ten new species of *Stigmodera (Castiarina)* are described: *S. ashburtonensis* sp. nov., *S. deliciosa* sp. nov., *S. distantia* sp. nov., *S. macquillani* sp. nov., *S. mayoiana* sp. nov., *S. murchisonensis* sp. nov., *S. sedlaceki* sp. nov., *S. tepperi* sp. nov., *S. watkinsi* sp. nov. and *S. williamsi* sp. nov.

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Introduction

New species of *Stigmodera (Castiarina)* have been collected recently by some very active collaborators. In particular, the innovative use of a mechanical cherry-picker in the Gosford district of N.S.W. over a flowering lilly-pilly (*Acmena* sp.), produced two new species in the *S. producta* Saunders mimicry complex. Although *Stigmodera (Castiarina)* species occur in New Guinea, few collections have been made there. A small collection made by Mr J. Sedlacek resulted in a further species being added to the New Guinea fauna. Ten new species are described here and other species are resurrected or placed in synonymy.

Materials and Methods

Male genitalia were prepared and displayed by the method described by Barker (1987). Abbreviations used in the text for museum and private collections following Watt (1979) are: AMSA Australian Museum, Sydney; ANIC Australian National Insect Collection, C.S.I.R.O., Canberra; BMNH British Museum (Natural History), London; Muséum Nationale d'Histoire Naturelle, Paris; NMVA National Museums of Victoria, Melbourne; QMBA Queensland Museum, Brisbane; SAMA South Australian Museum, Adelaide; TADA Department of Agriculture, Hobart; WADA Department of Agriculture, South Perth; AHQA Mr A. Hiller, Mt Glorious; GBVA Mr G. G. Burns, Mornington; MHSA Mr T. M. S. Hanlon, Ryde; RMNA Mr R. Mayo, Narara; MPWA Mr M. Powell, Attadale; ASSA Mr A. Sundholm, Elizabeth Bay; SWNA Mr S. Watkins, Caparra; GWNA Mr G. Williams, Lansdowne.

Species resurrected from synonymy

Barker (1979, 1986) wrongly followed Kerremans (1903) and Carter (1916) in listing *S. mimus* Saunders (Holotype female, Qld, BMNH) as a synonym of *S. pertyi* C & G (Holotype, Aust., MNHN). I have recently examined series of both collected in N.S.W. *S. mimus* has a red pronotum and fewer dark pronotal markings than *S. pertyi* which has a yellow pronotum. Their male genitalia as shown (Figs 1A, 1B) are quite distinct. I consider each a valid species.

New synonyms in *Stigmodera (Castiarina)*

Barker (1983) listed *S. acuta* Deuquet, 1956 (Holotype male, Acacia Plateau, N.S.W., *Harold Davidson*, AMSA) as a synonym of *S. delicatula* Kerremans, 1903 (Holotype female, N.S.W., *Standing*, BMNH) and described *S. pseudasilida*, designating the female paratype of *S. acuta* as a paratype. Barker (1986) resurrected *S. acuta* from synonymy and pointed out that the illustration of Deuquet (1956, Fig. 1) was not of *S. acuta*, but in reality the female paratype later designated a paratype of *S. pseudasilida*.

A re-examination of the types of *S. spectabilis* Kerremans and *S. delicatula* Kerremans has reconfirmed that *S. acuta* is synonymous with *S. delicatula*. The species is unique in having attenuated elytra with two very small equal spines, the margin rounded between. Deuquet (1956) p. 155 described the male of *S. acuta* as 'very acuminate, minutely lunate, very short narrowly separated spines,' a precise description of *S. delicatula*.

Blackburn (1890) described *S. deserti* as a variety of *S. atricollis* Saunders (Holotype male, S. Aust., BMNH) after examining a short series collected in the Queen Victoria Desert by the Elder expedition. He could find little difference between this species and the typical *S. atricollis*, except that it was much smaller and the fascia and apical marks were heavier

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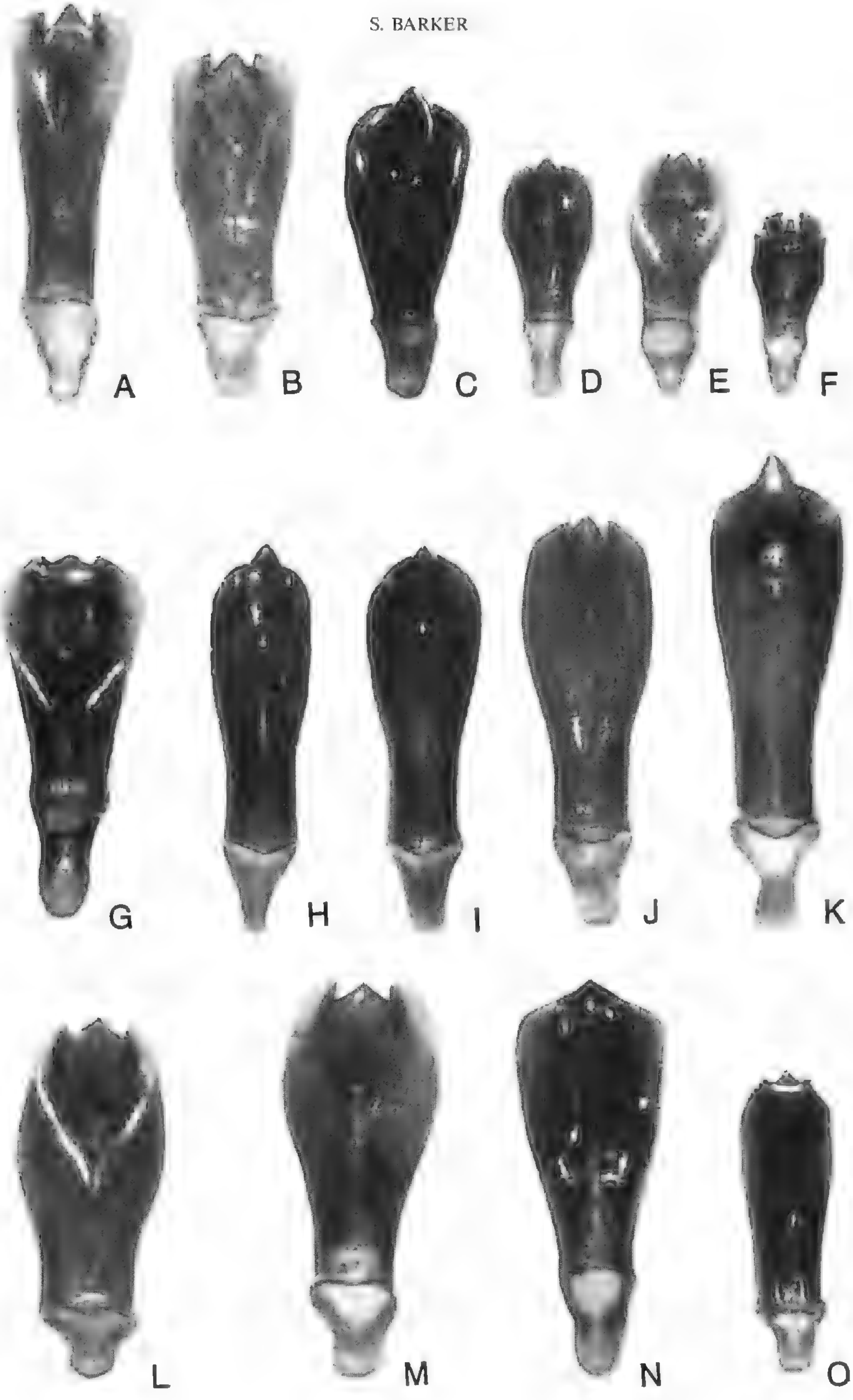
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than typical. Barker (1983) elevated *S. deserti* to specific status on the basis of differences between the genitalia of specimens attributed to *S. deserti* from the Murchison and Gascoyne districts, W.A. and those of *S. atricollis* (Figs 1E, 1F). Barker (1986) recognised that the genitalic comparison had not been made with *S. atricollis*, but instead with an undescribed W.A. species: *S. cruenta* Barker. A series of old specimens of *S. atricollis* collected in S. Aust. were examined, and a single recently collected male from the northern Flinders Ranges was dissected and illustrated alongside the genitalia of *S. cruenta* Barker (1986). It appears that the specimens attributed to *S. deserti* were unusually small specimens of *S. atricollis* which is widespread in W.A. and has been redescribed as *S. tripartita* Kerremans (Holotype male, Aust., BMNH). Barker (1979) listed *S. tripartita* Kerremans as a synonym of *S. atricollis* but Barker (1986) listed it as a valid species. The problem with the identification of *S. deserti* has occurred because of my inability to locate the type specimen. I now consider *S. deserti* and *S. tripartita* to be synonyms of *S. atricollis* which is a common and widespread species in arid areas of S. Aust. and W.A. The adults usually are collected on the flowers of *Cassia* sp., occasionally on the flowers of *Melaleuca uncinata* R.Br.

Problems with identification of two species of *Stigmodera (Castiarina)* have been caused by misidentification in Carter (1929). Pl. 32, Fig. 25 is labelled *cupricollis* Saunders, but illustrates *S. deyrollei* Thomson, whereas Fig. 31 is labelled *coccinata* (Hope) but illustrates *S. atronotata* Waterhouse. A further confusion is that the figures were not reproduced to the same scale. Moore (1987) labelled as *S. cupricollis* Saunders an illustration of *S. deyrollei* Thomson (a unifasciate morph, previously known as *S. sancta* Carter before being synonymised by Barker (1986)) and also wrongly identified an illustration of *S. tricolor* (Kirby) as *S. trifasciata* C & G (Pls 7, 8, Fig F).

Stigmodera (Castiarina) ashburtonensis sp. nov.
FIGS 1K, 3B

Holotype. ♂, Ashburton R., Ashburton Downs Stn, W.A., 27.viii.1977, *K. T. Richards*, ANIC.

Allotype. ♀, same data as holotype ANIC.

Paratypes. W.A.: 1 ♂, 2 ♀♀, same data as holotype, WADA, SAMA; 1 ♀, Cue, *Ellershaw*, SAMA; 1♂, 2♀♀, Cue, SAMA; 1♂, Cue, 27.iii.1899, *Ellershaw*, WAMA.

Colour. Head, antennae coppery-purple. Pronotum dark purple medially, coppery-purple laterally. Scutellum purple. Elytra orange with following dark blue markings: narrow basal margin; anteromedial spot on each elytron and one on suture; posteromedial fascia, convex anteriorly, reaching margin; anteroapical spot on suture. Ventral surface: sternum coppery-purple; abdomen dark purple. Legs: femora dark purple; tibiae and tarsomeres coppery-purple. Hairs silver.

Shape and sculpture. Head closely punctured, broad median sulcus, very short muzzle, eyes bulbous. Antennae compressed, segments: 1–3 obconic; 4–11 toothed. Pronotum closely punctured, basal fovea extending forwards to middle as glabrous line, basal notches surrounded by glabrous area on each side more marginal than medial; apical margin broadly projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, angled inwards, rounded, widest anteromedially, rounded to apex. Scutellum scutiform, flat, excavate. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially, narrowed to bispinose apex; both spines minute, rounded and indented between, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, sparse medium length hair. S_7: male truncate; female medially indented, faintly bilobed.

Size. Males, 15.9 × 5.8 mm (4). Females, 18.3 ± 0.26 × 6.8 ± 0.09 mm (6).

Male genitalia. (Fig. 1K). Parameres parallel-sided from base, rounded anteromedially and angled outwards, rounded posteromedially and parallel-sided, rounded apically. Median lobe blunt, sides acutely angled away. Apophysis of basal piece narrowed medially, truncate apically.

Remarks. Member of *S. trifasciata* C & G species group. Closest to *S. insignicollis* Blackburn. That species is smaller, has yellow elytra with a red margin, and the male genitalia (Fig. 1J) have parameres parallel-sided from base, rounded medially then parallel-sided, rounded apically. Median lobe blunt, sides acutely angled away. Apophysis of basal piece medium width, rounded apically. The red

Fig. 1. Photomicrographs of male genitalia of the following *Stigmodera (Castiarina)* species: A. *S. pertyi* C & G, B. *S. minimus* Saunders, C. *S. macquillani* sp. nov., D. *S. murchisonensis* sp. nov., E. *S. watkinsi* sp. nov., F. *S. williamsi* sp. nov., G. *S. mayoiana* sp. nov., H. *S. cylindracea* Saunders, I. *S. distantia* sp. nov., J. *S. insignicollis* Blackburn, K. *S. ashburtonensis* sp. nov., L. *S. tepperi* sp. nov., M. *S. burnsi* Barker, N. *S. delectosa* sp. nov., O. *S. sedlaceki* sp. nov.

margin fades in old specimens of *S. insignicollis* and they are difficult to distinguish. Ashburton R. specimens were collected on the flowers of *Petalostylis labicheoides* R.Br. The name is derived from the type locality.

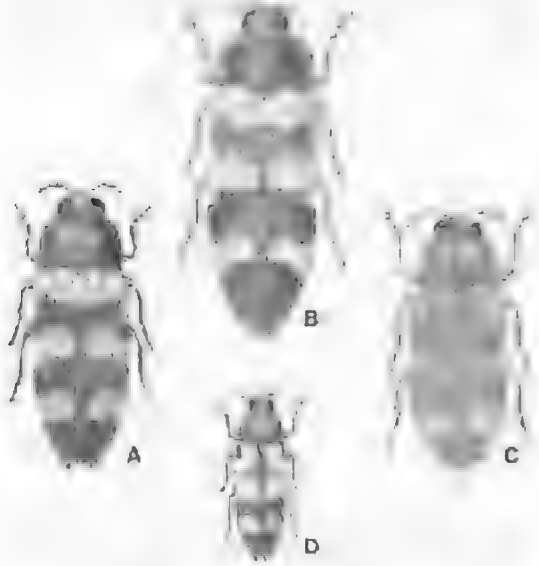

FIG. 2. A. *Stigmodera murchisonensis* sp. nov., B. *S. distantia* sp. nov., C. *S. watkinsi* sp. nov., D. *S. williamsi* sp. nov.(x3)

Stigmodera (Castiarina) distantia sp. nov. FIGS 1I, 2B

Holotype: ♂, 4 km W Zanthus, W.A., 21.x.1986, *M. Powell*, WAMA.

Allotype: ♀, same data as holotype, SAMA I 21207.

Paratypes. W.A.: 3 ♀♀, same data as holotype, MPWA.

Colour: Head mostly green, black at base. Antennae green. Pronotum black medially, green laterally. Scutellum black. Elytra yellow with following dark blue markings: narrow basal margin; anteromedial fascia consisting of three connected spots not reaching margin, in allotype three separate spots, one on each elytron and one on suture; posteromedial fascia reaching margin, projecting anteriorly from middle of each elytron; spade-shaped apical mark, last three marks connected along suture, red margin. Ventral surface and legs green. Hairs silver.

Shape and sculpture: Head shallowly punctured, shallow median sulcus, very short muzzle. Antennae compressed, segments: 1–3 obconic; 4–11 toothed. Pronotum shallowly punctured, basal fovea extending forwards to middle as glabrous line, basal notches represented by glabrous area on each side more marginal than medial; apical margin projecting medially, basal margin bisinuate; laterally parallel-sided at base, rounded to widest part medially, rounded to apex. Scutellum scutiform, glabrous, excavate. Elytra punctate-striate, intervals convex, shallowly punctured; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and narrowed to bispinose apex; blunt marginal spine, minute sutural spine, margin indented between, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, sparse medium length hairs. S_7: male truncate and slightly indented medially; female bilobed.

Size. Male, 13.5 × 4.8 mm (1). Females, 13.9 × 5.2 mm (4).

Male genitalia: (Fig. 1I). Parameres parallel-sided basally, widened anteromedially, rounded apically. Median lobe blunt, sides acutely angled away. Apophysis of basal piece moderately wide, rounded apically.

Remarks: Member of *S. trifasciata* C & G species group. The elytral markings and colouration most resemble *S. cylindracea* Saunders, except that the pronotum in *cylindracea* is all green and the body smaller and cylindrical. The male genitalia of *S. cylindracea* (Fig. 1H) have parameres parallel-sided basally, rounded anteromedially, parallel-sided, rounded apically. Median lobe sharp, sides acutely angled away. Apophysis of basal piece narrowed, rounded apically. All specimens were collected on the flowers of *Melaleuca uncinata* R.Br. The name is derived from *distantia* L. "remoteness".

Stigmodera (Castiarina) macquillani sp. nov. FIGS 1C, 3A

Holotype. ♂, Mt Algonkian 1073 m, Tas., 26.ii.1987, *P.McQuillan*, SAMA I 21208.

Paratype. ♂, same data as holotype, TADA.

Colour. Head green with yellow reflections. Antennae blue. Pronotum and scutellum green with yellow reflections. Elytra yellow with the following black markings with blue and blue-green reflections: very broad fascia from base to middle reaching margin, enclosing medial elongate yellow spot

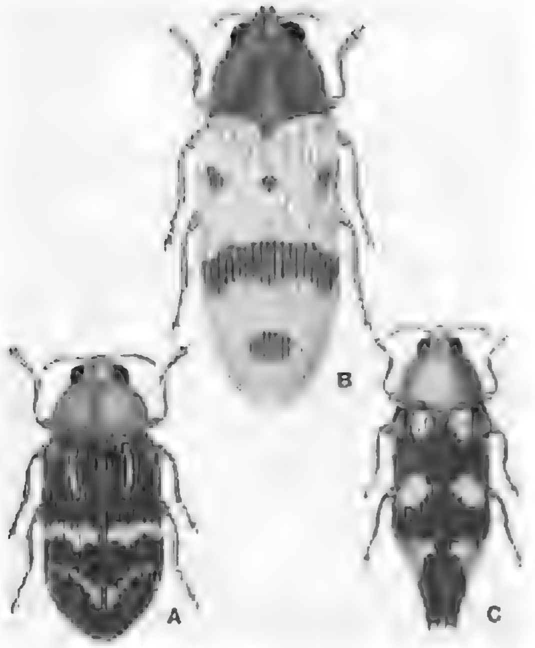

FIG. 3. A. *Stigmodera macquillani* sp. nov., B. *S. ashburtonensis* sp. nov., C. *S. mayoiana* sp. nov.(x3)

and one on margin at humeral callus; posteromedial fascia reaching margin, expanded on suture; spade-shaped mark covering apex, marks irregular. Ventral surface green with yellow reflections. Legs: dorsal surface blue-green; ventral surface green. Hairs silver.

Shape and sculpture. Head closely punctured, median sulcus, short muzzle, hairy. Antennae, segments: 1-3 obconic; 4-11 toothed. Pronotum closely punctured, basal fovea extending forwards to middle as impressed line then to apex as glabrous line; basal notches represented by glabrous area on each side more marginal than medial; apical margin projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, rounded to widest anteromedially, rounded and narrowed to apex, hairy. Scutellum scutiform, no punctures, excavate. Elytra costate, scutellary, 3rd, 5th, 7th and 9th intervals raised and smooth, those between flat and wrinkled; laterally slightly angled out from base, rounded at humeral callus, parallel-sided, rounded posteromedially and narrowed to truncate, spineless apex. Ventral surface with shallow punctures, edges of abdominal segments glabrous, long sparse hair. S_7: male truncate medially indented; female unknown.

Size. Males, 12.0 × 5.3 mm (2).

Male genitalia. (Fig 1C). Short. Parameres angled outwards from basal piece, rounded posteromedially, straight, rounded apically. Median lobe with sharp point, sides acutely angled away. Apophysis of basal piece broad, rounded apically.

Remarks. I am unable to group this species with any other. It is the third known species in the genus with hairy head and pronotum, the other two being *S. jubata* Blackburn and *S. rudis* Carter. All occur in montane areas in Tasmania and it is possible that the unusual presence of hair is associated with temperature regulation. Both specimens were collected on the flowers of *Leptospermum rupestre* J. D. Hook. Named after Mr P. McQuillan, Hobart.

FIG. 4. A. *Stigmodera deliciosa* sp. nov.; B. *S. sedlaceki* sp. nov., C. *S. tepperi* sp. nov.(x3)

Stigmodera (Castiarina) deliciosa sp. nov.
FIGS 1N, 4A

Holotype. ♂, Ourimbah, NSW, 6.xii.1987, *R. Mayo*, SAMA I 21209.

Allotype. ♀, Mt Glorious, Qld, 26.i.1982, *A. Hiller*, QMBA.

Paratypes. Qld: 1 ♀, Mt Glorious, 10.i.1984, *A. Hiller*, AHQA. N.S.W.: 1 ♂, same data as holotype, RMNA; 1 ♂, Ourimbah, 30.xi.1987, *R. Mayo*, RMNA; 1 ♂, Ourimbah, 29.xi.1987, *T. M. S. Hanlon*, MHSA; 9 ♂♂, Ourimbah, 30.xi./5.xii.1987, *R. de Keyzer, A. Sundholm*, ASSA.

Colour. Head bronze or purple bronze with green muzzle. Antennae, scutellum green. Pronotum green laterally, bronze or purple bronze medially. Elytra yellow with the following black markings: narrow basal margin; broad anteromedial fascia ends expanded anteriorly and posteriorly enclosing a yellow spot on each side and an elongate yellow mark on margin; posteromedial fascia ends expanded anteriorly and posteriorly enclosing a yellow spot on each side between it and the anteromedial fascia and elongate apical mark enclosing a yellow mark with red margin between itself and posteromedial fascia. Ventral surface green. Legs blue. Hairs silver.

