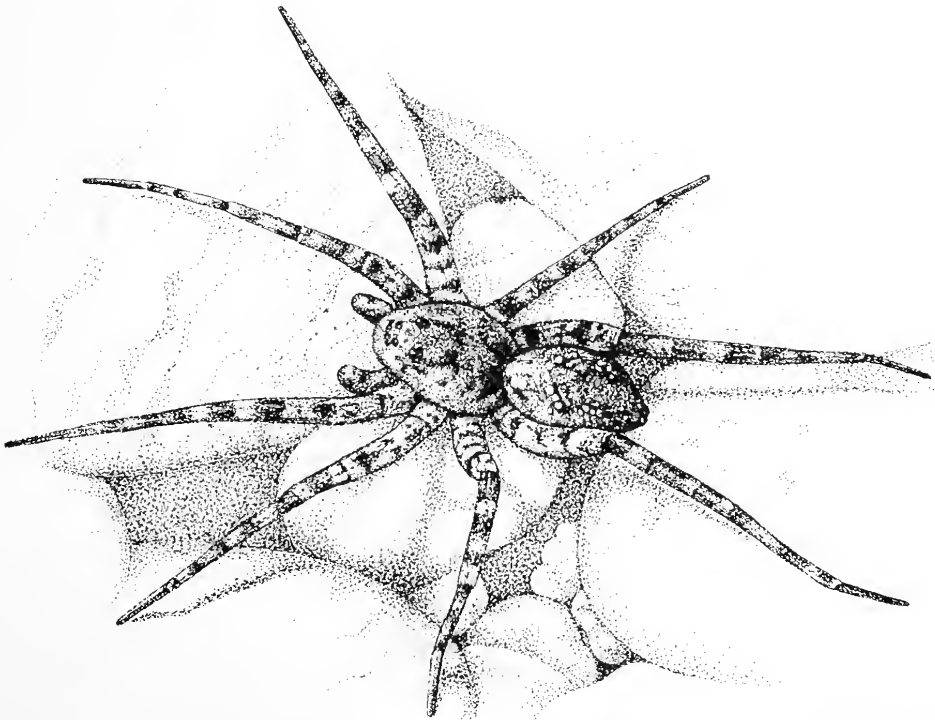


# Records of the Western Australian Museum



*Volume 23 Part 2 2006*

# Records of the Western Australian Museum

---

The *Records of the Western Australian Museum* publishes the results of research into all branches of natural sciences, and social and cultural history, primarily based on the collections of the Western Australian Museum and on research carried out by its staff members.

---

Collections and research at the Western Australian Museum are centred on Earth and Planetary Sciences, Zoology, Anthropology, Archaeology and History. In particular the following areas are covered: systematics, ecology, biogeography and evolution of living and fossil organisms; palaeontology; mineralogy; meteoritics; anthropology and archaeology; history; maritime history and maritime archaeology; and conservation.

---

## Western Australian Museum

Perth Cultural Centre, James Street, Perth, Western Australia 6000

Mail: Locked Bag 49, Welshpool DC, Western Australia 6986

Tel. (08) 9427 2700

Fax. (08) 9427 2881

E-mail [reception@museum.wa.gov.au](mailto:reception@museum.wa.gov.au)

### **Minister for Culture and the Arts**

The Hon. Sheila McHale MLA

### **Chair of Trustees**

Mr Tim Ungar BEc, MAICD, FAIM

### **Executive Director**

Dr Dawn Casey PSM FAHS

### **Editor**

Dr Kenneth J. McNamara BSc(Hons), PhD, FAAAS

### **Editorial Board**

Dr Alex Baynes MA, PhD

Dr Alex Bevan BSc(Hons), PhD

Ms Ann Delroy BA(Hons), MPhil

Dr Paul Doughty BSc(Hons), PhD

Dr Bill Humphreys BSc(Hons), PhD

Dr Barry Hutchins BSc(Hons), PhD

Dr Moya Smith BA(Hons) DipEd, PhD

The *Records of the Western Australian Museum* is published approximately three times per year. A series of *Supplements* is also produced. The *Records* are available for sale and exchange, the current price being \$11 plus postage per part. Each volume comprises four parts. Subscriptions can be taken out for whole volumes at a rate of \$33 plus postage. Supplements can be purchased from the W.A. Museum Bookshop. Prices on request. Prices include GST.