Shape and sculpture. Head shallowly punctured, median sulcus, medium-length muzzle. Antennae; segments: 1–4 obconic, 5–11 toothed. Pronotum shallowly punctured, glabrous, small basal fovea, extending forwards to middle as faint impressed line, basal notches on each side more marginal than medial; apical margin projecting medially, basal margin bisinuate; laterally parallel-sided at base, rounded to widest part anteromedially, rounded and narrowed to apex. Scutellum cordiform, faintly punctured, glabrous, excavate. Elytra costate, 3rd, 5th, 7th and 9th slightly raised, margin flattened, intervals faintly punctured, glabrous; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and tapered to bispinose apex; large sharp marginal spine, smaller sharp sutural spine, margin rounded between, apices diverging. Ventral surface shallow punctures, edges of abdominal segments glabrous, sparse medium length hairs. S_7: male truncate; female rounded. Meso-sternal process slightly inflated.

Size. Males, 13.8 ± 0.10 × 4.9 ± 0.04 mm (14). Females, 15.0 × 5.2 mm (2).

Male genitalia. (Fig. 1N). Parameres angled outwards from basal piece, rounded at apex. Median lobe pointed, sides obtusely angled away. Apophysis of basal piece moderately large, narrowed, rounded apically.

Remarks. This species is a member of the *S. producta* Saunders mimicry group. I am unable to place it in any species group on the basis of external morphology and structure of male genitalia. Adults were collected on *Euodia* sp. at Mt Glorious and on *Acmena* sp. at Ourimbah. The name is derived from *deliciosus* L., delightful.

Stigmodera (Castiarina) mayoiana sp. nov.
FIGS 1G, 3C

Holotype. ♂, Ourimbah, N.S.W., 20.xii.1987, *R. Mayo*, SAMA 21210.

Paratypes. N.S.W.: 1 ♂, Ourimbah, 23.xii.1987, *A. Sundholm, R. de Keyzer*, ASSA; 1 ♂, Ourimbah, 26.xii.1987, *R. Mayo*, RMNA.

Colour. Head green with yellow reflections, muzzle blue-green. Antennae, segments: 1 blue-green, 2-11 green with yellow reflections. Pronotum and scutellum green with yellow reflections. Elytra yellow with the following black markings: basal margin; anteromedial fascia; posteromedial fascia, the above all coalesced on margin enclosing, yellow basal spot, spot on humeral callus, anteromedial spot; mark covering apex and spines, between it and 2nd fascia a yellow spot merging with red mark on margin.

Shape and sculpture. Head shallowly punctured, shallow median sulcus, short muzzle. Antennae, segments: 1–4 obconic; 5–11 toothed. Pronotum shallowly punctured, glabrous, small basal fovea, small basal notches, more marginal than medial; apical margin straight, basal margin bisinuate; laterally angled inwards from base, rounded anteromedially, rounded and narrowed to apex. Scutellum tulipiform, glabrous, excavate. Elytra punctate-striate, 3rd, 5th, 7th and 9th intervals prominent, apical margin flattened, intervals convex and smooth; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and tapered to acuminate, bispinose apex; sharp marginal spine, smaller sharp sutural spine, margin rounded between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, short sparse hair. S_7: male truncate, slightly indented medially; female unknown. Mesosternal process inflated. Male: legs 2 and 3, tarsal pads absent tarsomeres 1–3, replaced by median spine, larger on tarsomere 3 than on tarsomeres 1 and 2.

Size. Males, 12.9 × 4.6 mm (3).

Male genitalia. (Fig. 1G). Parameres angled outwards from basal piece, rounded apically. Median lobe with sharp point, sides obtusely angled away. Apophysis of basal piece elongate, medium width, narrowed medially, rounded apically.

Remarks. This species is a member of the *S. producta* Saunders mimicry group. I am unable to group it with any other species on the basis of external morphology and structure of the male genitalia. Named after Mr R. Mayo, Narara.

Stigmodera (Castiarina) murchisonensis sp. nov.
FIGS 1D, 2A

Holotype: ♂, 56 km N Murchison R., W.A., 23.xii.1986, *M. Powell*, WAMA.

Allotype: ♀, same data as holotype, SAMA I 21211.

Colour: Head, antennae, pronotum bronze. Scutellum black. Elytra yellow with following black markings: narrow basal margin; anteromedial fascia, ends expanded anteriorly, not reaching margin, and posteriorly reaching margin; posteromedial fascia reaching margin, projecting anteriorly from middle of each elytron; apical mark, last three marks connected along suture. Ventral surface and legs bronze. Hairs silver.

Shape and sculpture: Head closely punctured, median sulcus, very short muzzle. Antennae compressed, segments: 1–3 obconic; 4–11 toothed. Pronotum closely punctured, basal fovea extending to middle as glabrous impressed line, then to apical margin as impressed line, basal notches represented by glabrous area on each side more marginal than medial; apical margin straight, basal margin bisinuate; laterally parallel-sided at base, rounded to widest part medially, rounded to apex. Scutellum scutiform. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and narrowed to bispinose apex; sharp marginal spine, small sharp sutural spine, margin rounded and indented between, apices diverging, apical margin subserrate. Ventral surface with shallow punctures, edges of abdominal segments glabrous, hairy, hairs short, S_7: truncate both sexes.

Size: Male, 11.3 × 4.1 mm (1). Female, 12.1 × 4.5 mm (1).

Male genitalia: (Fig. 1D) Short. Parameres parallel-sided basally, widened, rounded anteromedially, parallel-sided, rounded to apex. Median lobe blunt, sides acutely rounded away. Apophysis of basal piece moderately wide, rounded apically.

Remarks: Member of the *S. cupricauda* Saunders species group. Must resembles *S. chinnocki* Barker but male genitalia are more like those of *S. cupricauda* (Barker 1983). However *S. chinnocki* has denser punctuations on the head and pronotum, the elytral intervals are flatter and it has a southern distribution in W.A. and S. Aust. The name is derived from the type locality.

Stigmodera (Castiarina) sedlaceki sp. nov.
FIGS 1O, 4B

Holotype. ♂, Mt Kaindi, New Guinea, 2350 m, 24.i.1979, *J. Sedlacek*, SAMA I 21212.

Colour. Head, antennae, pronotum and scutellum dark blue. Elytra very dark blue with an elongate red mark on each elytron from base to anteromedial area over the humeral callus and along the margin, not reaching suture. Ventral surface and legs dark blue. Hairs silver.

Shape and sculpture. Head closely punctured, median sulcus, short muzzle. Antennae, segments: 1–4 obconic; 5–11 toothed. Pronotum closely punctured, basal fovea extending forwards to middle as glabrous line, basal notches represented by glabrous area on each side more marginal than medial; apical margin broadly projecting medially, basal margin bisinuate; laterally angled inwards from base, rounded to widest anteromedially, rounded and narrowed to apex. Scutellum cordiform, few punctures, glabrous, excavate. Elytra punctate-striate, intervals convex, smooth; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and narrowed to bispinose apex; sharp marginal spine, small, sharp sutural spine, margin rounded and indented between, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, short sparse hair. S_7: male truncate; female unknown. Mesosternal process slightly inflated.

Size. Male, 11.0 × 4.1 mm (1).

Male genitalia. (Fig. 1O). Parameres parallel-sided basally, rounded anteromedially, parallel-sided, rounded apically. Median lobe sharp, sides acutely angled away. Apophysis of basal piece medium width, narrowed, rounded apically.

Remarks. I am unable to group this with any other species on the basis of external morphology or structure of male genitalia. Superficially this resembles *S. borealis* Barker which is a similar colour and also has red elytral markings. However, *S. borealis* is a much smaller species and the elytral apices are markedly serrate whereas they are smooth in *S. sedlaceki*. Named after the collector Mr J. Sedlacek, Brookfield.

Stigmodera (Castiarina) tepperi sp. nov.
FIGS 1L, 4C

Holotype. ♂, Ardrossan, S. Aust., *J. G. O. Tepper*, SAMA I 21213.

Allotype. ♀, same data as holotype, SAMA I 21214.

Paratypes. S. Aust.: 2 ♂♂, 3 ♀♀, same data as holotype, SAMA; 1 ♂, Eyre's Pen., SAMA; 1 ♀, Hincks N.P., Eyre Pen., 7.x.1979, *D. V. Lucis*, SAMA; 1 ♀, Addison Park, Eyre Pen., 11.x.1981, *J. & D. Gardner*, SAMA: 1 ♀, Wharminda Soaks, Eyre Pen., 13.xi.1987, *G. G. Burns*, GBVA.

Colour. Head bronze-green. Antennae, segments: 1–2 blue-green; 3–11 bronze-green. Pronotum and scutellum bronze green. Elytra yellow with the following blue-green markings; narrow basal margin; short vitta over each humeral callus; narrow post-medial fascia not reaching margin; diamond-shaped pre-apical mark often reduced, all marks connected along suture. Ventral surface: sternum bronze-green; abdomen testaceous. Legs bronze-green. Hairs silver.

Shape and sculpture. Head closely punctured, short muzzle. Antennae, segments: 1–3 obconic; 4–11 toothed. Pronotum closely punctured, basal fovea extending forwards to middle as glabrous line, small basal notches on each side more marginal than medial; apical margin projecting medially, basal margin barely bisinuate; laterally rounded from base, widest postero-medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex; laterally angled out from base, rounded at humeral callus, concave, rounded postero-medially then tapered to bispinose apex; both spines small and blunt, margin straight and indented between, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, moderately hairy, hairs short. S_7: male truncate; female rounded.

Size. *Males*, 15.8 ± 0.48 × 6.0 ± 0.13 mm (5). Females, 15.2 ± 0.37 × 5.9 ± 0.22 mm (6).

Male genitalia. (Fig. 1L) Parameres parallel-sided from basal piece, rounded postero-medially, rounded and tapered, rounded to apex. Median lobe sharp, sides obtusely angled away. Apophysis of basal piece short, narrowed medially, rounded apically.

Remarks. This species is a member of the *S. stramineu* Saunders species group on the basis of its external morphology, structure of the male genitalia and testaceous abdomen. It most resembles *S. burnsi* Barker. However the head, pronotum and sternum are bronze-green whereas they are bright green in *S. burnsi*. The elytral markings are blue-green in *S. tepperi* and blue in *S. burnsi* and the male genitalia are a different shape and smaller in *S. tepperi*, despite individuals being the same size as *S. burnsi* (Fig. 1M). *S. tepperi* has been collected from the Yorke and Eyre Peninsulas, S. Aust., while *S. burnsi* has been collected on the Adelaide Plains, Murray Mallee and Victorian mallee districts. Named after the late Mr J. G. O. Tepper.

Stigmodera (Castiarina) watkinsi sp. nov.
FIGS 1E, 2C

Holotype: ♂, Mt York, Blue Mts, N.S.W., 15.xii.1987, *S. Watkins*, SAMA I 21215.

Allotype: ♀, same data as holotype, SAMA I 21216.

Paratypes. N.S.W.: 1♂, 1♀, Blue Mts, *G. Masters*, SAMA; 1 ♂, 1 ♀, Medlow, *H. J. Carter*, SAMA; 5 ♂♂, 4 ♀♀, same data as holotype, SWNA; 8 ♂♂, 8 ♀♀, Mt York, 21/25.xii.1985, 12.i.1986, 13/21.xii.1987, *S. Watkins*, SWNA; 17 ♂♂, 11 ♀♀, Mt Boyce, Blue Mts, 27.xii.1985, 13/15/17.xii.1987, *S. Watkins*, SWNA; 4 ♂♂, 3 ♀♀, Macquarie Pass, Mt Murray Rd, Blue Mts, 2.i.1986, *S. Watkins*, SWNA; 6 ♂♂, 2 ♀♀, Leura, 23.xii.1985, 28.xii.1987, *S. Watkins*, SWNA; 2 ♂♂, Wentworth Falls, 25.xii.1985, *S. Watkins*, SWNA; 1 ♂, Bald Knob Rd, Dundee, 19.xii.1987, *S. Watkins*, SWNA; 1 ♂, 1 ♀, 13km SW Ebor, *S. Watkins*, SWNA; 1 ♂, 2 ♀♀, Coxs Rd, State Forest, 20.xii.1987, *S. Watkins*, SWNA; 4 ♂♂, 1 ♀, Hartley Vale, 15.xii.1987, *S. Watkins*, SWNA; 2 ♂♂, 4 ♀♀, 14–16 km NE Deepwater, 20.xii.1987, *G. Williams*, GWNA.

Colour: Head and antennae blue-green with yellow reflections or blue. Pronotum blue-green or blue medially, orange laterally except neck collar and base. Scutellum blue-green with yellow reflections or blue. Elytra orange, with following markings either green with yellow reflections or blue with purple reflections: very broad basal fascia; postero-medial fascia reaching margin, expanded anteriorly on anterior margin at suture and posteriorly on posterior margin at suture; spade-shaped apical mark, all marks connected along suture. Ventral surface and legs green with yellow reflections or green blue. Hairs silver.

Shape and sculpture: Head closely punctured, median sulcus, short muzzle. Antennae, segments: 1–3 obconic; 4–11 toothed. Pronotum closely punctured, basal fovea extending forwards to apical margin as impressed line; apical margin projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, rounded to widest part medially, rounded to apex. Scutellum scutiform, punctured, flat. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and narrowed to rounded, spineless apex; apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, moderately hairy, hairs short. S_7: male truncate; female rounded.

Size: Males, 10.2 ± 0.10 mm × 3.9 ± 0.04 mm (54). Females, 10.8 ± 0.12 × 4.2 ± 0.05 mm (39).

Male genitalia: (Fig. 1E). Short. Parameres widened basally, rounded medially, narrowed, rounded apically. Median lobe sharp, sides acutely angled away. Apophysis of basal piece medium width, tapered, rounded apically.

Remarks: Member of *S. distinguenda* Saunders species group. Carter (1929) apparently confused this species with *S. grata* Saunders, as he listed *S. grata* occurring in Qld, N.S.W., Vic., and S. Aust. *S. grata* is red on the dorsal surface with blue markings and occurs only on Fleurieu Peninsula and on Kangaroo Island, S. Aust. It is a larger species and its male genitalia are distinct from those of this species (Barker 1983). The elytral colour and pattern are distinct from all other members in this species group (Barker 1986). Named after Mr S. Watkins, Caparra.

Stigmodera (Castiarina) williamsi sp. nov.
FIGS 1F, 2D

Holotype. ♂, Wingham, N.S.W., 3.xii.1987, *G. Williams*, SAMA I 21217

Allotype. ♀, same data as holotype, SAMA I 21218.

Paratypes. N.S.W.: 2 ♂♂, 2 ♀♀, Wingham, 3–5.xii.1987, *G. Williams*, GWNA.

Colour. Head; apex yellow-green; base coppery. Antennae yellow green. Pronotum and scutellum coppery. Elytra pale yellow with the following black markings with green reflections: narrow basal margin; curved mark over each humeral callus connected to basal margin; anteromedial fascia represented by diamond-shaped mark on suture and a medial mark on each side and one on margin variably absent in some specimens; posteromedial fascia reaching margin, projecting anteriorly on suture and on anterior margin closer to lateral margin than suture; mark covering apex, all marks connected along suture. Hairs silver.

Shape and sculpture. Head closely punctured, broad median sulcus, short muzzle. Antennae, segments: 1–4 obconic; 5–11 toothed. Pronotum closely punctured, basal fovea; apical margin straight, basal margin bisinuate; laterally parallel-sided at base, rounded to widest part medially, rounded to apex. Scutellum scutiform, few punctures, glabrous, excavate. Elytra punctate-striate, intervals convex, smooth; laterally angled out from base, rounded at humeral callus, concave, rounded posteromedially and narrowed to bispinose apex; sharp marginal spine, minute sutural spine, margin rounded and indented between, apices hardly diverging. Ventral surface shallowly punctured, edges of abdominal segments glabrous, sparse very short hairs. S_7 truncate in both sexes.

Size. Males, 6.6 × 2.3 mm (3). Females, 6.8 × 2.4 mm (3).

Male genitalia. (Fig. 1F) Short. Parameres widened basally, rounded anteromedially then narrowed, widened pre-apically, rounded apically. Median lobe pointed, Apophysis of basal piece wide, rounded apically.

Remarks. The male genitalia of this species most closely resemble those of *S. sieboldi* C & G. Barker (1983) Fig. 1K. Both species belong in the *S. crenata* (Don.) species group. *S. sieboldi*, Barker (1983) Fig. 4E, has bicolourous pronotum, blue medially and green laterally. It has orange-red elytra with black pre- and post-medial fascia and pre-apical mark, is a larger species and occurs only in southern W.A. Named after Mr G. Williams, Lansdowne.

Distribution of S. puteolata *Carter*

I have examined a single male specimen of *S. puteolata* Carter, collected by Mr E. E. Adams on *Eremophila bignoniiflora* (Benth.) F. Muell. near the junction of the Dawson and MacKenzie Rivers, central Queensland. There is a single specimen of the same species in the S.A. Museum, collected at Ooldea, S. Aust. These records represent a considerable range extension as the species was previously known from the eastern goldfields district, W.A.

Erratum

Barker (1987) p. 136. Holotype of *Stigmodera (Castiariana) dugganensis* Barker SAMA should read No I 21181 not I 21178

Acknowledgments

I thank the following for assistance: Dr G. F. Gross and Dr E. G. Matthews, South Australian Museum; Dr D. S. Horning, Macleay Museum, Sydney; Dr A. Neboiss, National Museum of Victoria; Dr R. Chinnock, S.A. Herbarium, Adelaide; Mr K. T. Richards, Department of Agriculture, South Perth; Mr P. McQuillan, Department of Agriculture, Hobart; Mr T. Weir, A.N.I.C.; Miss C.M.F. von Hayek, British Museum, (N.H.); Dr T. F. Houston, Western Australian Museum; Mr E. E. Adams, Edungalba; Mr G. G. Burns, Mornington; Mr H. Demarz, Quinns Rocks; Mr T. M. S. Hanlon, Ryde; Mr A. Hiller, Mt Glorious; Mr R. Mayo, Narara; Mr M. Powell, Attadale; Mr A. Sundholm, Elizabeth Bay; Mr S. Watkins, Caparra; Mr G. Williams, Lansdowne; Miss H. Vanderwoude, Dr J. Gardner and Mr P. Kempster Department of Zoology, University of Adelaide.

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TRANSACTIONS OF THE

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

VOL. 112, PART 4

A NEW SPECIES OF SCINCID LIZARD RELATED TO *LEZOLOPZSMA ENTRECASTEAUXII*, FROM SOUTHEASTERN AUSTRALIA

BY *MARK N. HUTCHINSON*, & STEPHEN C. DONNELLAN†*

Summary

A scincid lizard, *Leiolopisma rawlinsoni* sp. nov., is described from southeastern Australia. It is confined to swampy habitats from sea level to subalpine elevations and is rare in collections. The new species belongs to the *L. baudini* species-complex, which also includes two other eastern species, *L. entrecastreauxii* Groups 1 and 2 (Donnellan & Hutchinson in press) and a southwestern species, *L. baudini* Greer, 1982.

KEY WORDS: Taxonomy, species-complex, *Leiolopisma,* Scincidae, Reptilia, distribution, ecology.

A NEW SPECIES OF SCINCID LIZARD RELATED TO *LEIOLOPISMA ENTRECASTEAUXII*, FROM SOUTHEASTERN AUSTRALIA

by MARK N. HUTCHINSON[*], & STEPHEN C. DONNELLAN[†]

Summary

HUTCHINSON, M. N. & DONNELLAN, S. C. (1988) A new species of scincid lizard related to *Leiolopisma entrecasteauxii*, from southeastern Australia. *Trans. R. Soc. S. Aust.* 112, 143-151, 30 November, 1988.

A scincid lizard, *Leiolopisma rawlinsoni* sp. nov., is described from southeastern Australia. It is confined to swampy habitats from sea level to subalpine elevations and is rare in collections. The new species belongs to the *L. baudini* species-complex, which also includes two other eastern species, *L. entrecastreauxii* Groups 1 and 2 (Donnellan & Hutchinson in press) and a southwestern species, *L. baudini* Greer, 1982.

KEY WORDS: Taxonomy, species-complex, *Leiolopisma*, Scincidae, Reptilia, distribution, ecology.

Introduction

Donnellan & Hutchinson (in press), using allozyme electrophoresis, showed that the eastern Australian skinks identified as *Leiolopisma entrecasteauxii* (Duméril & Bibron, 1839) included at least three distinct biological species. Morphological features appeared to correlate with the biochemical markers, and both the morphology and biochemistry suggested that the common ancestor of the three species had initially diverged into two entities. One consisted of a pair of species (*L. entrecasteauxii* Groups 1 and 2), between which morphological and electrophoretic divergence was slight, but which differed appreciably (five fixed genetic differences) from the third species (*L. entrecasteauxii* Group 3). Studies by Hutchinson & Donnellan (in prep.) indicate that the name *entrecasteauxii* belongs to one of the two closely related species; which one is still uncertain because of the overlap in morphological characters between Groups 1 and 2 plus the poor state of preservation of the type specimens. The morphology of the Group 3 skinks, particularly the light dorsolateral line centred on scale row 3, makes it clear that none of the available names presently synonymized with *L. entrecasteauxii* applies to these specimens, so that a new name is required for them.

The new species is especially similar in some respects to *L. baudini* of Western Australia. *L. baudini* was described from a single specimen which showed several scalation and colour pattern differences from *L. entrecasteauxii (s.l.)*, although it strongly resembled the eastern "species" and was regarded as its closest relative (Greer 1982). Since the holotype description was published, further specimens of *L. baudini* have been collected and work in progress (Hutchinson & Donnellan in prep.) will provide data on variation within this species. *L. baudini* and the new species share higher supraciliary and lower midbody scale row counts than are seen in *L. entrecasteauxii* Groups 1 and 2, but differ from each other in several other scalation and colour pattern features.

The new species, *L. baudini* and the two eastern species included in *L. entrecasteauxii (s.l.)* form a closely related group of species which we term the *L. baudini* species-complex.

Materials and Methods

Definition of head shields and methods for making scale counts follow Greer (1982). The positions of the longitudinal stripes are also as described by Greer, in terms of their position on one or more longitudinal scale rows. Scale rows are numbered on each side starting from the paravertebral row as row 1 and proceeding laterally. Scalation features occurring bilaterally, such as supraciliaries, upper and lower labials, presuboculars and subdigital lamellae, were counted on both sides, and mean and modal values therefore refer to the overall values for both sides. Measurements of preserved specimens were made using a steel ruler graduated to 0.5 mm. Snout-vent lengths (SVL) were measured to the nearest 1.0 mm, as were tail lengths (TL), while forelimb length (FLL) and hind limb length (HLL) were measured to the nearest 0.5 mm. Eye, palpebral disc and ear diameters were measured using a calibrated microscope eyepiece to the nearest 0.1 mm.

Females with snout-vent lengths equal to or longer than that of the smallest female in the population containing oviducal eggs or embryos were assumed to be sexually mature. Sexual maturity in males was judged by the presence of enlarged testes.

The following collections included specimens of the new species, or provided comparative material of the other species in the complex. Institutional abbreviations follow Leviton *et al.* (1985): Australian Museum, Sydney (AMS); Australian National

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[*] School of Biological Sciences, La Trobe University, Bundoora, Vic. 3083.

[†] South Australian Museum, North Terrace, Adelaide, S. Aust. 5000.

Wildlife Collection, Canberra (ANWC); Author's collection, La Trobe University (MNH); Museum of Victoria, Melbourne (NMV); Queen Victoria Museum, Launceston (QVMT); South Australian Museum, Adelaide (SAMA); Tasmanian Museum, Hobart (TMH); Western Australian Museum, Perth (WAM).

TAXONOMY

The *Leiolopisma baudini* species-complex

The term "species-complex" is used here for the first time in relation to these lizards, although Greer (1982) had already pointed out some of the similarities which suggested a close relationship between *L. baudini* and the eastern species then known as *L. entrecasteauxii*. The complex consists of at least four species (Donnellan & Hutchinson in press), all members of the Australian viviparous *Leiolopisma* radiation (Greer 1982; Hutchinson *et al.* 1988).

The *L. baudini* species-complex belongs to the *Eugongylus* subgroup of the *Eugongylus* group (Greer 1979) within the subfamily Lygosominae, and has nine of the ten character states outlined by Greer (1979) as being diagnostic for the *Eugongylus* subgroup. The only exception to this concerns the palate, which varies between the typically alpha condition, with smoothly diverging medial margins of the pterygoids, to one with a marked development of posteromedially directed processes similar to the beta palate condition of the *Lampropholis* subgroup (MNH pers. obs.). *Leiolopisma* is a "grade" group of generalized, window-eyed *Eugongylus* group species. It is not demonstrably a natural group and is in need of revision. We use Greer's (1974) concept of *Leiolopisma* as modified by Sadlier (1986), differing from the latter author only in that, currently, we include *Pseudemoia* (*sensu* Rawlinson 1974b) within *Leiolopisma*.

Content: Leiolopisma baudini Greer, 1982; *L. entrecasteauxii* Group 1; *L. entrecasteauxii* Group 2; *L. rawlinsoni sp. nov.* It should be noted that Group 1 and Group 2 (Donnellan & Hutchinson in press) are assemblages which only partly correspond to the division of this species into Forms A and B (Pengilley 1972)[1].

Characteristics of the *L. baudini* species-complex

In inferring the evolutionary polarity of the character states discussed below, outgroup comparison, using the other Australian *Eugongylus* group taxa as the outgroup, has been the method used to identify plesiomorphic character states.

Within the *Eugongylus* subgroup, the *L. baudini* species-complex is characterized by the following combination of primitive and derived character states: a relatively deep, blunt head and a relatively deep body with moderate limbs (hind limb normally 30% to 40% of snout-vent length); paired frontoparietals and distinct interparietal; supranasals and postnasals present or absent; large to moderately small midbody scales (in 23–36 rows); a very large transparent disc (diameter > 50% of eye diameter) in the moveable lower eyelid; upper temporal fenestra closed; 30 or fewer presacral vertebrae. The species are sexually dichromatic, with males developing areas of red pigmentation, and three (no data available for *L. baudini*) are viviparous.

Of these, four are synapomorphies: viviparity, a large palpebral disc, a closed upper temporal fenestra and sexual dichromatism. These four in combination are unique within the *Eugongylus* group, implying that the *L. baudini* species-complex is not only readily defined but also monophyletic.

Derived character states of the L. baudini *species-complex*

Large palpebral disc: A transparent palpebral disc is present in most *Eugongylus* group taxa. It is usually moderately sized, with a diameter about 40% of the eye length. In the *L. baudini* species-complex, the disc is markedly larger, 50–60% of the eye diameter. This large disc appears to be apomorphic with respect to the smaller disc seen in other taxa with movable eyelids, but plesiomorphic (and possibly immediately ancestral to) the state seen in ablepharine genera such as *Morethia* and *Cryptoblepharus*.

Dichromatism: Greer (1980, 1982) has commented on the presence of areas of red colouring present in some Australian *Leiolopisma* and related genera. In the *L. baudini* species-complex, as in some, but not all, of the other taxa with red pigmentation, the colour is limited to males. This sexual dichromatism reaches its most vivid development in late summer-autumn, when testis size is at a maximum and mating occurs. Whether the presence or absence of red pigment *per se* is plesiomorphic or apomorphic in the *Eugongylus* group is not clear. However, sexual dichromatism is relatively rare in this group of skinks and is probably apomorphic.

Viviparity: By far the most common mode of reproduction in the *Eugongylus* group is oviparity, and this is no doubt the plesiomorphic condition. Viviparity occurs only in some *Leiolopisma* species in Australia (Greer 1982), and in most *Leiolopisma* and all *Cyclodina* in New Zealand (Hardy 1977). Viviparity is therefore an apomorphic character state in the *L. baudini* species-complex. The

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[1] PENGILLEY, R. (1972) Systematic relationships and ecology of some lygosomine lizards from southeastern Australia. Unpub. PhD thesis, Dept of Zoology, Australian National University, Canberra.

reproductive mode of *L. baudini* is not yet known. However, it appears to mate in autumn, as evidenced by enlarged testis size in males and fresh bite scars around the chest and shoulder area of females, and autumn mating is a characteristic of viviparous skinks in southeastern Australia (Smyth 1968; Rawlinson 1974a).

Upper temporal fenestra: This opening in the skull roof, bordered by the parietal and postfrontal in the *Eugongylus* group, is a plesiomorphy in skinks. The opening, when present, is reduced in the *Eugongylus* group, and in many taxa it is completely obliterated or no more than a pinhole. This apomorphic condition (completely closed or almost so) is present in the *L. baudini* species-complex.

Leiolopisma rawlinsoni sp. nov.

FIGS 1-4

Lygosoma (Liolepisma) entrecasteauxii (part) Lucas & Frost (1894).

Leiolopisma entrecasteauxii (part) Rawlinson (1967, 1971, 1975); Spellerberg (1972); Cogger (1975); Greer (1982); Cogger *et al.* (1983).

Leiolopisma entrecasteauxii Form A (part) Jenkins & Bartell (1980). [designation *ex* Pengilley (1972)[1]].

Leiolopisma entrecasteauxii Group 3 Donnellan & Hutchinson (in press).

Holotype: NMV D55450. Adult male. Mouth of Bunyip River (Main Drain) (38° 13′ S; 145° 26′ E), 6.5 km E Tooradin, Vic. Collected by P. Robertson on 21.vi.1981).

Diagnosis: Member of the *L. baudini* species-complex, characterized by strongly striped colour pattern completely lacking lighter or darker dorsal, lateral or caudal speckling, light dorsolateral line on scale row 3, and having dorsal and head scales with highly glossy surface.

Generally distinguished from other eastern species in complex (*L. entrecasteauxii* Groups 1 and 2) by position of light dorsolateral stripe on scale row 3 (rather than row 4, or 3+4), in normally having 6, rather than 5, supraciliaries, and by having fewer rows of midbody scales (mode 26, rather than 30). Most similar in these respects to *L. baudini* (*sensu* Hutchinson & Donnellan in prep.), from which it is distinguished by lacking partial or complete supranasal or postnasal scales and any trace of light dorsal or caudal flecks, and by mid-lateral white stripe continuing clear and straight-edged from groin to side of head, rather than becoming vague and wavy-edged anterior to axilla. Also distinguished from *L. baudini* by highly glossed dorsal scales, by having fewer subdigital lamellae (17-23, mean 19.0, versus 20-25, mean 22.3) and higher paravertebral scale counts (in males, 57-63, mean 59.6, versus 50-58, mean 54.1; in females 57-65, mean 62.2, versus 53-60, mean 57.6), and by its strict preference for densely vegetated swampy habitats.

Etymology: Named after Peter A. Rawlinson, Department of Zoology, La Trobe University, in recognition of his studies of the scincid lizard fauna of southeastern Australia.

Description of holotype: Moderate-sized with pentadactyl limbs overlapping when adpressed, snout relatively blunt, head and body deep and squarish in cross-section, and colour pattern

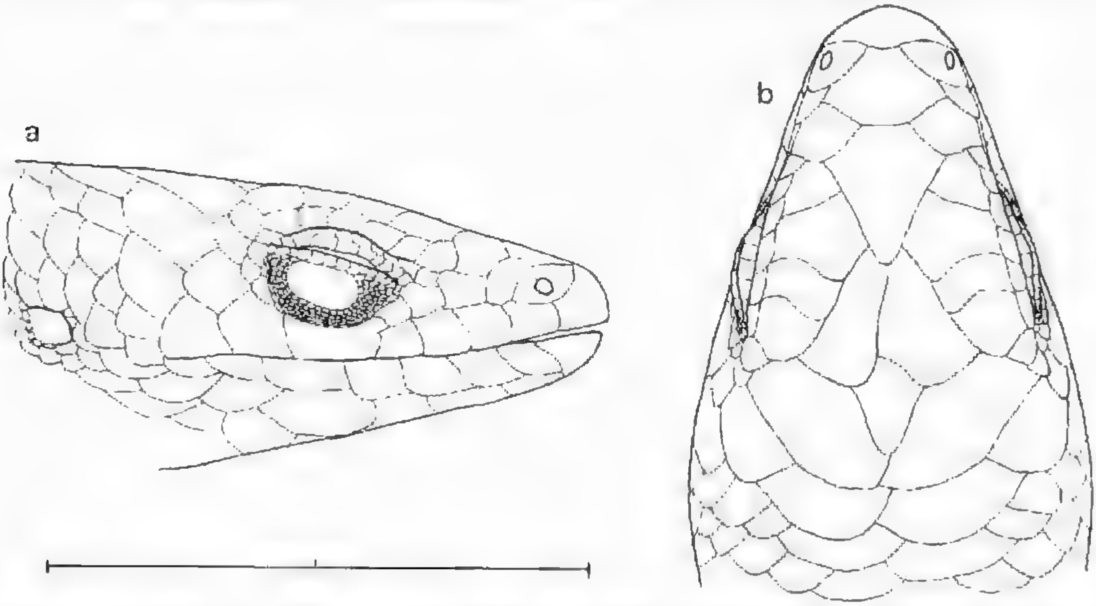

FIG 1. Holotype of *Leiolopisma rawlinsoni* sp. nov. (NMV D55450). Head scalation in (a) right lateral and (b) dorsal view. Scale bar = 10 mm.

consisting solely of longitudinal dark and light stripes. Hemipenis columnar (Greer 1979) not deeply bifurcated. Iris paler than pupil.

Midbody scales in 26 rows. Dorsal scales with three moderately strong keels, lateral scales more weakly tricarinate; trailing edges of dorsal and lateral scales angularly three-sided rather than smoothly rounded. Paravertebral scales 60. Midventral scales (mental to preanal inclusive) 63. Preanals 10, median four distinctly enlarged. Palmar and plantar tubercles rounded. Subdigital lamellae smooth, undivided, 20 under fourth toe. Dorsal surface of digits covered by single row of scales. No trace of supranasals or postnasals. Width of rostral-frontonasal suture less than half width of frontonasal. Prefrontals well separated; frontal contacting frontonasal. Supraoculars 4, second largest; first and second contacting frontal. Frontoparietals paired. Interparietal distinct, almost as large as a frontoparietal. Parietals large, in contact behind interparietal. Each parietal bordered posterolaterally by upper secondary temporal and enlarged nuchal. Supraciliaries 6. Loreals 2, anterior taller than broad, posterior squarish. Preoculars 2, lower largest and undivided. One presubocular. Upper ciliaries 9, lower ciliaries 13. Large transparent disc in lower eyelid, bordered above by 4 (left) or 5 (right) lower ciliaries. Upper labials 7, fifth subocular. One primary and two secondary temporals. Lower labials 7. Postmental contacting first and second lower labials. Ear opening subcircular, without enlarged lobules.

Dimensions: SVL 53 mm. TL 91 mm (distal half regenerated). FLL 13.0 mm (25% of SVL). HLL 20.5 mm (39% of SVL). Head width 7.4 mm (14% of SVL). Length of eye 2.4 mm. Length of palpebral disc 1.4 mm (58% of eye length). Maximum diameter of ear opening 0.9 mm (38% of eye length).

Colour (in preservative): Dorsal surface of head, back, tail and limbs medium greyish olive. Straight-edged black vertebral stripe occupying medial third of two paravertebral scale rows (row 1 on each side), fading anteriorly on nuchal scales and posteriorly about 20 mm on to base of tail. Prominent, straight-edged white dorsolateral stripe along middle of scale row 3 on each side, bordered by black lines; stripe fading anteriorly to level of ear but still visible on head behind supraciliary scales. Clear white midlateral stripe, bordered by narrow black lines, along scale row 6 (intruding slightly on to row 5) from posterior margin of ear opening, above axilla to base of hind leg. Pale dorsolateral and pale midlateral stripes extending well on to tail, becoming progressively less well defined; upper lateral zone between these stripes dark brown, colour extending forward over temporals to eye, where it narrows and continues as dark loreal streak to naris. White midlateral stripe extending forward as thinner white line from upper margin of ear opening along upper labials to below eye. No trace of darker or lighter speckling on dorsal or lateral patterns. Top of head unmarked except for few dark smudges on supraoculars. Upper surfaces of limbs with dark flecks arranged longitudinally, forming weak lines. Lower cheeks and sides of neck weakly marbled with grey, otherwise ventral surfaces immaculate silvery white. Palmar and plantar surfaces and basal subdigital lamellae grey-white; distal subdigital lamellae brown.

Variation

Paratypes: AUSTRALIAN CAPITAL TERRITORY. (ANWC). R2980, Picadilly Circus. (NMV). D38218, Mt Ginini; D59874, Ginini Flats.

NEW SOUTH WALES. (NMV). D36966, 16 km N of Tin Mine Hut; D59873, Smiggin Holes; D59875–76, Round Mountain; D60875–76, Daniers Gap, Kosciusko National Park; D60873–74, Tooma Reservoir, Kosciusko National Park; D60877, Kiandra.

VICTORIA. (AMS). R15837, Healesville; R67484, Tolmie; R67574, Maroondah Hwy, 5 km S of Buxton; R81649, 4 km SSW of Woodside East; R91693, 9.1 km [road] S of Forge Creek; R97269, Gembrook State Forest. (NMV). D722, Western Port; D1852, Ringwood; D2392, Alexandra; D11711, Benambra; D34210, 4 km SW of Bemm River; D36964, Port Campbell; D37325, 4 km N of Whittlesea; D37492, Yan Yean; D37500, 4 km N of Darby River, Wilsons Promontory; D39918, "St Kilda Junction", Wilsons Promontory; D40191, French Island; D42059, high plains NE of Benambra; D47553, Davies Plains (NE of Benambra); D47608, 10 km NE of Benambra; D48409, Boneo; D48411, 7 km E of Stringybark Creek, Healesville; D48412–13, Yan Yean; D48943, Dennison Lake; D48948–49, Jack Smiths Lake [= Salt Lake]; D52700, 2.5 km E of Tooradin; D54525–26, saltmarsh between Tankerton and Tortoise Head, French Island; D55344–45, Cockatoo Creek, 1.5 km S of Yellingbo; D55388, Gembrook State Forest; D55448–49, mouth of Bunyip River, main drain, 6.5 km E of Tooradin; D56601, 4 km SSW of Woodside East; D56606, Bayles; D57035, 5.4 km N of Koetong; D59797–800, 4 km SSW of Woodside East; D59869–70, Deep Creek, 4 km E of Tooradin; D59871–72, 4 km SSW of Woodside East.

SOUTH AUSTRALIA. (SAMA). R17492, N of Mt Gambier (Dismal Swamp area); R23098, Bool Lagoon.

TASMANIA. (NMV), D12349, Cape Barren Island.

Referred Specimens: (AMS). R4174, R27008, Victoria, (no other data).

Scalation: Midbody scales in 23–30 rows (mean 26.6, mode 26, n = 61). Paravertebral scales 57–64 (mean 60.7, n = 51). Subdigital lamellae under fourth toe 17–23 (mean 19.0, n = 30). No supranasal or postnasal scales. Prefrontals nearly always separated (in contact in 4 out of 64, freq = 0.06). Supraciliaries 5–8 (mean 5.9, mode 6, n = 61). All have 7 (symmetrically) upper labials. Usually one presubocular, less frequently two similar-sized presuboculars present on one or both sides (mean 1.2, n = 30). Lower preocular and

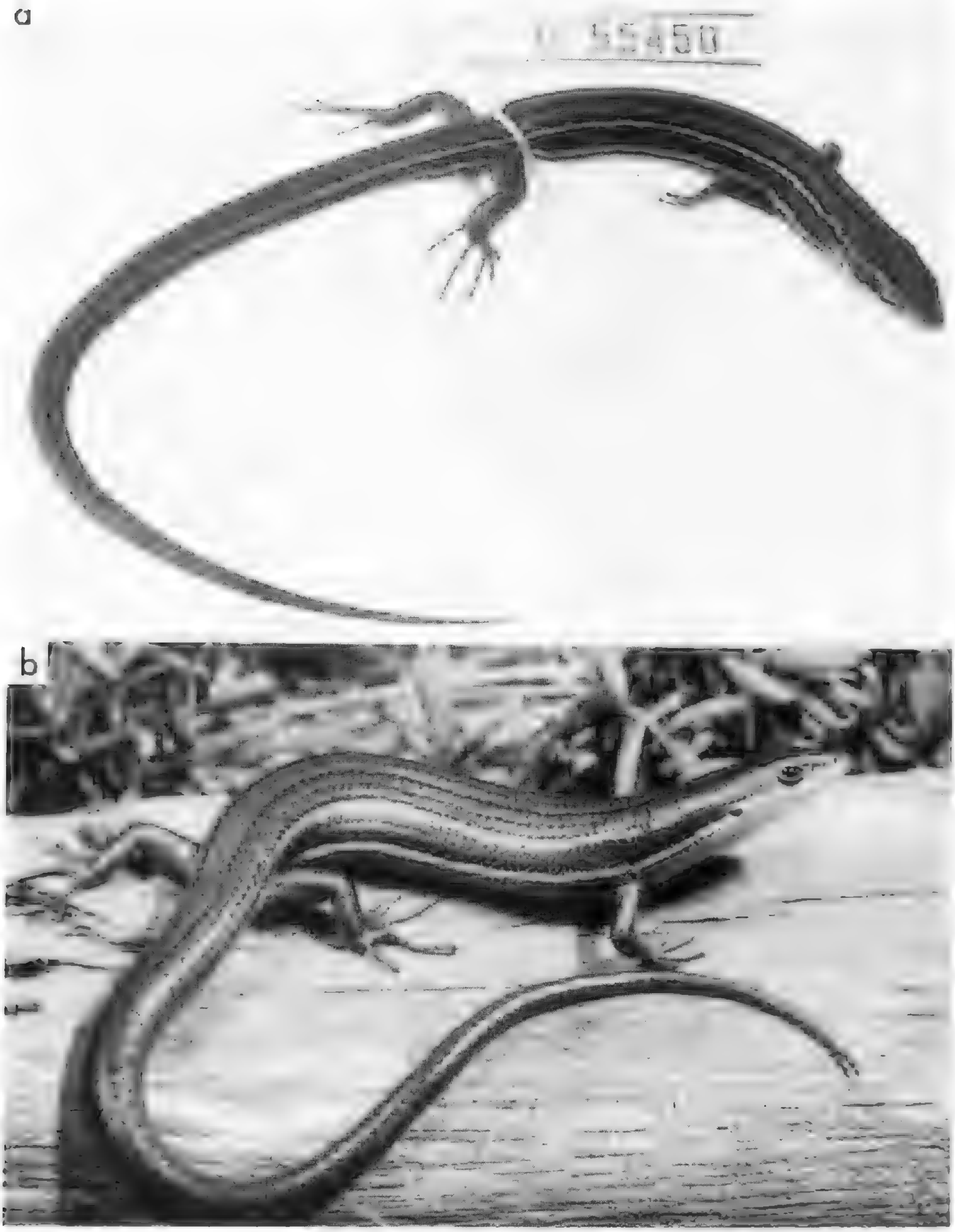

FIG. 2. (a) Holotype of *Leiolopisma rawlinsoni* sp. nov. (MNV D55450), as preserved. (b) Paratype NMV D55449 (adult female) from type locality, in life.

anterior loreal undivided in all specimens. Lower labials usually 7, sometimes 8 (mean 7.1, n = 30).

Dimensions: SVL of adult males 37-63 mm (mean 48.3, n = 25), of adult females 40-61 mm (mean 51.4, *n* = 22). Smallest juvenile 27 mm. HLL 30-40% of SVL, TL 157-185% of SVL (mean 172%, n = 8).

Colour (in preservative): Generally very similar to holotype. Ground colour often darker, vertebral stripe strong, faint or absent. Laterodorsal black lines may be well developed, running along junction between scale rows 1 and 2 on each side. Dorsolateral light stripe always runs down middle of scale row 3. White midlateral line generally centred on scale row 6, but often including upper part of row 7 for part of its length. In specimen with lowest midbody scale count (NMV D55345, MBSR=23) midlateral white stripe running down middle of row 5. No trace of light or dark speckling on any specimen. Paratype AMS R81649 (4 km SSW of Woodside East, Vic.) is illustrated by Greer (1982, Fig. 5).

Colour in life: Generally similar to colour in preservative, but usually more greenish. Scales with a very noticeable opalescent gloss. Belly cream to pale yellow. Breeding males may have weak orange midlateral stripe.

Sexual dimorphism: SVL of adult females on average is larger than that of males. Although largest specimen examined was male (NMV D48411, 63 mm SVL), most males were small, less than 50 mm SVL. Females appear to mature at slightly larger SVL (40 mm) than males (37 mm). Paravertebral scales significantly more numerous in females (57-65, mean 62.2) than in males (57-63, mean 59.3); $t_{43} = 4.73$, $p < .001$. Females with significantly shorter limbs; HLL in females ranges 29.5%-37.8% of SVL (mean 33.4, SD = 2.39), while males range 32.6%-40.0% (mean 36.6, SD 1.86); $t_{41} = 4.84$, $p < .001$. Larger SD in females because relative leg length appears to decrease as females grow larger, suggesting negative allometric growth of limbs. HLL dimorphism much less evident if only small adults considered; when comparison restricted to adults less than 50 mm SVL, mean value for females rises to 35.2 (SD = 1.95) while that for males remains the same (36.7, SD = 1.98); $t_{19} = 1.70$, $p > 0.1$. Sexual dichromatism does not appear to be well developed, in contrast to two other eastern members of the species-complex. W. Osborne (pers. comm.) has recorded breeding males with weak orange colouring in anterior part of midlateral white stripe, but males collected in southern Victoria in early summer showed no orange colour at all (MNH, pers. obs.), while red pigment also absent in others collected in June. No live colour data available for Victorian specimens collected during height of breeding season, February-April.

Distribution

L. rawlinsoni is restricted to southeastern Australia, and apparently occurs in several disjunct areas, in southeastern S.A., southwestern Victoria, south-central Victoria, alpine areas of northeastern Victoria through the Snowy Mountains of N.S.W. to the Brindabella Ranges on the N.S.W. - A.C.T. border, and Cape Barren Island in Bass Strait (Fig. 3). The status of several of the outlying populations is unknown since they are based on single specimens, from Port Campbell (SW Vic.), Cape Barren Island, and Bemm River (SE Vic.). The species is rare in collections, so that future range extensions (e.g. to Tasmania) or discovery of populations bridging apparent gaps are possibilities.

Geographic Variation

Colour pattern is very conservative, all specimens having a light to dark olive green to grey-brown dorsum with the dorsolateral white stripe on scale row 3. The major colour pattern variations consist of reduction or absence of the vertebral stripe, and the addition of a pair of black laterodorsal stripes, and the degree to which the upper lateral zone is pale centred. Geographic variation in colour does not appear to be much greater than local variation.

Variation in scalation is also minor. The principal geographic variation is the degree of carination of the dorsal scales, which is most pronounced in southern Victorian specimens, but greatly reduced or virtually absent in other populations. In all populations the modal midbody scale row count is 26, and only two specimens are known to exceed 28 (NMV D48943 from Dennison Lake and NMV D1852 from Ringwood have 30). Six supraciliaries is by far the most common count in most areas, but the three western-most specimens, from southeastern South Australia and Port Campbell, Victoria, have five supraciliaries.

Cranial Osteology

The skull (Fig. 4) conforms to the *Eugongylus* subgroup (Greer 1979) in having 11 premaxillary teeth, a completely closed Meckel's groove and the palatal rami of the palatines well developed and in broad medial contact. It is similar in most respects to that of the other members of the complex, with the upper temporal fenestra closed by expansion of the parietal, but differs from *L. entrecasteauxii* Group 1 and Group 2 in pterygoid structure. The latter two species show an angularity or process on the medial margins of the palatal rami of the ptery-

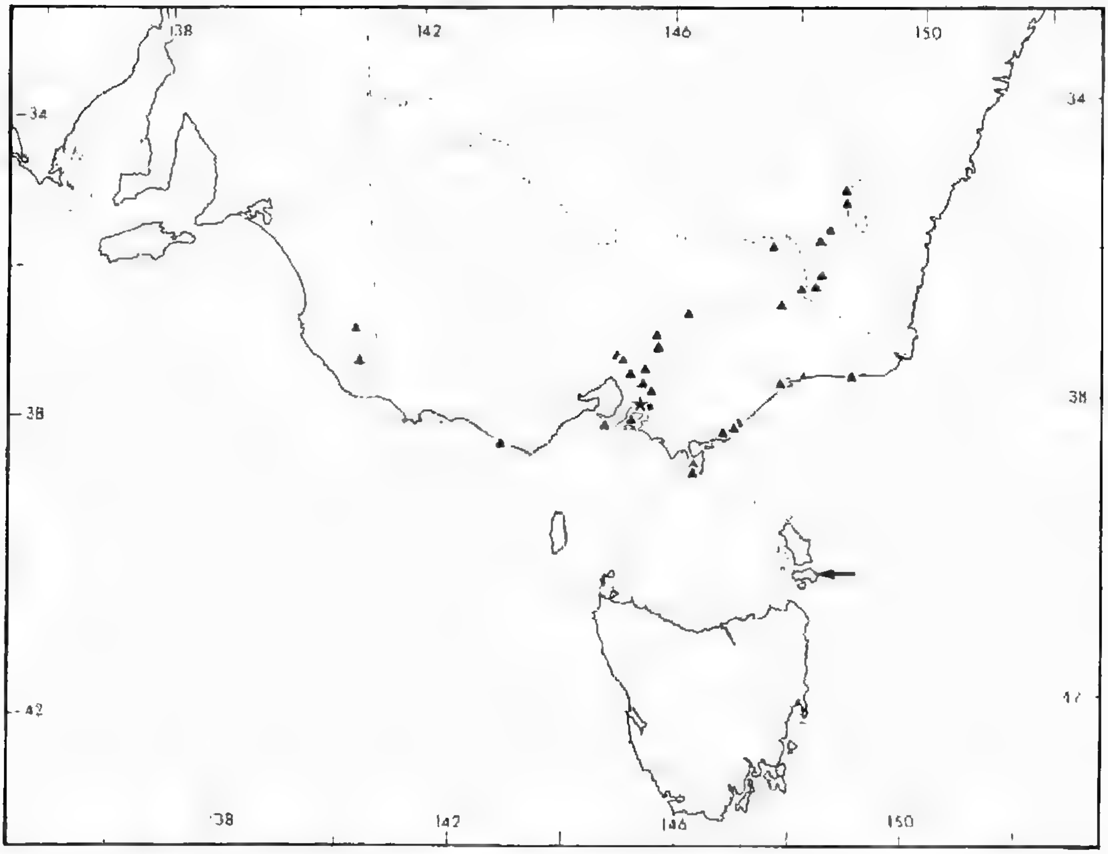

FIG. 3. Distribution of *Leiolopisma rawlinsoni* sp. nov. The star indicates the type locality, and the arrow, Cape Barren Island.

goids, in some specimens resembling the beta palatal processes of the *Lampropholis* subgroup (Greer 1979). The two specimens of *L. rawlinsoni* examined have little development of these processes. One of the two specimens examined shows a modest angularity of the medial margins, while the other has completely smooth, evenly diverging pterygoids as in the typical alpha palate.

Ecology and Reproduction

L. rawlinsoni is known entirely from localities characterized by the presence of very humid microenvironments. In southern Victoria, the species has been found in saltmarshes, boggy creek valleys, the margins of permanent lakes and swamps and in wet heathland, while at high altitudes in northeast Victoria and southeast N.S.W., it occurs in similar swampy habitats, including fens and sphagnum bogs. These habitats are usually densely vegetated at ground level, and the species apparently basks and forages largely within this cover. The swampy habitat preference of this species is reflected by the fact that most of the southern Victorian localities from which it has been collected have yielded specimens of *Egernia coventryi*, also known to be an obligate swamp/wet heathland species (Smales 1981; Schulz 1985). Similarly, at the high altitude localities, such as Davies Plains, Vic., and the Perisher area, N.S.W., *L. rawlinsoni* is syntopic with *Eulamprus kosciuskoi*, an alpine swamp specialist (Coventry & Robertson 1980).

Throughout its range, *L. rawlinsoni* is broadly sympatric with one or both of its close relatives, *L. entrecasteauxii* Group 1 and Group 2. At several localities (e.g. the Woodside area, Vic. and the Perisher area, N.S.W.), *L. rawlinsoni* and *L. entrecasteauxii* Group 2 are syntopic, while *L. entrecasteauxii* Group 1 has been collected within 1 km of *L. rawlinsoni* in the Perisher area and in the Yan Yean area north of Melbourne. Morphological data reinforce the electrophoretic evidence that there is no intergradation between these sympatric or adjacent populations.

The dense vegetation of the species' preferred habitat may explain one of the more striking aspects

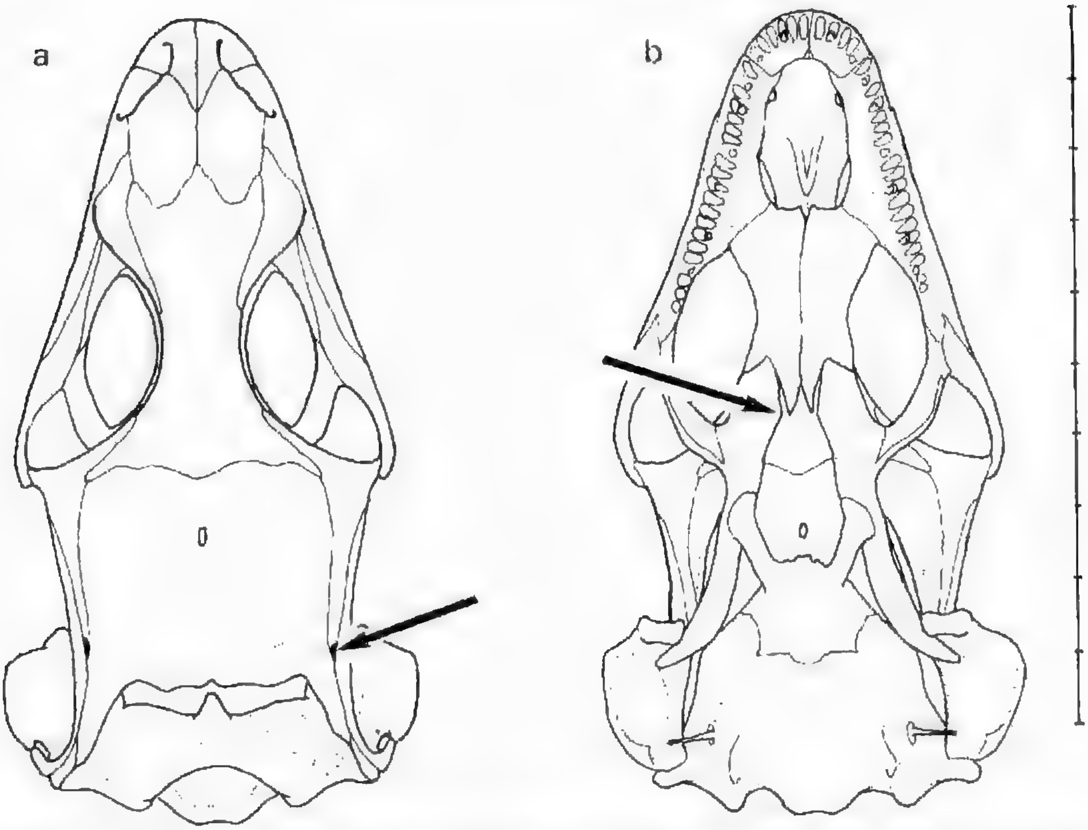

FIG. 4. Skull of *Leiolopisma rawlinsoni* sp. nov. in (a) dorsal view and (b) palatal view. Arrows point to (a) the position of the minute upper temporal fenestra and (b) the palatal rami of the pterygoids which show a slight angularity in this specimen. Specimen MNH No. 85/46, 4 km SSW of Woodside East, Vic. Scale bar = 10 mm.

of this skink: its relative rarity in collections. It is widely distributed through the well-collected south-east of Australia, where many other small species of skink have been collected in large numbers. The two near relatives of *L. rawlinsoni*, *L. entrecasteauxii* Group 1 and Group 2, are represented in southeastern museum collections by many hundreds of specimens, including long series from some sites, but these same collections have yielded only 64 specimens of *L. rawlinsoni*, with the greatest number from any one location being eight.

The species is viviparous, litter size ranging 4–8 (mean 5.6, n = 13). Females with oviducal eggs or developing young have been collected as early as 15 October and as late as 28 January. As with the other eastern species, males show a peak in testicular size during late summer-autumn, and females ovulate in mid spring, so that overwintering of sperm by the females must occur.

Acknowledgments

The following colleagues assisted in providing access to or loans of specimens in their care: A. J. Coventry (NMV), R. H. Green (QVMT), A. E. Greer and R. Sadlier (AMS), K. Medlock (TMH), T. D. Schwaner (SAMA), L. A. Smith (WAM) and J. Wombey (ANWC). W. Osborne, Zoology Dept, ANU, Canberra and P. Robertson, Fisheries & Wildlife Division, Victoria, provided access to specimens held by them and gave valuable information on field biology. D. Walsh, Dept of Zoology, La Trobe University, provided photographic assistance. Earlier drafts of the manuscript were improved by the helpful comments of P. Baverstock, R. Andrews, M. Mahony, M. Adams and an anonymous reviewer. This work was funded in part by ARGS grant No A1841625 to P. Baverstock and a CTEC special research grant to M. Hutchinson.

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MUSTELICOLA ANTARCTICUS SP. NOV. (CESTODA: TRYPANORHYNCHA) FROM AUSTRALIAN ELASMOBRANCHS, AND A REASSESSMENT OF THE FAMILY MUSTELICOLIDAE DOLLFUS, 1969

BY RONALD A. CAMPBELL & IAN BEVERIDGE†*

Summary

Mustelicola antarcticus sp. nov. is described from adult worms in the spiral valve of *Mustelus antarcticus* (Guenther) collected in coastal waters off Bicheno, Tasmania. Characters differentiating *M. antarcticus* from *M. woodsholei* Dollfus, 1969, the only other known species, are a much smaller ratio of pars bulbosa to pars vaginalis (1: 1.3 versus 1: 2.1), approximately twice as many testes per segment (av. 780 versus 3W), and reversed order of hook sizes 2(2') and 3(3') for the two species. The armature of *M. woodsholei* is completely described for the first time. As in *M. antarcticus,* it consists of a unique poeciloacanthous type consisting of three double chainettes and is most similar to members of the Lacistorhynchidae Guiart, 1927 and Callitetrarhynchinae Dollfus, 1942. Other new morphological features described are an hermaphroditic sac, pre-formed uterine pore, lack of true prebulbar organs, and origin of the retractor muscle in the anterior 113 of the bulb. The family Mustelicolidae is considered justified, based on unique features of the armature, scolex and genitalia, and is redefined accordingly.

KEY WORDS: Mustelicola, Cestoda, Trypanorhyncha, new species.

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KEY WORDS: *Mustelicola*, Cestoda, Trypanorhyncha, new species.

Introduction

Dollfus (1969) erected the family Mustelicolidae for a single trypanorhynch found in the spiral valve of *Mustelus canis* (Mitchill, 1815) caught in Atlantic coastal waters near Woods Hole, Massachusetts. Dollfus considered the armature of *Mustelicola woodsholei* to be of the atypical heteroacanthous type though a complete description of the tentacular armature and reproductive system was not provided. Schmidt (1986) revised the systematics of the cestodes and considered Mustelicolidae to be a synonym of Eutetrarhynchidae Guiart, 1927, making the genus *Mustelicola* Dollfus, 1969 a synonym of *Parachristianella* Dollfus, 1946. The precise position of the species within *Parachristianella* was not specified. Schmidt's proposed synonymy of an atypical heteroacanth (*Mustelicola*) with a typical heteroacanth (*Parachristianella*) prompted a re-examination of *M. woodsholei* to determine the exact nature of its armature and anatomy. Attempts to find additional specimens of *M. woodsholei* have been fruitless, but a second species, described herein, was recently collected from *Mustelus antarcticus* (Guenther, 1870) off the coast of Tasmania. In this paper the description of the type species is corrected and expanded, a new species is added to the genus, the taxonomic position of the family re-assessed, and the family Mustelicolidae redefined.

Materials and Methods

Mustelicolid cestodes were found in the spiral valves of two of 73 sharks (*Mustelus antarcticus*) examined off southern Australian coasts and were fixed in hot 10% buffered formalin. Whole mounted specimens were stained with Celestine blue, dehydrated in ethanol, cleared in clove oil and mounted in balsam. Tentacles were dissected free, examined in glycerol, and mounted in glycerine jelly. Some segments were embedded in paraffin, serially sectioned at 8–10 μm, and stained with Harris' hematoxylin and eosin. Dollfus' holotype was examined from the Museum National d'Histoire Naturelle, Paris. The specimen was remounted and a tentacle removed and examined to provide precise orientation of the armature. Drawings were made with the aid of a drawing tube.

Measurements are given in micrometers, unless otherwise stated, as the range followed by the mean and the number of measurements (n) in parentheses.

Terminology for trypanorhynch morphology follows Dollfus (1942). Specimens have been deposited in the South Australian Museum (SAM), Adelaide.

Mustelicola woodsholei Dollfus, 1969

FIGS 1–9

Description: Measurements of the holotype specimen. Scolex and strobila acraspedote, total length 6.7 cm, maximum width 1070. Scolex 4160

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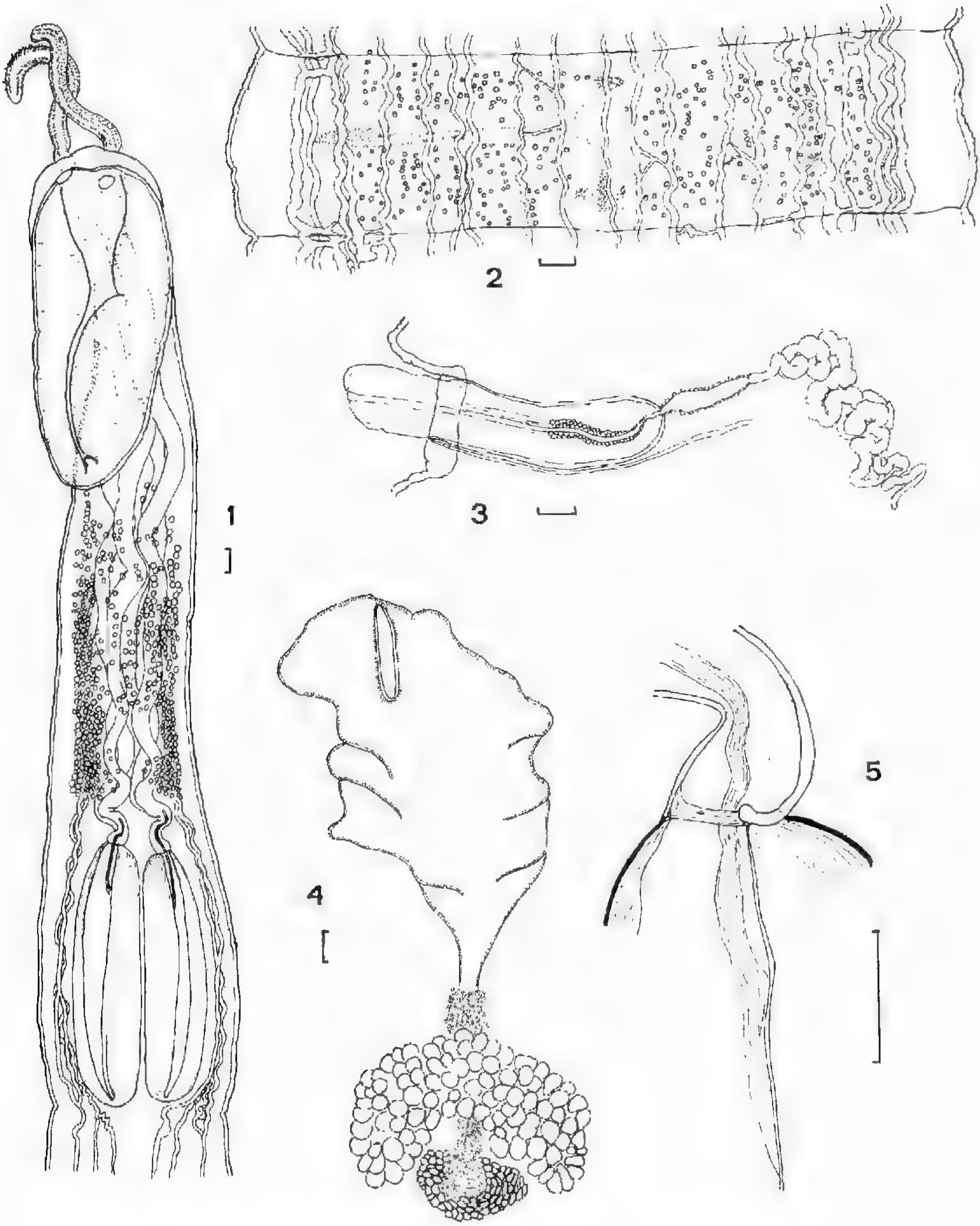


FIGS 1-5. Anatomy of *Mustelicola woodsholei*. 1. Scolex. 2. Immature proglottid showing osmoregulatory ducts. 3. Male genital terminalia. 4. Uterus and preformed uterine pore. 5. Detail of bulb showing origin of tentacle sheath and insertion of retractor muscle. Scale lines: 0.1 mm.

long, subcylindrical, slightly wider in region of bulbs, maximum width in region of bulbs, 860. Two bothridia, oval, elongate, 1520 long, maximum width 640, with broad indistinct rim, not indented posteriorly. Pars vaginalis 2840 long, tentacle sheaths slightly sinuous, not coiled; each sheath originating from bulb in prominent, symmetrical, lateral sinuosity; circular muscle bands similar to those associated with prebulbar organ present at posterior end of sheath, but thickening of lateral wall of sheath and "nucleus" absent; numerous gland cells surround tentacle sheaths in pedunculus scolecis. Bulbs short, 1200 long, 280 in diameter; retractor muscle originates in anterior third of bulbs. Pars post-bulbosa, 200 long; junction of scolex and neck demarcated by a slight constriction. Scolex ratio (pbo: pv: pbulb) 1: 2.1: 0.8.

Tentacles not fully extended, longest tentacle 1400; diameter 80 at base, 70 in mid-region; basal swelling and distinct basal armature absent. Armature heteromorphous, poeciloacanthous. Principal rows alternate, beginning on internal face; hooks hollow, arranged in ascending half spiral rows of six hooks each (Fig. 7). Hooks 1(1') to 4(4') rose-thorned shaped, with gently curved blades and long bases of implantation; hooks 1(1') 24–30 (28, n=10) long, bases 18–28 (24, n=10), height 13–18; hooks 2(2') slightly larger, blade 26–38 (33, n=10) long, base 22–28 (24, n=10), height 17–24; hooks 3(3') 30–34 (33, n=10) long, base 20–22 (21, n=10), height 20–24; hooks 4(4') 26–30 (28, n=10) long, base 14–21 (17, n=10), height 17–20; hooks 5(5') spiniform, 14–22 (19, n=10) long, base short, 8–14 (11, n=10), height 10–14; hooks 6(6') in tandem or "satellite" position with respect to 5(5'), spiniform, blade 14–16 (15, n=10) long, base 6–8 (7, n=10), height 10–12. External surface of tentacle with 3 double chainettes, distinctly separated from principal rows, paired elements in each chainette opposite each row of principle hooks; chainette elements subtriangular, 16–22 (19, n=10) long, base 12–16 (14, n=10), height 10–13.

First evidence of segmentation 900 from scolex; segments initially much wider than long, becoming almost as long as wide. Mature segments acraspedote, 1900–2500 (2240, n=5) by 3080–3470 (3260, n=5); genital pores alternate irregularly; genital pore 45–50% of segment length from anterior margin. Cirrus (?) sac elongate, 890–980 (930, n=4) by 200–260 (220, n=4), cirrus unarmed, sinuous when retracted; proximal cirrus surrounded by a few layers of gland cells; internal seminal vesicle absent; external seminal vesicle elongate, diminutive, with single surrounding layer of cells; vas deferens passes medially, coils anteriorly then posteriorly to ovarian isthmus. Testes numerous, approximately 300 in immature segments, scattered through medulla; testis diameter 40–50 (43, n=5). Vagina a very thin tube, closely paralleling cirrus sac along posterior margin; course of vagina could not be traced to genital pore. Ovary bilobed in dorsoventral view, situated near posterior margin of segment, lobes 350–450 (390, n=5) by 310–380 (350, n=5); Mehlis' gland post-ovarian 280–300 (200, n=5) by 330–400 (360, n=5), U-shaped; uterine duct covered by dense mass of gland cells, passes anteriorly to join uterus about 150 anterior to ovarian isthmus; uterus thin-walled, saccular, extends to anterior margin of segment; preformed uterine pore present near anterior end of uterus. Vitelline glands follicular, circumcortical, follicles c. 50 in diameter.

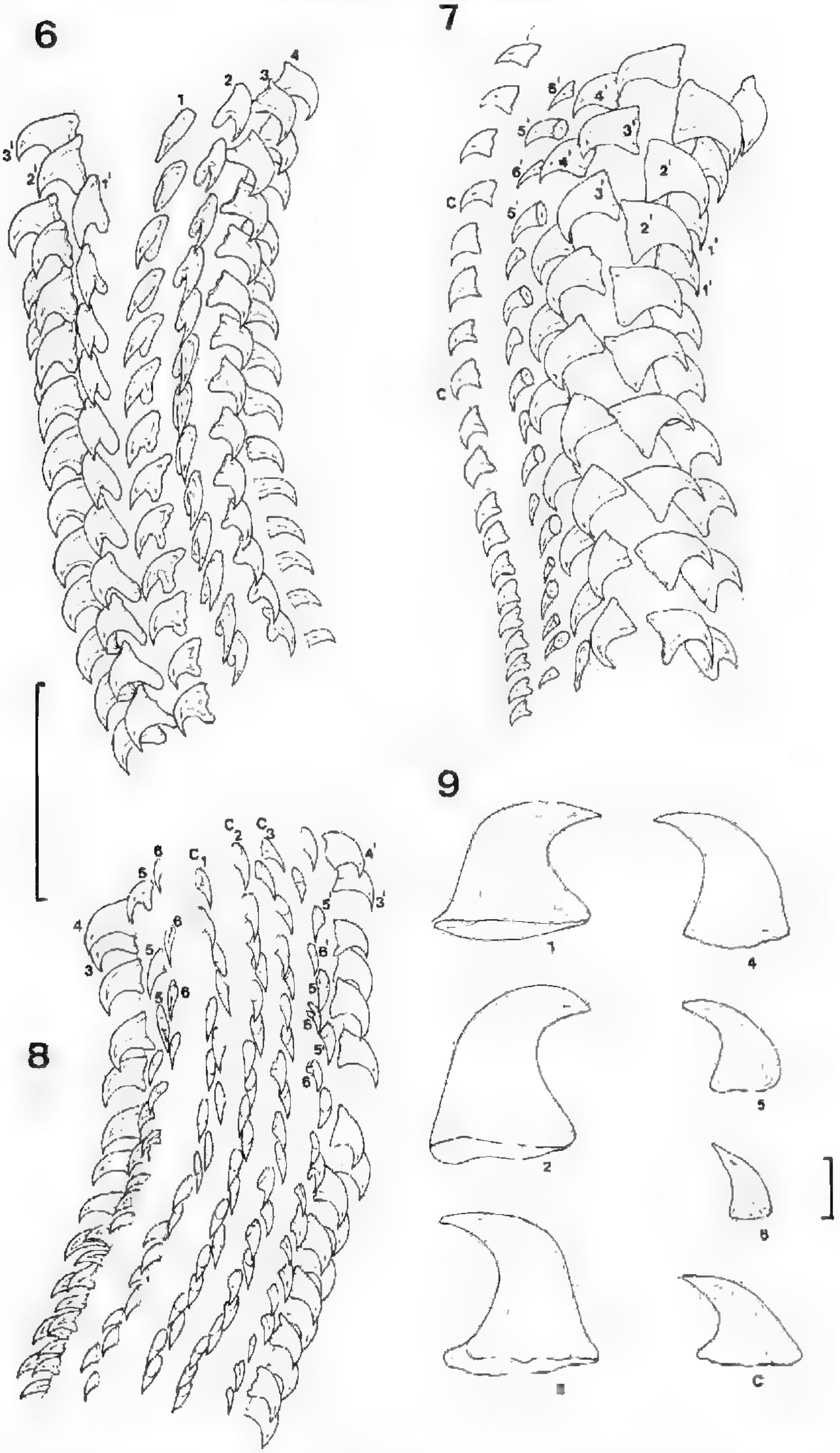
Osmoregulatory system complex, most clearly visible in immature segments; complex of 4–6 large canals present at lateral margins of segments, canals anastomose frequently; on dorsal and ventral surfaces of segments are 10–12 narrower canals, either straight or regularly sinuous which branch and anastomose infrequently; three pairs of longitudinal canals visible in posterior end of scolex; anterior commissures not visible.

Eggs ovoid, 43–55 (45, n=3) by 25–35 (28, n=3).
Host and Locality: Mustelus canis (Mitchill, 1815), at Woods Hole, Massachusetts, U.S.A.

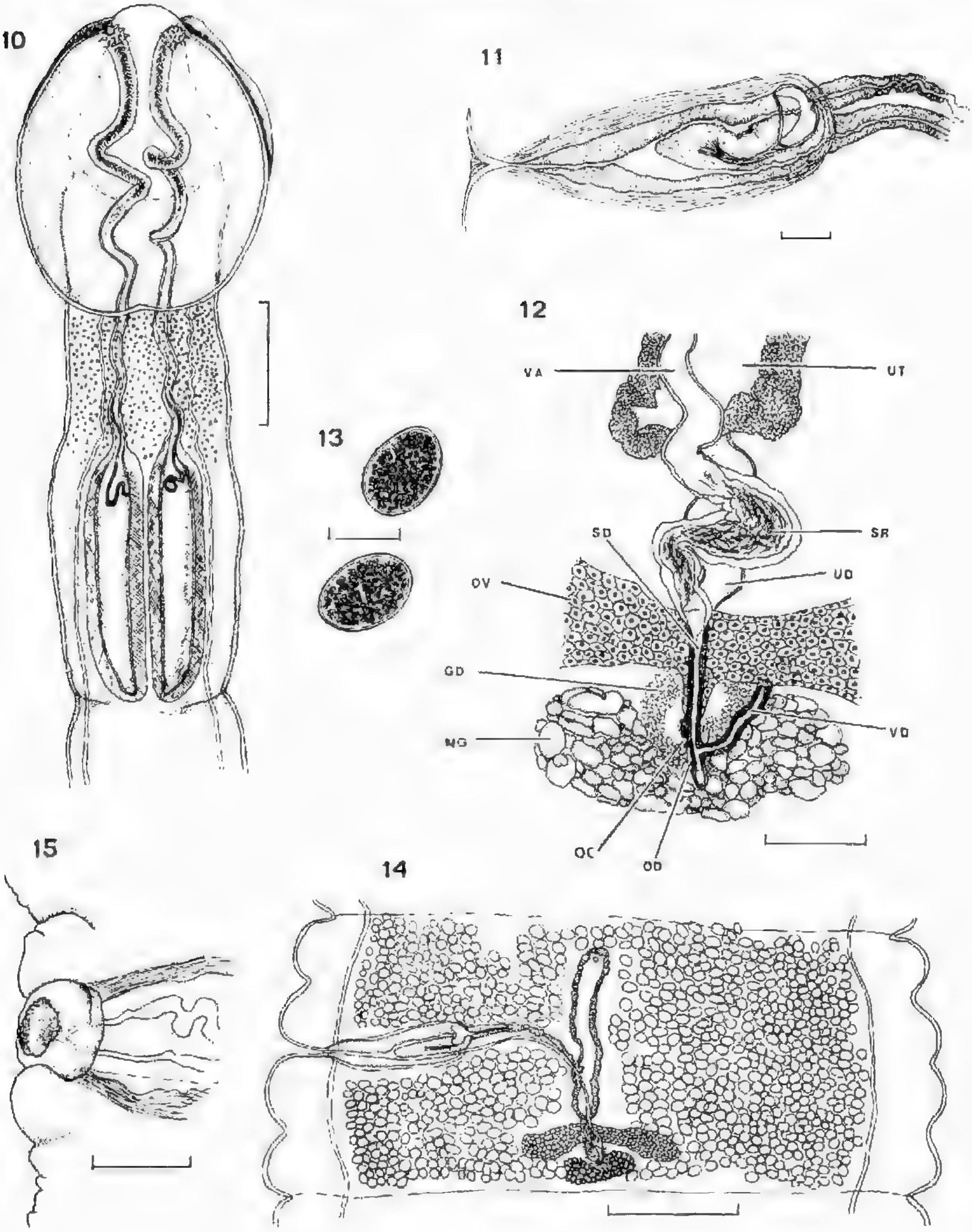
Mustelicola antarcticus sp. nov.
FIGS 10–19

Description: Measurements of three fragmented adult specimens. Scolex and strobila acraspedote, strobila up to 6 cm long; maximum width 4.1 mm. Scolex 2720–2832 (n=2) long, subcylindrical, slightly distended in region of bulbs, maximum width at bulbs 792; scolex demarcated from neck by a slight constriction. Two bothridia, broadly oval, rim indistinct, slightly indented posteriorly, length 1000–1140 (n=4) by 980–1020 (n=4). Pars vaginalis 1520–1640 (n=2), tapering into junction with bulbs; tentacle sheaths slightly sinous; small gland cells scattered in parenchyma of pedunculus scolecis. Bulbs 1080–1240 by 240–320 in diameter; prebulbar organs absent; retractor muscle originates near anterior extremity of bulb; pars postbulbosa extremely short, 80 long. Scolex separated from strobila by slight constriction. Scolex ratio (pbo: pv: pbulb) 1:1.3: 0.9.

Armature poeciloacanthous, with three chainettes of paired hooks on internal face. Fully everted tentacles 1.7 mm long; diameter 114 at base, 99 at mid-tentacle, 46 at tip; basal armature and swelling absent. Principal rows alternate, beginning on internal face, forming ascending half spirals of six hooks each. Hooks 1(1') rose-thorn shaped, with sharply angular blades and long bases of



FIGS 6–9. Armature of *Mustelicola woodsholei*. 6. Internal face, metabasal region, turned slightly toward antibothridial face. 7. Antibothridial face, metabasal region, external face on left. 8. External face, metabasal region, showing three double chainettes (C_1-C_3). 9. Hooks 1–6 of principal row drawn to scale and chainette hook (c). Scale lines: Figs 6–8, 0.1 mm; Fig 9, 0.01 mm.



FIGS 10-15. Anatomy of *Mustelicola antarcticus* sp. nov. 10, Scolex. 11. Hermaphroditic sac. 12. Female reproductive system. 13. Eggs. 14. Mature proglottid. 15. Bulbous eversion of genital pore. Scale lines: Figs 10, 14, 0.5 mm; Fig 15, 0.3 mm; Figs 11, 12, 0.1 mm; Fig. 13, 0.03 mm. GD, gland cells; MG, Mehlis' glands; OC, oocapt; OD, oviduct; OV, ovary; SD, sperm duct; SR, seminal receptacle; UD, uterine duct; UT, uterus; VA, vagina; VD, vitelline duct.

implantation, blades 33–36 (35, n=10) long, height 15–19 (n=10); hooks 2(2') larger, blade length 39–42 (40, n=10), base 29–31 (30, n=10), height 13–21 (n=10). Hooks 3(3') similar to 2(2') but smaller; blades 32–36 (34, n=10) long, base 23–26 (24, n=10), height 15–28 (n=10); hooks 4(4') only slightly curved, 27–30 (29, n=10) long, base length 17–18 (17, n=10), height 15–21 (n=10); hooks 5(5') smaller, 21–22 (21, n=10) long; bases 14–16 (15, n=10), height 13–15 (n=10); hooks 6(6') in tandem or "satellite" position anterior to 5(5'), spiniform, 17–18 (17, n=10) long, base 6–9 (8, n=10), height 10–13 (n=10). External surface of tentacle with three double chainettes, distinctly separated from principal rows, chainette elements subtriangular, 22–25 (23, n=10) long, base 12–14 (13, n=10), height 13–17 (n=10).

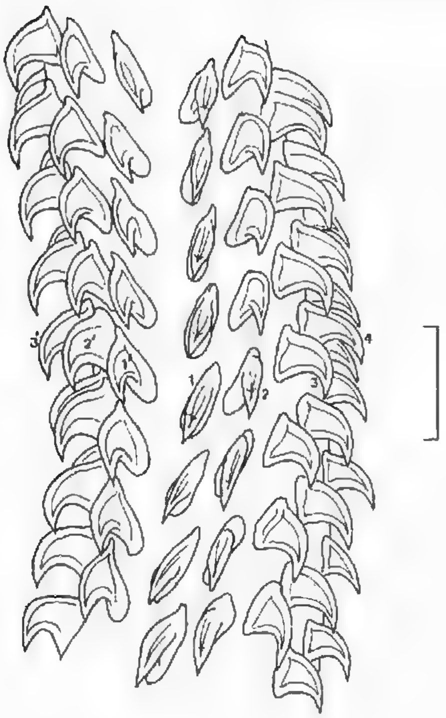
Number of segments about 200 (n=1). First segments appear 1.7–2 mm posterior to scolex. All segments wider than long, acraspedote, enlarging with age. Mature segments always wider than long, 900–3400 by 1560–5600. Gravid segments always longer than wide, 1080–1800 by 3900–4200. Genital pores marginal, irregularly alternating, equatorial, located 50% of segment length from anterior margin. Testes medullary, subspherical, 42–76 by 38–49 (n=20), layered, occupying available space between longitudinal osmoregulatory canals and extremities of segment. Testes number about 741–803 (780, n=5) per segment. Hermaphroditic sac 544–1160 (696, n=10) by 176–352 (248), surrounded by weakly developed layer of muscle fibres. Cirrus unarmed, glandular, immediately distal to ovoid internal seminal vesicle. Vagina median, dilated to form seminal receptacle anterior to ovarian isthmus, turns laterally, lying parallel with posterior margin of hermaphroditic sac and then enters sac; genital sinus opens by a single duct at genital pore. Contraction of walls of hermaphroditic sac forms bulbous, sucker-like protuberance in which cirrus and vagina are brought close to the surface. External seminal vesicle present. Vas deferens coiled, arches toward midline, runs parallel with vagina posteriorly toward ovary. Ovary posteromedial, bilobed in dorsoventral view, crescent-shaped, maximum dimensions 650–980 by 178–520, isthmus up to 80 long. Mehlis' gland postovarian, shallow U-shaped, maximum dimensions 112–120 by 256–288. Vitellaria follicular, irregularly shaped, forming a layer enclosing osmoregulatory canals and reproductive organs, maximum dimensions of follicles 56–64. Uterus median, thick-walled, terminating near anterior margin of segment, voluminous in gravid segments. Uterine pore near distal extremity of uterus. Eggs oval, 38–49.5 (45.6, n=10) by 26.6–34.5 (30.4, n=10), thick-shelled, non-operculate, unembryonated.

Host and Locality: *Mustelus antarcticus* (Guenther, 1870) (type host), off Bicheno, Tasmania, coll. B. G. Robertson.
Site in host: Spiral valve.
Types: Holotype SAM V4104, two paratypes SAM 17875.
Etymology: The specific name is after that of its host, *M. antarcticus*. Following Article 30a(i) of the International Code of Zoological Nomenclature, the generic name is masculine in gender.

Discussion

Dollfus (1969) described *M. woodsholei* and erected the genus *Mustelicola* and family Mustelicolidae for it based on a single specimen. Distinctive characters of the new genus were based upon the armature, viz. *Mustelicola* is an atypical heteroacanth with twice as many hooks in longitudinal files of the external face as occur in longitudinal files of the internal face (Dollfus 1969). This diagnosis was never expanded. Schmidt (1986) subsequently synonymised both the family and genus with the typical heteroacanth *Parachristianella* in the Eutetrarhynchidae.

Unfortunately only a single specimen of *M. woodsholei* exists and it is not satisfactory for the complete description of the reproductive system. However, some specimens of the new species, *M. antarcticus* described above, were gravid and clearly provide these details. A generic definition can therefore be derived from the combined characters of the two species. The two species possess a combination of characters not found together in other trypanorhynch cestodes, foremost of which is the type of armature. Examination of the armature of the type species, *M. woodsholei*, clearly shows major discrepancies with the original description (Dollfus 1969) and these must be addressed because some of them have major consequences for its taxonomic position. In addition, four characters differ substantially from the original description. Firstly, a preformed uterine pore is present and clearly visible as a mass of cells at the anterior end of the uterine anlagen in immature segments. Secondly, an external seminal vesicle is present. Thirdly, the tentacle retractor muscle originates in the anterior third of the bulbus not at the posterior end. Fourthly, a typical prebulbar organ is not present. Muscle elements surrounding the origin of the sheath are present in *Mustelicola* but it is not comparable to the prebulbar organ of eutetrarhynchids. In the latter group, an enlarged projection of the external surface of the tentacle sheath, 16



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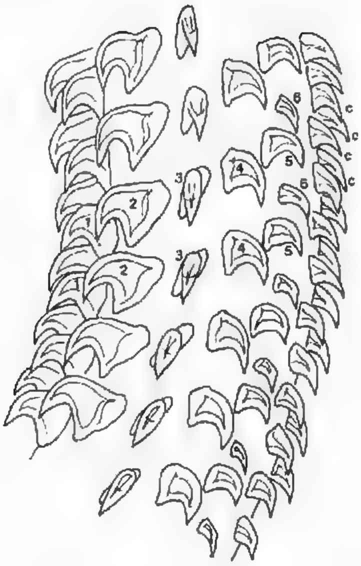

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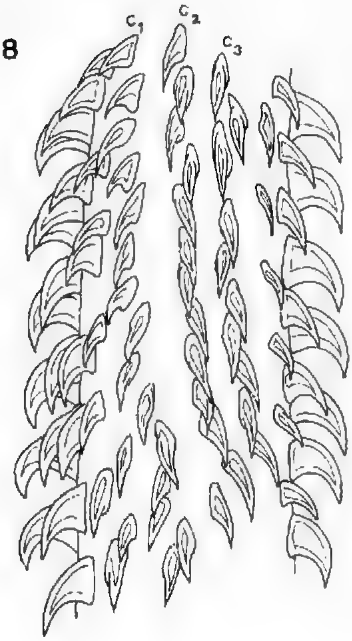

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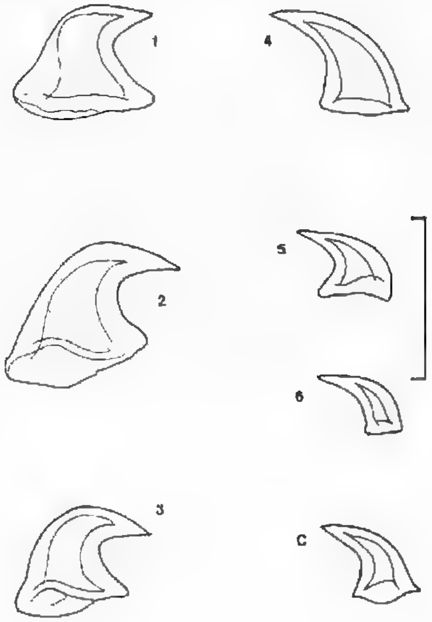

FIGS 16-19. Armature of *Mustelicola antarcticus* sp. nov. 16. Internal face, metabasal region. 17. Bothridial face, metabasal region, external face is on right. 18. External face, metabasal region, showing 3 double chainettes, C_1-C_3. Note slight counterclockwise torsion of tentacle. 19. Hooks 1-6 of principal row drawn to same scale and chainette hook (c). Scale lines: Figs 16-18, 0.05 mm; Fig 19, 0.03 mm.

sometimes described as being nucleated and supported by circular bands of muscle running around the tentacle sheath is clearly visible (Dollfus 1942).

The most important character of the genus, is the armature which is poeciloacanthous in form and not that of an atypical heteroacanth or a typical heteroacanth. Dollfus (1969) did not illustrate the external surface of the tentacle armature fully. By re-orienting the type specimen and examining an isolated tentacle, a unique poeciloacanthous arrangement consisting of three double chainettes was clearly seen (Figs 6–9). This same armature was seen in specimens of the new species, *M. antarcticus*, described above. When compared with the armature of genera such as *Lacistorhynchus* and *Callitetrarhynchus* there is a remarkable constancy of hook number. In both of these genera, each row contains five major hooks. Hook 6, however, is small and is situated slightly out of alignment with the principle row. Hooks 7 and 8, the so-called "satellite hooks", are arranged in tandem, much as the pairs of hooks 9(9') of the chainette. If the armature of *Lacistorhynchus* and *Callitetrarhynchus* were rearranged simply by displacing hook 5 so that it lay in tandem with hook 6, and hooks 7 to 9 were of the same shape, then there would be six hooks per principal row and three chainettes formed, exactly the armature present in *Mustelicola*. Because of the similarities of hook number and disposition we believe that *Mustelicola* has close affinities to *Lacistorhynchus* and *Callitetrarhynchus*; both genera, of course, are poeciloacanths. A hermaphroditic duct is also present in *Mustelicola*, *Lacistorhynchus* and *Callitetrarhynchus*.

Details of the reproductive system of *Mustelicola woodsholei* could not be obtained because the single specimen lacks fully developed segments. However, the major organs can be seen and the vagina can be traced in close parallel to the "cirrus sac" to a point beyond its midlength where it appears to unite. The sac is surrounded by a coat of muscle fibers and a dilation is apparent in the vas deferens before it enters the sac. In *M. woodsholei* all the mature segments have everted cirri and hence the details of the distal ducts cannot be determined. It probably possesses a hermaphroditic sac. In the new species, *M. antarcticus*, details of the "cirrus sac" can be seen clearly. The vagina enters the sac on its posterior margin, and the unarmed cirrus resides in a sinus cavity distal to an internal seminal vesicle. A common duct leads to the genital pore on the segment margin. This arrangement is, therefore, a hermaphroditic sac not a cirrus sac. Contraction of the muscular coat causes formation of a sucker-like protuberance in which the sinus cavity is brought to the surface.

Both *M. woodsholei* and *M. antarcticus* possess armatures of six hooks per principal row and three chainettes, two bothridia, pars bothridialis longer than pars bulbosa, lack prebulbar organs, possess numerous gland cells in the pedunculus scolecis, acraspedote segments, uterine pores, saccate uteri, crescent-shaped ovaries, and U-shaped shell glands. *M. antarcticus* may be distinguished from *M. woodsholei* by the following characters: scolex proportions of pars bothridialis to pars vaginalis (1: 1.3 versus 1: 2.1); hooks 2(2') and 3(3') differ in form (abruptly curved in *M. antarcticus* versus gently curved in *M. woodsholei*) and size (hook length 2(2') markedly larger than 3(3') in *M. antarcticus* but equal to or slightly smaller in *M. woodsholei*; testis number (about 780 in *M. antarcticus* versus about 300 in *M. woodsholei*); internal seminal vesicle in *M. antarcticus* apparently absent in *M. woodsholei*.

We propose that the diagnoses of the family and genus be emended to include these corrections and distinctive characters that separate them from other trypanorhynchs as follows:

Mustelicolidae Dollfus, 1969, emended

Diagnosis: Order Trypanorhyncha. Poeciloacanthous with multiple chainettes opposite principal rows. Scolex with two, well-separated sessile bothridia with free margins. Rhyncheal apparatus well developed. True prebulbar organs absent. Tentacles and bulbs relatively short. Segments numerous. Genital pores marginal. Testes numerous, intervascular, internal or external seminal vesicles present. Ovary posterior. Uterus saccular with ventral pore. Vitellaria circumcortical. Adults parasitic in spiral valve of elasmobranchs. Type and only genus:

Mustelicola Dollfus, 1969 emended

Diagnosis: Scolex acraspedote. Two bothridia patelliform, rimmed, without posterior notch; not contiguous apically. Pars bothridialis longer than pars bulbosa. Bulbs short. Pars postbulbosa very short. Tentacle sheaths irregularly sinuous. Retractor muscle originates in anterior portion of bulb. Tentacles lack basal swelling. Armature consisting of three double chainettes opposite hooks 1(1') of principal rows. Principal rows alternate. Strobila anapolytic (?), segments acraspedote. Genital pores irregularly alternate. Hermaphroditic sac present, cirrus present, internal seminal vesicle present;

external seminal vesicle present. Testes medullary, surround ovary and available intervascular space. Ovary bilobed in dorsoventral view, shell gland well developed; uterus median, pore preformed. Vitelline follicles form a sleeve enclosing all reproductive organs. Eggs anoperculate. Osmoregulatory system complex, anastomosing frequently.

Type species: Mustelicola woodsholei Dollfus, 1969.

Other species: M. antarcticus sp. nov.

Hosts: Spiral valves of triakid sharks.

Acknowledgments

Our thanks to Dr A. Petter, Laboratoire des Vers, Muséum National d'Histoire Naturelle, Paris, for loan of the type specimen.

This project was supported financially by the Australian Biological Resources Study.

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CHROMOSOME NUMBERS AND KARYOTYPES OF SOME AUSTRALIAN STIGMODERINI (COLEOPTERA: BUPRESTIDAE)

*BY JENNIFER A. GARDNER**

Summary

Karyotypes of eight species of Australian Stigmoderini are illustrated and compared. *Stigmodera (S.) goryi* Gory & Laporte, *S.* (S.) *porosa* Carter, *S. (Themognatha) donovani* Gory & Laporte, *S. (T) heros* Gehin, *S. (T) tricolorata* Waterhouse and *S.* (T.) *viridicincta* Waterhouse have a diploid complement of 22; *S.* (T.) *alternata* Lumholtz and *S. (T) nickerli* Obenberger have 2n = 20. A chromosome number of 2n = 22 is reported for 26 additional species. All Stigmoderini studied have an Xy_p sex-determining mechanism.

KEY WORDS: Coleoptera, Buprestidae, Stigmoderini, Chromosomes.

CHROMOSOME NUMBERS AND KARYOTYPES OF SOME AUSTRALIAN STIGMODERINI (COLEOPTERA: BUPRESTIDAE)

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Summary

GARDNER, J. A. (1988) Chromosome numbers and karyotypes of some Australian Stigmoderini (Coleoptera: Buprestidae). *Trans. R. Soc. S. Aust.* **112**, 163-167, 30 November, 1988.

Karyotypes of eight species of Australian Stigmoderini are illustrated and compared. *Stigmodera (S.) goryi* Gory & Laporte, *S. (S.) porosa* Carter, *S. (Themognatha) donovani* Gory & Laporte, *S. (T.) heros* Gehin, *S. (T.) tricolorata* Waterhouse and *S. (T.) viridicincta* Waterhouse have a diploid complement of 22; *S. (T.) alternata* Lumholtz and *S. (T.) nickerli* Obenberger have 2n = 20. A chromosome number of 2n = 22 is reported for 26 additional species. All Stigmoderini studied have an Xy_p sex determining mechanism.

KEY WORDS: Coleoptera, Buprestidae, Stigmoderini, Chromosomes.

Introduction

Coleopteran cytogenetics was pioneered by Stevens in the first decade of the twentieth century, and two species of buprestids, un-named spruce borers, were among the earliest examined (Stevens 1906). Smith & Virkki (1978) listed 22 species of buprestid, whose diploid chromosome number ranged from 12-26.

The Xy_p association is one in which the y is very small, approaching the lower limit of visibility. The X and y form a characteristic ring bivalent which Stevens (1906) described as a "parachute" in which the X chromosome represents the parachute proper, and the y represents the load. It is the commonest system in Polyphaga, occurring in practically all families, and Smith (1950) adopted the symbol Xy_p.

This study was undertaken as part of a revision of the tribe Stigmoderini. The aim was to determine if karyological characters could contribute to an assessment of the higher categories as delineated on the basis of morphological characters.

Materials and Methods

Adult male specimens were dissected as soon as possible after capture. Based on the technique of Imai *et al.* (1977) the testes were treated with a cold hypotonic (1% sodium citrate solution) for 1 h, then 0.005% w/v colchicine in hypotonic for 15 min before fixation in 3:1 ethanol: acetic acid for 30 min. The cells were spread and air-dried before staining with 10% Giemsa in Sörensen buffer at pH 6.8 for 15 mins. Photomicrographs were taken on a Zeiss Photomicroscope Model III at magnification 400x, using a green filter and Agfa-Gevaert Copex Pan Rapid Tri 13 film. Chromosome preparations and corresponding specimens are lodged in the South Australian Museum, Adelaide.

Chromosome counts were obtained for the following species: *Stigmodera (Stigmodera) cancellata* (Donovan), *S. (S.) goryi* Gory & Laporte, *S. (S.) gratiosa* Chevrolat, *S. (S.) macularia* (Donovan), *S. (S.) porosa* Carter, *S. (S.) roei* Saunders, *S. (Themognatha) alternata* Lumholtz, *S. (T.) barbiventris* Carter, *S. (T.) bonvouloiri* Saunders, *S. (T.) chalcodera* Thomson, *S. (T.) chevrolati* Gehin, *S. (T.) donovani* Gory & Laporte, *S. (T.) heros* Gehin, *S. (T.) mitchelli* Hope, *S. (T.) mniszechi* Saunders, *S. (T.) nickerli* Obenberger, *S. (T.) parvicollis* Saunders, *S. (T.) pubicollis* Waterhouse, *S. (T.) regia* Blackburn, *S. (T.) tricolorata* Waterhouse, *S. (T.) variabilis* (Donovan), *S. (T.) viridicincta* Waterhouse, *S. (Castiarina) adelaidae* Hope, *S. (C.) argillacea* Carter, *S. (C.) cupreoflava* Saunders, *S. (C.) decemmaculata* (Kirby), *S. (C.) flavopicta* (Boisduval), *S. (C.) grata* Saunders, *S. (C.) rufipennis* (Kirby), *S. (C.) sexplagiata* Gory, *S. (C.) simulata* Gory & Laporte, *S. (C.) subnotata* Carter, *S. (C.) sublincta* Carter, and *S. (C.) triramosa* Thomson.

Between one and three karyotypes were made from mitotic metaphase spreads of 17 species, and where more than one was made, there was good agreement, to the nearest percentage, between the relative total chromosome lengths (TCL) and arms, as measured from the enlarged photographic prints. Karyotypes are assigned formulae following Smith (1965).

Results

Of the 34 species examined, *S. nickerli* and *S. alternata* have a diploid complement of 20, the rest have 2n = 22. All have an Xy_p sex-determining mechanism (Figs 1, 2). Karyotypes of 17 species are summarized in Table 1, and eight of these are illustrated in Fig. 3

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Autosomes are predominantly metacentric, but some of the karyotypes analysed have acrocentrics e.g. *S. nickerli* (autosome 9), *S. viridicincta* (autosomes 7 and 10), or submetacentrics e.g. *S. tricolorata* (autosome 10). Changes in arm ratio may be due to pericentric inversion, changes in heterochromatin, or reciprocal translocation (Imai *et al.* 1977). Karyotype variations due to pericentric inversions in congeners are known in many genera of beetles (Yadav & Pillai 1979).

Of the eight species whose karyotypes are illustrated, six (*S. porosa, S. nickerli, S. tricolorata, S. goryi, S. alternata,* and *S. donovani*) have an autosomal pair with a nucleolar organizer region (NOR) (Figs 3a, b, d, e, g, h). When present, it is usually on autosome 8, or one of the adjacent chromosomes which are often so close in length that it is difficult to order them exactly. The position of the NOR is either pro-centric on the long arm as in *S. porosa,* or subterminal as in *S. nickerli* and *S. alternata.* In the latter cases, the distal ends of the arms form satellites.

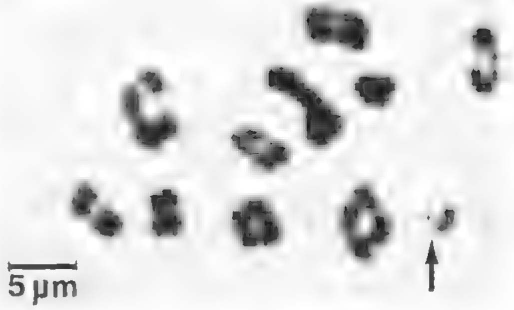

Fig. 1. Late male meiotic metaphase I of *Stigmodera (S.) gratiosa,* arrow indicates Xy_p bivalent.

In *S. nickerli* and *S. alternata,* autosome 1 is approximately twice the length of autosome 2, and represents about 22–23% TCL (Table 1). In the other Stigmoderini, autosome 1 varies from 1–1.5 x length of autosome 2 and represents only 12–15%

TABLE 1. *Karyology of 17 species of Stigmoderini.* A = autosomes; superscripts m, sm, sa, a, represent metacentric, submetacentric, subacrocentric and acrocentric respectively; S, M, L = small, medium and large size of X chromosome relative to autosomes; A1% = length of autosome 1 expressed as a % TCL; NOR = autosome number on which NOR occurs, where several autosomes are the same length so that the exact order cannot be determined, the number is given as a group; — indicates that no NOR was discerned.

Taxon	Formula	X	A1%	NOR
Stigmodera (Stigmodera)				
cancellata	$10\ A^m + X^m y_p$	S	17	—
goryi	$10\ A^m + X^{sm} y_p$	S	13	7-8
gratiosa	$10\ A + X y_p$	S	13	—
macularia	$10\ A + X^{sm} y_p$	L	18	—
porosa	$10\ A^m + X^{sa} y_p$	L	18	7-8
roei	$10\ A^m + X^{sm} y_p$	L	16	—
S. (Themognatha)				
alternata	9 $A^m + X^m y_p$	S	22	8
barbiventris	$10\ A^m + X^a y_p$	S	15	—
chevrolati	7 $A^m + 3\ A^{sm} + X^{sm} y_p$	S	13	—
donovani	$10\ A + X^{sm} y_p$	S	14	6-8
heros	$10\ A^m + X^{sa} y_p$	L	15	—
mitchelli	9 $A^m + 1\ A^{sa} + X^a y_p$	S	12	—
nickerli	8 $A^m + 1\ A^a + X^{sm} y_p$	S	23	8
regia	9 $A^m + 1\ A^a + X y_p$	M	12	—
tricolorata	9 $A^m + 1\ A^{sm} + X^{sa} y_p$	S	13	7-8
cariabilis	8 $A^m + 2\ A^{sm} + X^a y_p$	S	13	7-9
viridicincta	8 $A^m + 2\ A^a + X^a y_p$	S	15	—

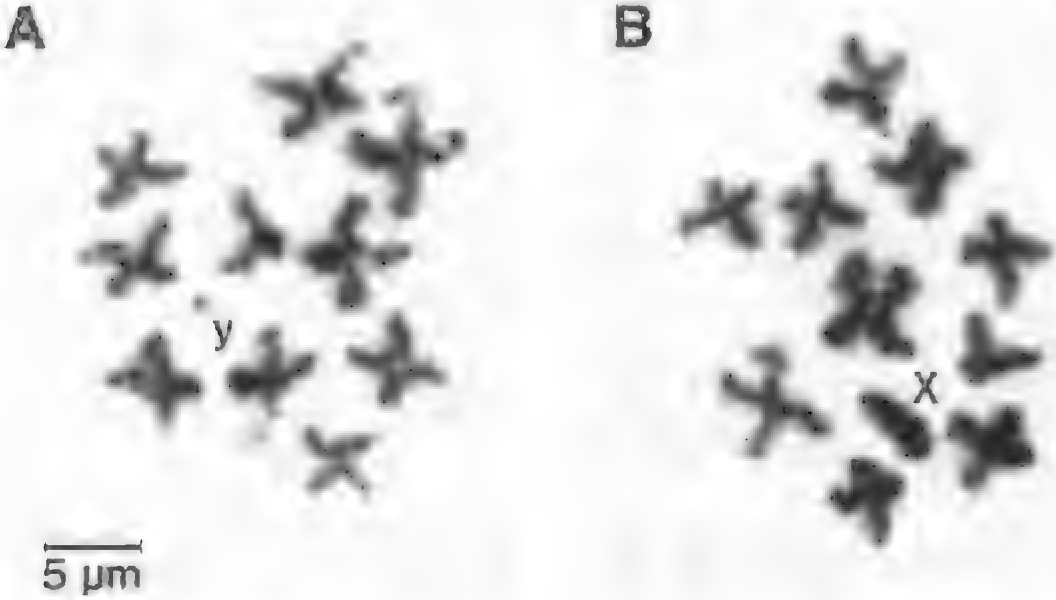

Fig. 2. Male meiotic metaphase II of *Stigmodera regia* (A) 10 A + y; (B) 10 + X.

TCL *S. (Themognatha)*, or 13-18% TCL *Stigmodera (sensu stricto)*.

The most distinctive difference between species is the relative size of the X chromosome (see Table 1). In some species e.g. *S. porosa* and *S. heros*, the X approaches the largest autosome in length, but in most it is one of the smallest. In the majority of species the arms of X are unequal, often markedly so, and the X is heterochromatic as indicated by both the differential staining and its diphasic form. A chromosome appears diphasic when the euchromatic arms condense earlier and the split between their chromatids becomes clearly visible, whereas the condensation of the heterochromatic arms proceeds more slowly and the chromatids remain jointly coiled for a longer time (Smith & Virrki 1978).

Discussion

The study of 34 species of Stigmoderini indicates generic stability of chromosome number. The limited data on other buprestids support this e.g. the four species of *Agrilus* studied by Smith (1949, 1953) have 20 or 22; the three species of *Dicerca* reported have 20 (Smith 1953), and two species of *Sternocera* have 26 (Asana *et al.* 1942).

The differences in chromosome number of *S. (T.) nickerli* and *S. (T.) alternata*, with 2n = 20 may be due to Robertsonian rearrangements. Centric fusion or fission are suggested when there is a change in the number of chromosomes, but not in the total number of major chromosome arms (the fundamental number). The centric fusion of two acrocentric autosomes such as 7 and 10 of *S viridcincta* could have given rise to a karyotype such as *S. alternata* with nine metacentric autosomal pairs. The fused chromosomes would approximate in size the large relative length of chromosome 1.

On the other hand, translocations have played an important role in the karyotype evolution of beetles (Virkki 1984). The large size of autosome 1 in *S. nickerli* and *S. alternata* (22% TCL) may have evolved from a karyotype similar to the other *Stigmodera* by translocation of one of the smaller autosomes (6-9% TCL) on to autosome 1 (12-18%), followed by a pericentric inversion which resulted in the new autosome 1 reverting to a metacentric.

The preponderance of species with 2n = 20 + Xy_p in Stigmoderini suggests that 22 chromosomes may be the ancestral condition of the tribe, with the complements of *S. nickerli* and *S. alternata* being apomorphic.

The Xy_p sex-determining mechanism has been recorded in ten of the 21 species of Buprestidae reported by Smith & Virkki (1978), the others had XY, Xy, neo-XY or XO. Crowson (1981) maintained that it is the most primitive condition, and is suspected to have been a feature of the ancestors of the Endopterygota at the beginning of the Permian period, although this question is still under

Fig. 3. Male karyotypes derived from mitotic metaphase plates. (A) *Stigmodera porosa*; (B) *S. tricolorata*; (C) *S. viridicincta*; (D) *S. donovani*; (E) *S. goryi*; (F) *S. heros*; (G) *S. nickerli*; (H) *S. alternata*. Arrows indicate NORs, all karyotypes are at the same scale.

debate. Opinions about the mechanism of pairing X_p and y_p have oscillated between nucleolar and chiasmate modes and there is now evidence for both associations (Virkki 1984).

It is probable that the variation in relative size of the X chromosome is due to the duplication or deletion of constitutive heterochromatin which could occur without deleterious effects. Structural alterations such as translocations also may have been responsible for some of the variation observed. Variations in the X chromosome do not correspond to species groups formed on the basis of other characters (Gardner 1986[1]).

Crowson (1981) asserted that chromosomal features of Coleoptera do not provide very reliable characteristics of taxa at higher levels, though he noted two exceptions: superfamily Cantharoidea in which all 25 species studied have an XO sex-determining mechanism; and superfamily Curculionoidea in which the karyotypes of all species studied are derived from a basic ten autosomal pairs, not nine. Blackman (1980) in his study of 180 species of Aphidae expressed a similar opinion, although he found that in general, chromosome data corroborate generic concepts since there is a clear tendency for the chromosome number to be stable at this level, and that differences in chromosome numbers sometimes agree with recognized subgeneric groupings.

Yadav & Pillai (1979) in their study of phylogenetic relationships of genera and subfamilies of Scarabaeidae, placed considerable importance on chromosome number which they found varies from $n = 6$-11, with 150 of the 194 species having the modal number of $n = 10$. They considered the two tribes Adorrhinyptiini and Adoretini to be closely related because they both have $2n = 22$. However, the occurrence of $2n = 22$ in two genera from other subfamilies, *Geotrupes* and *Dynamopus*, not considered taxonomically close on other grounds was considered to be parallelism.

My exploratory chromosome studies of Stigmoderini support the general observation of generic stability in chromosome number and suggest that karyology may be useful in delimiting species groups. *S. nickerli* and *S. alternata* which both have 20 chromosomes are morphologically very similar. The use of C-banding techniques when more material becomes available could provide insights into the relationships between the complements of 20 and 22, the evolution of the acrocentrics, and the evolution of the X chromosome.

Coleopteran cytogenetics is still in its infancy because of the small size of the chromosomes and associated problems of obtaining high quality karyotypes, so perhaps it is too early to assess its use in systematics. Uniformity of many of the gross chromosomal features supports the naturalness of Stigmoderini as a group, but gives less scope for elucidating relationships within the tribe. More detailed karyological analyses in the future may provide valuable phylogenetic information, and be useful at the level of species group.

Acknowledgments

This work was supported by a Commonwealth Postgraduate Award and an Australian Museum Trust Postgraduate Award, and undertaken in the Department of Zoology, University of Adelaide.

For the provision of fresh specimens I am indebted to Mr A. Sundholm, Mrs N. Cawthorne, and Mr M. Hanlon, all of Sydney.

For their constructive comments on an earlier draft of this manuscript I thank Dr M. Mahony, South Australian Museum, Dr D. Hayman, Department of Genetics, and Dr M. Davies, Department of Zoology, University of Adelaide.

I am grateful to Dr S. Barker for his support and supervision, Dr G. Browning for instruction in karyological techniques, and Mr P. Kempster for assistance in preparing the plates. I especially thank my husband, Doug, for his constant encouragement and for accompanying me on collecting trips across the continent in search of live material.

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A NEW SPECIES OF *NOTOPLAX* (MOLLUSCA: POLYPLACOPHORA: ACANTHOCHITONIDAE), FROM NEW SOUTH WALES, AUSTRALIA

*BY K. L. GOWLETT-HOLMES**

Summary

A new species, *Notoplax lancemilnei* sp. nov., is described from deep water off central New South Wales, Australia. It most closely resembles *N. speciosa* Adams but is distinguished from it by the larger, more irregular tegmentum pustules, ridges filling in part of the insertion plate grooves, and by its colour. The new species was trawled by the F.R.V. "Kapala" in 400-500 m of water.

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GOWLETT-HOLMES, K. L. (1988) A new species of *Notoplax* (Mollusca: Polyplacophora: Acanthocithonidae), from New South Wales, Australia, *Trans. R. Soc. S. Aust.* **112**, 169–173, 30 November, 1988.

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Introduction

The shallow water chiton fauna of eastern Australia is relatively well known (Iredale & Hull 1927), but few collections of chitons have been made in waters over 50 m in depth. During recent experimental fishing operations in the continental shelf waters of eastern Australia by the F.R.V. "Kapala", a number of chitons belonging to the genus *Notoplax* were collected. Most of these proved to be specimens of *Notoplax mayi* (Ashby, 1922), but three specimens could not be assigned to any known species of *Notoplax* and were recognised as belonging to an undescribed species of the genus. This new species is described here.

Materials and Methods

The material reported here is deposited in the Australian Museum, Sydney (AM) and the South Australian Museum, Adelaide (SAM). It was trawled by the F.R.V. "Kapala" during experimental fishing operations. All material is preserved in 2% formaldehyde/propylene glycol solution. As all specimens are curled, length measurements are along the curved surface, and width measurements are maximum width. A linear measurement is also given for the holotype. As the radula of the holotype disintegrated during preparation, the radula was removed from one of the paratypes (SAM D18436) for examination under the scanning electron microscope (SEM) using the method of Bandel (1984). Colour descriptions are from spirit specimens and follow Kornerup & Wanscher (1978).

Notoplax lancemilnei sp. nov.

FIGS 1–3.

Holotype: AM C151130, partially disarticulated, in spirit 107 × 37.45 mm (39.7 mm linear), trawled by F.R.V. "Kapala" at 439 m depth, off Wollongong, N.S.W., Aust., (34°21–19'S, 151°23–25'E), collected by K. Graham, 13.xii.1978.

Paratypes: SAM D18436, one complete specimen (radula removed), in spirit 79 × 29.35 mm, with same collection data as holotype. AM C148995, complete specimen in spirit, 133 × 39.35 mm, trawled by F.R.V. "Kapala" at 503–452 m depth, off Sydney, N.S.W., Aust., (34°18–23'S, 151°26–23'E), collected by K. Graham, 5.xii.1983.

Diagnosis: Large chiton to about 100 mm. Carinated; low elevation; valves small in relation to girdle (Figs 1A–D). Tegmentum white; about 30–35% of articulamentum; jugum smooth, about 1/12 width of tegmentum; pustules irregular, "U"-shaped, rounded to almost rectangular. Articulamentum white, slit formula 5/1/5, with ridges filling in part of slit grooves. Girdle very fleshy, completely encroaching between valves; colour pinkish white, made up of a brownish red base colour with dense clear spicules; small white sutural tufts (Fig. 2A).

Description of Holotype: Tegmentum of anterior valve (Fig. 3A) with five slightly raised radial ribs; sculptured with random pustules, very small, not coalescing, mainly "U"-shaped near apex, becoming larger and irregularly rounded in shape towards outer edge of tegmentum, with very large, irregular pustules on ribs. Slits 5, very short, about 1/10 width of insertion plate, in broad, shallow grooves for 1/4–1/3 width of insertion plate, grooves then filled in with prominent ridge to edge of tegmentum.

Median valves (Fig. 3B, D) beaked, anterior edge slightly concave; jugum smooth, narrow, about 1/12 width of tegmentum, toothed near beak. Lateral and pleural areas separated by low diagonal rib; both areas sculptured with random pustules, pustules very small, mainly "U"-shaped near beak, becoming larger and irregularly rounded to almost rectangular toward outer edge of tegmentum,

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Fig 1. *Notoplax lancemilnei* sp . nov. paratype (AM C148995), A. lateral view, × 1.5; B. dorsal view, × 1.8; C. anterior view, × 1.6; D posterior view, × 1.6.

pustules usually larger on rib. Tegmentum with numerous random aesthetes on and in between pustules (Fig. 2B). Slit 1, short, about 1/6 width of insertion plate, in broad, shallow groove 3/4–4/5 width of insertion plate, groove bordered by distinct ridges which merge to form a broad ridge filling in the groove to edge of tegmentum; slit, groove and ridge angled sharply posteriorly across insertion plate.

Posterior valve (Fig. 3C, E, F) tegmentum longer than wide; jugum smooth, narrow, weakly toothed near mucro. Antemucronal area sculptured with random, irregular "U"-shaped to almost rectangular pustules, very small near mucro, becoming larger towards outer edge of tegmentum. Mucro granulose, in posterior 1/4 of tegmentum; postmucronal area slightly convex, steep, sculptured like antemucronal area with four ribs of larger, irregular, rounded pustules. Slits 5, short, 1/5–1/6 width of insertion plate, in deep grooves ½ to almost whole width of insertion plate, grooves bordered by distinct ridges which merge to form ridges like on median valves to edge of tegmentum.

Girdle large, very fleshy, completely encroaching between valves, densely covered with numerous clear, long (1.5–3 mm), thin (90–100 μm), very slightly curved, sharp-tipped spicules. Sutural tufts small, with many clear, straight, sharp-tipped spicules (1–2.5 mm long, 70–100 μm wide).

Ctenidia numerous, merobranchial, abanal, 33 on right side and 36 on left, tapering large to small anteriorly.

The radula disintegrated during preparation but examination of the fragments showed it to be identical to the radula extracted from the paratype (SAM D18436).

Etymology: Named for Mr K. Lance Milne (1915-) who, as an avid collector of chitons from many parts of the world, has made significant contributions to the collections of SAM. In particular, his large, diverse collection of chitons in spirit forms the basis of SAM's present significant spirit collection of chitons. He also published several papers on chitons, including descriptions of several new species from eastern Australia. His continuing enthusiasm and support for work on chitons in Australia is greatly appreciated.

Additional Characters from Paratypes: Radula (Fig. 2C,D) with central teeth narrower basally, with wider, asymmetrical, concave heads; first lateral teeth forming large folds around central teeth, one on higher side of central tooth longer than other; major lateral teeth elongate, narrower basally, with wider tricuspidate heads, central cusp about twice as long as outer cusps, central cusp with a shallow dorsal groove either side of median ridge.

Variation: Other than minor variations in sculpture, the two paratypes are like the holotype and vary only in the number of gills. The smaller paratype has a similar number of gills to the holotype, with 34 ctenidia on right and 33 ctenidia on left sides. As the other paratype is much larger than the holotype, it has more gills, with 44 ctenidia on right and 39 ctenidia on left sides. In this larger paratype, the anterior jugum of the posterior valve breaks up into a series of large "U"-shaped pustules. This feature may be related to greater maturity of the specimen.

Range: Central New South Wales, Australia.

Habitat: Unknown. Trawled in 400–500 m depth.

Comparison with other species: *N. lancemilnei* was compared with other species of *Notoplax* in the collections of AM, SAM, the Museums of Victoria, Melbourne (NMV), the Western Australian Museum, Perth (WAM) and the Tasmanian Museum and Art Gallery, Hobart (TM). It most closely resembles *N. speciosa* (H. Adams, 1861) but can be distinguished by the characters given in Table 1. Both *N. lancemilnei* and *N. speciosa* can be distinguished from other Australian species of *Notoplax* by their large size and the large, fleshy girdle with long, fine spicules completely encroaching between the relatively small valves.

Remarks: An unusual feature of *N. lancemilnei* is the asymmetrical heads of the central teeth of the radula. This feature has not been recorded for any other member of the family. However, I have found it also in two other species, both of uncertain systematic status, in the family. A more detailed examination of radulae of species in the Acanthochitonidae is required to establish the extent of this unusual feature. The only other record of central radula teeth with asymmetric heads in the Polyplacophora is for *Choriplax grayi* (H. Adams & Angas, 1864), the sole member of the family Choriplacidae (Gowlett-Holmes 1987).

The current restricted range of *N. lancemilnei* is a reflection of the few collections of chitons that have been made in deep water in Australian seas. This range undoubtedly will be extended when further collections of chitons from deep water are made.

Acknowledgments

I thank Ms S. Morris, British Museum (Natural History), London, for the loan of a syntype of *N. speciosa* (BMNH 1951.2.7.2/1), and the following curators and collection managers for providing data and specimens from collections held by their respective institutions: Mr I. Loch (AM), Ms S. Boyd (NMV), Dr F. E. Wells (WAM) and Ms E. Turner (TM). The photographs were taken by Mrs J. Forrest and Ms A. Renfrey (SEM). Mr I. K. Grant

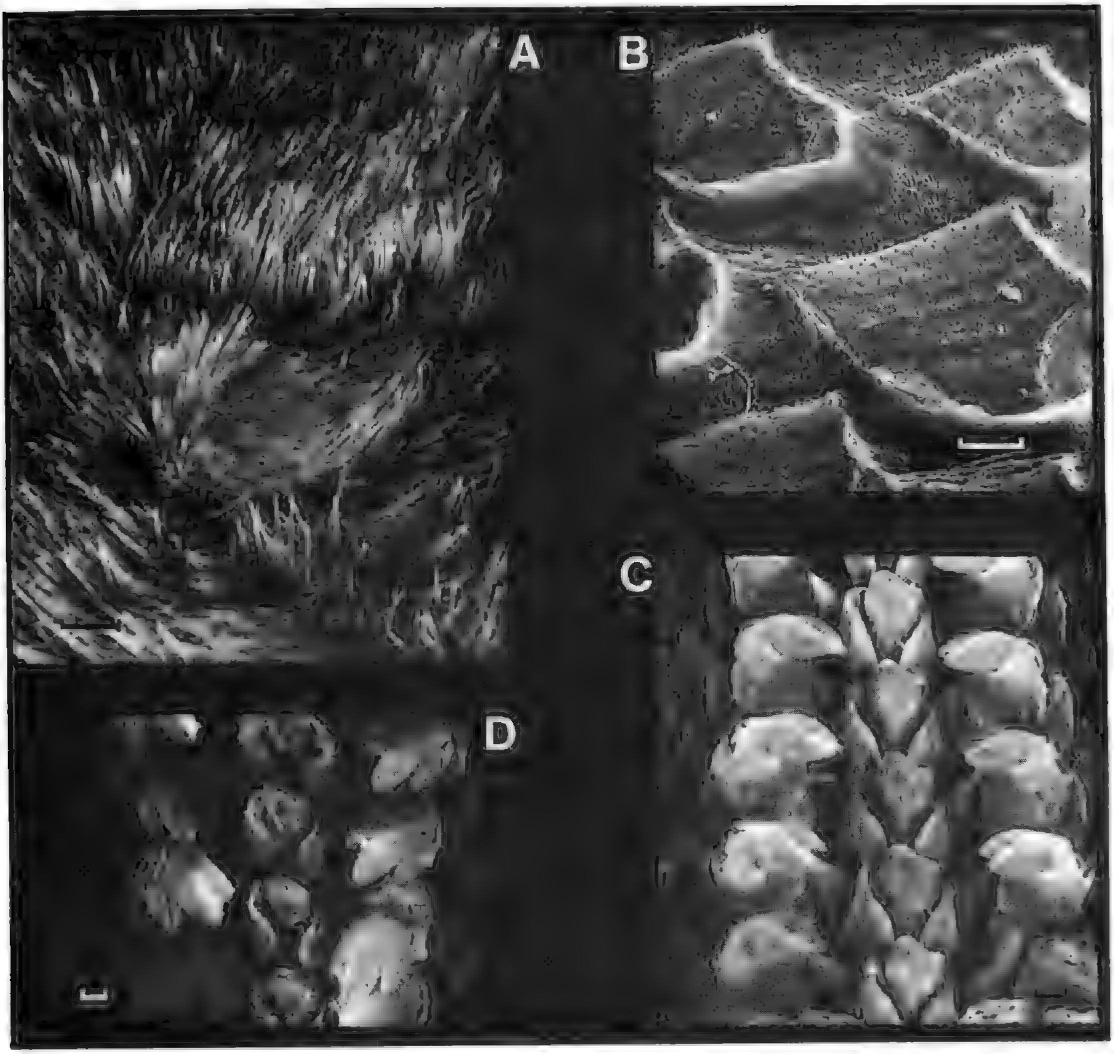

Fig. 2. *Notoplax lancemilnei* sp. nov. A. girdle and sutural tuft, paratype, scale bar = 1 mm (AM C148995); B. detail of tegmentum surface showing aesthetes, holotype, scale bar = 100 μm (AM C151130); C. radula, paratype, scale bar = 100 μm (SAM D18436); D. radula, detail of major lateral teeth heads, paratype, scale bar = 100μm (SAM D18436).

is thanked for his assistance with Fig. 3. Dr D. Duckhouse and Ms T. Cochran are thanked for critical comments. This work was supported in part by a grant from the Keith Sutherland Award, administered by AM.

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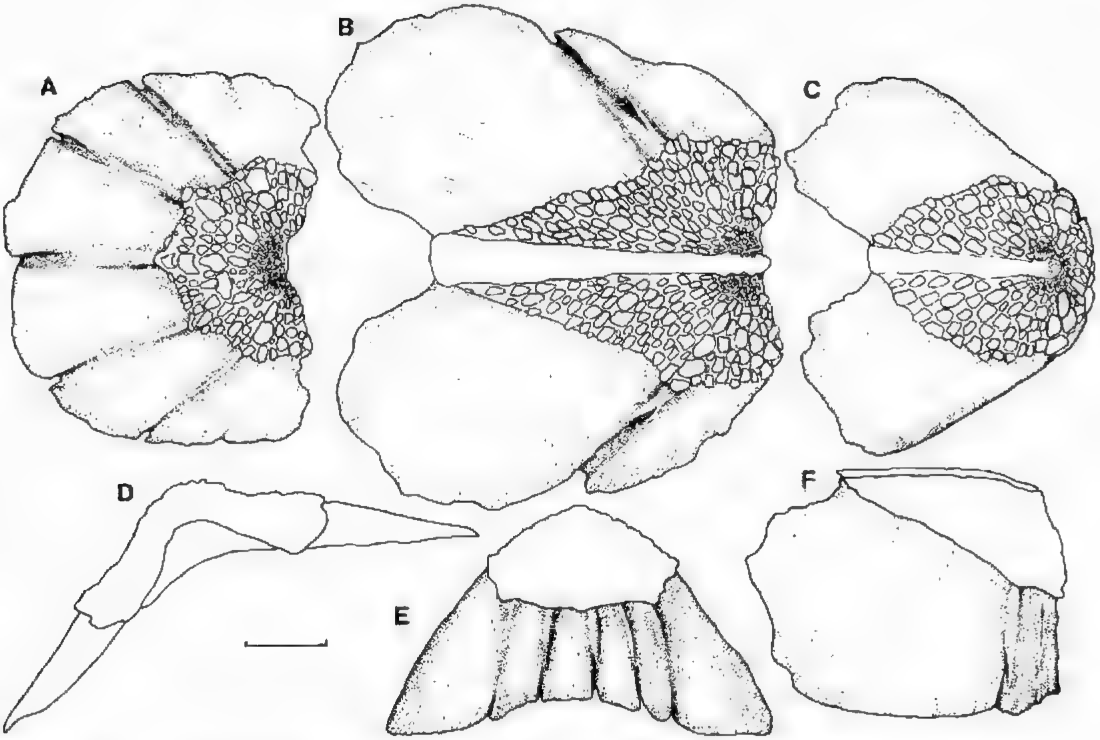

Fig. 3. *Notoplax lancemilnei* sp. nov. holotype (AM C151130), A. anterior valve; B. median valve; C. posterior valve; D. median valve (posterior profile); E. posterior valve (posterior profile); F. posterior valve (lateral profile); scale bar = 2 mm.

TABLE 1. *Distinguishing characters of* Notoplax speciosa *and* N. lancemilnei *sp. nov.*

Character	*N. speciosa*	*N. lancemilnei*
Tegmentum colour	coloured	white
Girdle colour	orange, greyish to brownish orange	pinkish white
Sutural tuft colour	orange	white
Pustules on valves	small	larger, more irregular
Insertion plate slit length (width insertion plate)		
1. anterior valve	1/5-1/4	1/12
2. median valves	about 1/3	about 1/6
Insertion plate slit grooves	grooves to edge of tegmentum, no ridges	grooves partly to edge of tegmentum, ridges rest of way
Ctenidia each side	26-32	33-44
Radula		
1. central teeth	head symmetrical	head asymmetrical
2. major lateral teeth	central cusp of head about 4 times as long as outer cusps	central cusp of head about twice as long as outer cusps

ACCUMULATION OF PERIPHYTON ON ARTIFICIAL SUBSTRATA NEAR SEWAGE SLUDGE OUTFALLS AT GLENELG AND PORT ADELAIDE, SOUTH AUSTRALIA

BY V. P. NEVERAUSKAS

Summary

BRIEF COMMUNICATION

ACCUMULATION OF PERIPHYTON ON ARTIFICIAL SUBSTRATA NEAR SEWAGE SLUDGE OUTFALLS AT GLENELG AND PORT ADELAIDE, SOUTH AUSTRALIA.

Two sewage sludge outfalls are sited in seagrass meadows offshore from the metropolitan area of Adelaide (Fig. 1). There has been extensive loss of the seagrasses *Posidonia (P. sinuosa* and *P. angustifolia)* and *Amphibolis (A. antarctica* and *A. griffithii)* around the Port Adelaide sludge outfall[1] and plants in partially-affected areas have an increased abundance of epiphytes on their leaves[2]. Increased growth of epiphytes in response to increased nutrient levels in the water is an apparent cause of the decline of seagrass beds[3] and studies with artificial substrata indicated that the rate of increase of epiphyte biomass reflected the pattern of seagrass loss[4]. Lesser effects have apparently occurred on seagrasses near the Glenelg sludge outfall[5].

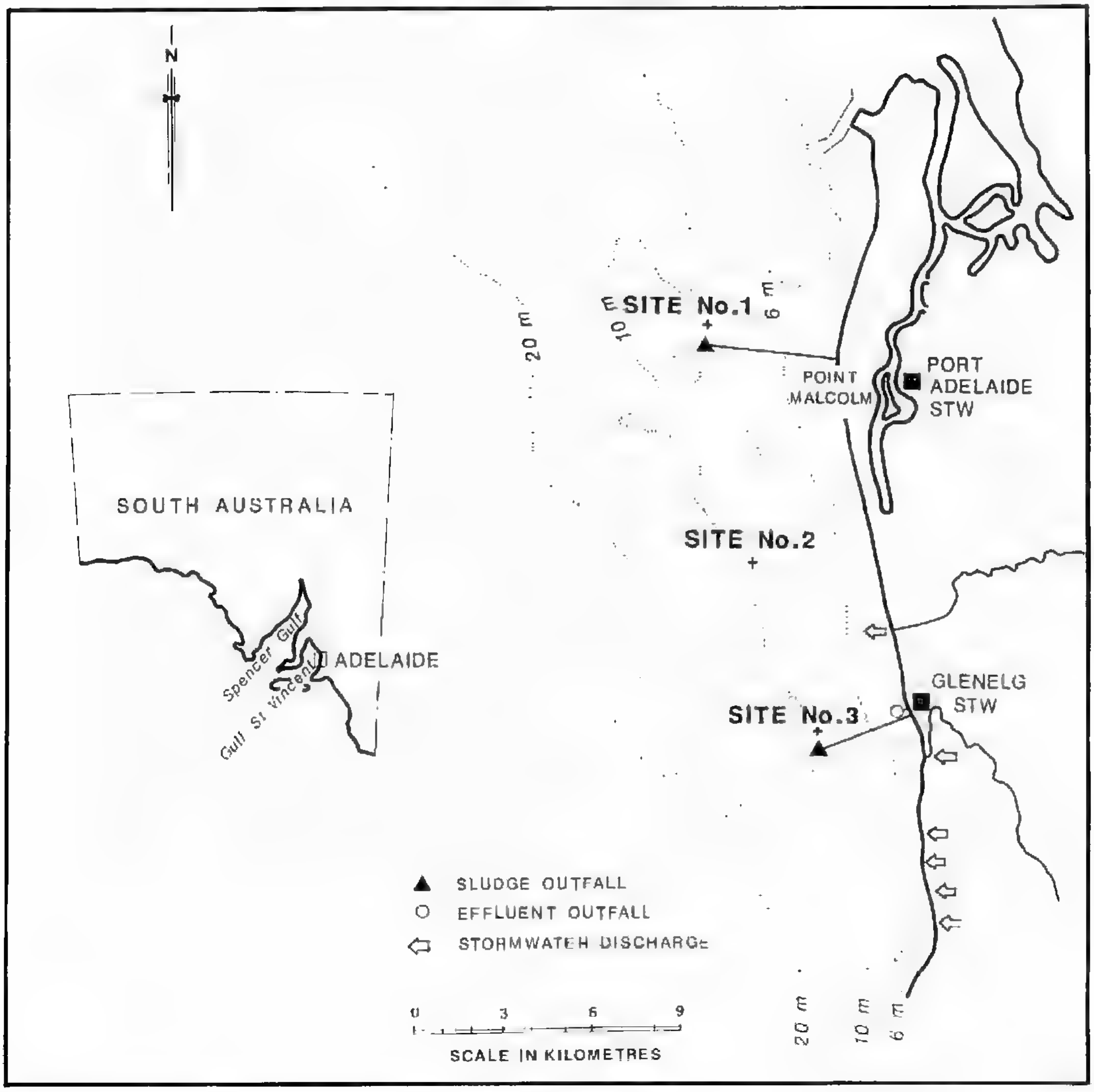

Fig. 1. Study area and sites for deployment of artificial substrata.

The aim of this study was to compare increases in epiphyte biomass at sites adjacent to the two outfalls. Underwater observations indicated that in late summer extensive mats of algae developed throughout the denuded area at Port Adelaide. There were signs of increased algal growth near Glenelg but no such mats developed, suggesting that seagrass epiphyte growth may have been reduced in that area.

The accumulation of epiphyte biomass (referred to as periphyton[6]) on artificial substrata was assessed at three sites (Fig. 1). Site 1 was 500m N of the Port Adelaide sludge outfall, coincident with a site used in a previous study[4]. Site 3 was in a similar position relative to the Glenelg sludge outfall and site 2 was a control site situated in apparently healthy seagrass meadows. The depth of water at each site was approximately 13m.

150 substrata were deployed at each site in the early part of November 1986 and sub-sampled at monthly intervals for five months. The dimensions of the substrata, their mode of deployment, collection and processing have been described previously[4].

The design of this study was simple and it was essentially unreplicated. It did not measure within-site variability nor was an estimate made of variability between different control sites. Underwater observations did, however, indicate that each site was homogeneous over a large area and site 1 has been surveyed in detail[1]. Periphyton biomass accumulation has been studied at a number of different control sites[4,7] and these factors strongly suggested that the above sources of variation were small compared to the variation between experimental and control sites.

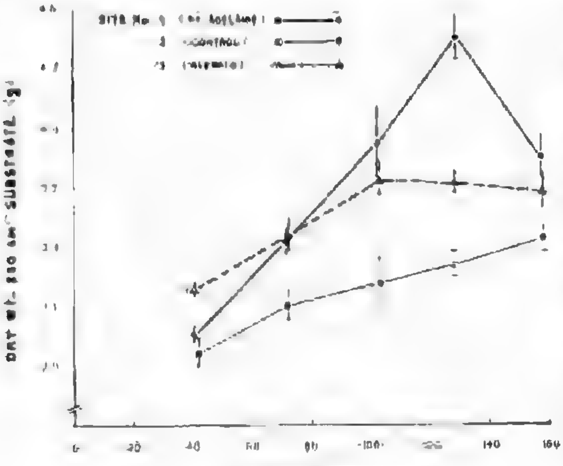

Fig. 2. Changes in dry weight of substrata due to accumulation of periphyton. Mean ± S.D. (n = 5).

Changes in the dry weight of substrata, as a result of the accumulation of periphyton, are shown in Fig. 2. At all times the mean value of dry weight on substrata at the control site was below that recorded at the experimental sites. There were also differences between these two sites. Periphyton biomass accumulation was initially greater at site 3, adjacent to the Glenelg outfall than at site 1, adjacent to the Port Adelaide outfall. After this initial result however, periphyton biomass accumulation was greater and reached higher values at site 1.

Detailed studies at the Port Adelaide outfall have indicated that the most important factor determining the distribution of sludge is tidal flow. It is oriented in a north-south direction and as a result sludge is mostly confined to a narrow strip north and south of the outfall. The Glenelg outfall has not been studied in the same detail but it is known that the tidal flow is similar to that at Port Adelaide both in strength and direction[8].

The two experimental sites used in this study were directly north of each outfall and therefore influenced by sludge, a rich source of soluble nitrogen and phosphorus. The composition and concentration of these nutrients in sludge discharged from both Sewage Treatment Works (STW) are similar. Discharge rates are similar but an average of 480kL of sludge is daily discharged from Glenelg STW and 280kL from Port Adelaide STW. It is likely that the initial differences between the substrata at the corresponding sites was a reflection of a greater availability of nutrients at Glenelg.

The differences between the biomass estimates on the substrata at the experimental sites during February and March were associated with distinct changes at the two sites. At Port Adelaide large algae developed and, attached to residual seagrass fibre with its associated mussel beds, formed extensive mats up to 50cm in depth. They were similarly prominent on the artificial substrata. Though it remained visibly greater than at the control site, such growth of algae did not occur around the Glenelg outfall and no large algae developed on the substrata deployed there.

During the last month of exposure, periphyton biomass at Port Adelaide decreased sharply. The early part of autumn is often associated with the first significant storms of the year and large algae are physically removed from the area[4]. Other observations suggested that a similar mechanism may have affected the accumulation of periphyton biomass at Glenelg. When the substrata were sampled divers noted that at Port Adelaide the water column was calm except for tidal movement. At Glenelg a distinct swell was consistently present and this resulted in vigorous motion of the substrata over and above their response to the tide.

While no data are available to compare the incident wave energy at the two sites, the gradient of the seafloor, the presence of offshore shoals at Point Malcolm and the presence of erosion cusps within seagrass beds south of Point Malcolm indicate that wave energy differs between the two sites[9]. It is possible that the initially higher periphyton biomass at the Glenelg site was a reflection of a faster growth rate of algae. As they became larger, however, they were removed by wave action and this resulted in smaller increases in periphyton biomass relative to the Port Adelaide site.

In Western Australia the species of periphyton found on artificial substrata were similar to the epiphytes found on the leaves of *Posidonia australis*[10]. It is likely that the same applies in the present study. The response of periphyton to increased levels of nutrients, from sludge, may therefore indicate the response of seagrass epiphytes under the same conditions.

The results presented above suggest that seagrasses in the vicinity of the Glenelg outfall do not accumulate quantities of epiphytes as large as those which accumulated on seagrasses around the Port Adelaide outfall. Individual species of epiphytes may grow faster at the former site but due to greater incident wave energy they are removed from the seagrass before they blanket and burden the leaves as they do at Port Adelaide.

Thus one of the major factors known to cause the decline of seagrass beds seems to be reduced at the Glenelg sludge outfall. This may help to account for the apparently large differences between the extent of seagrass decline around this outfall[5] and the extent of decline around the Port Adelaide sludge outfall[1].

I thank Steve Slack and Debra Mooney for their capable assistance.

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BRIEF COMMUNICATION

USE OF GROWTH RINGS TO DETERMINE AGE IN THE FRESHWATER TORTOISE *CHELODINA LONGICOLLIS*: A CAUTIONARY NOTE

Counts of laminal growth rings visible on the shells of freshwater North American testudines have been used to determine the ages of individual animals[1,2]. Periods of brumation coincide with the formation of deep grooves in the epidermis of the shell[3], which are initially hidden in the interlaminal seams. They become visible after spring growth commences forming a ridge delineating the outer edge of the groove[4] and the spreading of the interlaminal seams brings the grooves to the surface. For north temperate species[5], a "year" can be added to the known age of individuals when the groove becomes visible[6]. The grooves are generally known as growth rings[5,7].

Coincident with the recommencement of growth is the formation of a new, deeper layer of epidermis[8]. The margin of the plate of scute epidermis laid down in the previous season's growth is delineated by the growth ring formed at the commencement of the next season of growth[9]. Old layers of epidermis may be retained in terrestrial testudines[8], but in aquatic species they are usually shed, either as single [8] or, eventually, multiple layers[9]. Repeated scute ecdysis causes growth rings to weaken then disappear[7].

Temporary cessation of growth during the growing season may result in the formation in many species of shallow grooves, termed minor growth rings[8,9]. However, minor growth rings are not associated with the formation of a new layer of epidermis[8,9].

Measurement of the gaps between major growth rings, together with counts of their number, have been used to determine growth rates in any particular past year[7,10].

Determination of age based on counts of growth rings requires that the number of growth rings produced by a sample of the population over a long period of time be known, and the only satisfactory means of determining the periodicity of growth ring production is to conduct capture-recapture exercises[7] over several years. Usually, it is assumed that only one major growth ring is formed annually[11], and for north temperate species this assumption is normally valid[5]. However, the assumption that only one growth ring is formed annually by a particular population of a species is not always verified.

The technique of aging has been applied to an Australian species (*Pseudemydura umbrina*) by Burbidge[12]. The technique of determining growth rates has been applied to *Chelodina longicollis* by Parmenter[13] and, with reservations, to *C. longicollis* and two other Australian species (*Emydura macquarii* and *Chelodina expansa*) by Chessman[14].

Although verification of the annual deposition of growth rings was undertaken by Burbidge for the populations of *Pseudemydura umbrina*[15], there is no clear indication that the periodicity of deposition of growth rings has been determined for populations of *C. longicollis*. Parmenter developed an argument inferring that annual deposition of growth rings occurred in *C. longicollis*, because the species ceases to grow during annual brumation; but there is no evidence that he verified the conclusion[13]. Chessman initially assumed that growth rings were deposited annually, but on comparison with growth rates, as determined on recapture, he concluded that the deposition of growth rings may be affected by growth rate, and that major growth rings may have been confused with minor rings[14].

Parmenter extrapolated from conclusions relevant to North American species to *C. longicollis*; but North American winters are longer and more severe than winters in the range of *C. longicollis*. Daily mean temperatures in the mid west of the United States differ by about 25°C between mid Summer and mid Winter[16] (Table 1), but the difference is only 14°C at Armidale, near where Parmenter undertook his field study. The activity period for *Kinosternon flavescens* in Oklahoma is 140 days[2], but Parmenter reports an activity period of 250–280 days for *C. longicollis*[13]. Without marked annual temperature cycles the growth of turtle scales is often even and free of interruptions[19]. On the coastal plain of the Gulf of

TABLE 1. *Daily Mean Temperatures at Meteorological Stations Near Testudine Study Sites*

STATION	SPECIES	DAILY MEAN °C MID-SUMMER	TEMPERATURE°C MID-WINTER
Tulsa, Ok, U.S.A.	*Kinosternon flavescens*[2]	27.9	2.9
Lansing, Mi, U.S.A.	*Chrysemys picta*[4]	22.1	–4.3
Omaha, Ne, U.S.A.	*Chelydra serpentina*[6]	25.3	–5.4
St Louis, Mi, U.S.A.	*Pseudemys scripta*[7]	26.4	–0.1
Kansas City, Ks, U.S.A.	*Terrapene ornata*[5]	27.2	–0.7
Phoenix, Az, U.S.A.	*Kinosternon sonoriense*[10]	32.9	10.4
New Orleans, La, U.S.A	*Sternothaerus carinatus*[17]	28.4	13.3
Colon, Panama	*Pseudemys scripta*[9]	26.6	26.8
Armidale, N.S.W., Aust.	*Chelodina longicollis*[13]	20.4	6.6
Melbourne, Vic., Aust.	*Chelodina longicollis*[14]	19.9	9.6
Mildura, Vic., Aust.	*Chelodina longicollis*[14]	24.1	10.1
Adelaide, S.A., Aust.	*Chelodina longicollis*[18]	22.6	11.2

Source of climatic data — "World Survey of Climatology", ed. H.E. Landsberg, Elsevier, Amsterdam, (1971).

References are to studies undertaken in vicinity of stations.

Mexico, the winters are more moderate, with daily mean temperature differences of about 13°C[16]. On the plain the growth rings were not as clear in *Sternotherus odoratus* as they were in emydid turtles, and the need for caution in their unverified use for age determination was emphasised[17].

Further south the climate is even more equable (Table 1). Colon, Panama, is close to the study sites of Moll & Legler[9], yet they noted the formation of up to four major growth rings in a single year in a population of *Pseudemys scripta*. Their conclusion was that growth rings are not necessarily related to temperature variation, and attributed the formation of growth rings in this population to cessation of feeding during periods of flooding[4].

Cagle stated that any interruption in the supply of food or in the ability of the individual to utilise food may result in the formation of a major growth ring[7], and Chessman reports minimal stomach contents in one population of *C. longicollis* in both mid-Summer and Winter[14], perhaps because *Duplinia carinata* was the major food item in that population, and *D. carinata* can exhibit a diphasic annual population cycle[20]. Hence the potential exists for multiple annual production of growth rings by populations of *C. longicollis*.

Here I record the number of growth rings formed in an individual *C. longicollis* over a known period. The animal was caught twice during a study on a population of this species which inhabits a number of ponds on the campus of Roseworthy Agricultural College, 45 km N of Adelaide.

The animal was first captured on 29.Jan.80. It was numbered using a pattern of drill holes in its marginal scutes, a technique which often leads to retention of old epidermal layers after scute ecdysis. The drill holes may heal with a hollow bridge of epidermal tissue connecting the shed epidermal layers of the upper and lower surfaces of the scutes, like a rivet through the hole. The subsequent capture was on 25.Nov.83.

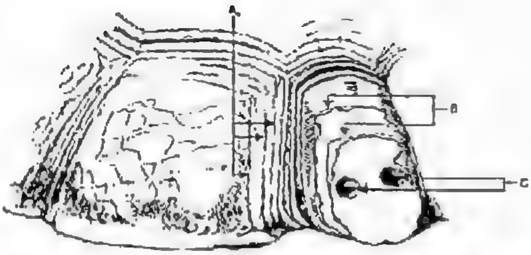

Fig. 1 Anteiror view of nuchal and first right marginal scutes. A, growth ring on bare scute; B, growth ring on retained epidermal layer; C, drill hole.

Six old epidermal layers were retained on both of the drilled scutes, but none on the other scutes. There was one visible growth ring on each of the retained epidermal layers, which corresponded precisely with the margin of the next most superficial retained epidermal layer (Fig. 1). Four growth rings which occurred towards the periphery of the bare scutes, corresponded in position to the four largest growth rings imprinted on the deeper retained epidermal layers on the drilled scutes. It was concluded that these growth rings were of the major type. Six had been produced in three years and ten months.

I contend that it is not valid to assume that one growth ring is produced in each year by *C. longicollis*: verification of the periodicity of production of growth rings is required for any population under study.

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THE EUROPEAN SHORE CARB, CARCINUS MAENAS IN THE CORONG – A POTENTIAL THREAT TO LOCAL FISHERIES

BY W. ZEIDLER

Summary

BRIEF COMMUNICATION

THE EUROPEAN SHORE CRAB, *CARCINUS MAENAS* IN THE COORONG — A POTENTIAL THREAT TO LOCAL FISHERIES

This note is to record the presence of the European Shore Crab, *Carcinus maenas* (Linn.) (Fig. 1), in the Coorong, South Australia, and to alert agencies to the damaging effects it may have on the ecology of the Coorong and hence the local fishing industry, should it become established.

Fig. 1. *Carcinus maenas* ♂ from West Lakes, S.A.

Ten years ago[1] I recorded the occurrence of *C. maenas* in S. Aust. and gave a brief overview of its introduction to Australia and current distribution. In S. Aust. the species had been restricted to the Outer Harbour, West Lakes and Port River areas, habitats it typically favours. It was thought at the time that natural spread was unlikely due to unsuitable habitats along the coast, but that introduction via ships' fouling and ballast was possible. Such an introduction appears to have occurred at Hallett Cove, 25 km S. of Adelaide, by shipping activities at the nearby oil refinery at Port Stanvac[2]. The recent capture of a specimen from the Coorong, however, if it is not an isolated specimen, suggests that the dispersal abilities of the crab have been underestimated.

The Coorong specimen, a mature male (carapace 85 mm × 65 mm), was caught by a local fisherman, Mr W. Ayres, in December 1986 near "Ti Tree" about 6 km S.E. of Tauwitchere Barrage, (about 20 km from the Murray River mouth). It was mottled light brown-grey in colour but specimens are usually grey-green. Just how this specimen got into the Coorong is open to conjecture. Most shipping activities in the Coorong are recreational and passage through the mouth is considered hazardous and is rarely attempted. Similarly, it is doubtful that a relatively poor swimmer such as *C. maenas*[3] (or its larvae) could have entered the Coorong by this route on its own. The possibility that is is an isolated case of human transfer cannot be ruled out but seems unlikely.

While *C. maenas* may not be of much ecological significance in the already degraded Port Adelaide-Outer Harbour area[1], its potential effect on the fauna of the Coorong is unknown. Its aggressive, non-selective predatory habits have already made it a pest in New England, U.S.A., where it is the major predator of the commercially harvested soft-shell clam, *Mya arenari* Linn.[4]. It has also recently been recorded from South Africa where laboratory experiments have shown that it is a potential predator of a number of local molluscs and perhaps other marine life.[3] Should *C. maenas* become established in the Coorong it may become a major predator of a variety of local fauna and could alter the ecology of the Coorong Lagoon sufficiently to threaten the local fishing industry.

The current status of *C. maenas* in the Coorong is unknown and no more specimens have been forthcoming from fishermen since the initial discovery. Future monitoring of the situation is essential because once established, *C. maenas* could be difficult to control in a semi-closed system such as the Coorong. More important however, is to establish how this animal initially arrived in the Coorong so that future access can be prevented.

I am grateful to Bill Ayres, Meningie, for bringing the specimen to my attention and for trying to capture more specimens.

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