Printed and published by the Western Australian Museum

© Western Australian Museum, July 2006

ISSN 0312 3162

Cover: The wolf spider *Venatrix amnicola* is a habitat specialist and is restricted to gravelly river shores in the Great Dividing Range in South Eastern Australia.

Drawing by Jill Ruse.

# The birds of Gag Island, Western Papuan islands, Indonesia

R.E. Johnstone

Western Australian Museum, Locked Bag 49, Welshpool DC, Western Australia 6986

**Abstract** – This report is based mainly on data gathered during a biological survey of Gag Island by a joint Western Australian Museum, Museum Zoologicum Bogoriense and Herbarium Bogoriense expedition in July 1997. A total of 70 species of bird have been recorded for Gag Island and a number of these represent new island and/or Raja Ampat Archipelago records. Relative abundance, status, local distribution and habitat preferences found for each species are described, extralimital range is outlined and notes on taxonomy are also given. No endemic birds were recorded for Gag Island but a number of species show significant morphological variation from other island forms and may prove to be distinct taxonomically.

## INTRODUCTION

Gag Island (0°25'S, 129°53'E) is one of the Western Papuan or Raja Ampat Islands, lying just off the Vogelkop of Irian Jaya, between New Guinea and Halmahera, Indonesia. These islands include (from north to south) Sayang, Kawe, Waigeo, Gebe, Gag, Gam, Batanta, Salawati, Kofiau, Misool and a number of small islands (Figure 1). Gag Island is separated from its nearest neighbours Gebe Island to the north-west, and Batangpele Island to the north-east, by about 40 km of relatively deep sea. Gag Island is roughly oval shaped 12 km long by 7 km wide with its longest axis directed N-S and with a surface area of 56 km<sup>2</sup> (Figure 1). The east coast is deeply indented by the shallow Gambir Bay, which penetrates about 1.5 km inland. Most of the coast is rocky but there are a number of sandy beaches on the northern and western sides. Gag Island consists mostly of undulating hills, the highest peak Gunung Susu rising to 311 m. The island contains a number of small rivers and creeks including the Musawalo River in north and the Wapob River in east draining into Gambir Bay. Sago swamps and fresh water springs are abundant including a fairly large spring fed lagoon in the south-west corner. There is a small village on the north side of Gambir Bay and a number of residents at Kampung Tua on the northern coast. Domestic goats and domestic fowl occur throughout the cultivated areas and do not appear to have greatly disturbed the vegetation.

Gag Island was visited by the joint Western Australian Museum, Museum Zoologicum Bogoriense and Herbarium Bogoriense group between 9 and 20 July 1997. The major aim of the preliminary bird survey was to document the avifauna of the island and provide data on local distribution, status and habitat preferences. A small collection was also made of species that

undergo geographic variation for taxonomic, morphological and genetic studies. The annotated checklist provided covers every species recorded, both historically and during this survey.

In the annotated list I summarise for each species its relative abundance (whether it is very common, common, moderately common, uncommon, scarce or rare), whether it feeds alone or in groups, status (a judgement on whether it is a vagrant, visitor or resident), habitat preferences and breeding season. Extralimital range is also briefly outlined and for those species that are recognised as undergoing geographical variation, taxonomic notes have been provided.

## Habitats

Eleven major habitat types were recognised on Gag Island.

1. *Marine*. Includes coastal seas, stacks, reef flats and sandy and rocky shores.
2. *Kebun*. Cultivated areas, mainly coconut plantations but also banana, taro, breadfruit and mango etc (Figure 2).
3. *Disturbed volcanic forest*. Mostly secondary forest backing kebun in northern part of island (Figure 1).
4. *Primary volcanic forest*. Lowland rainforest covering most of the northern third of the island. Tall luxuriant forest with a variable canopy, 30–35 m with emergents to 45 m. Dominant genera include *Diospyros* sp., *Sterulia longifolia*, *Planchonella* sp., *Celtis philippensis*, *Tricalysia malaccensis*, *Canarium littorale* and *Champereia manillana* (Figure 5).
5. *Sago vegetation*. Fairly extensive stands around Gambir Bay and along Wapob River.
6. *Grassland*. Includes airstrip, open grassy areas

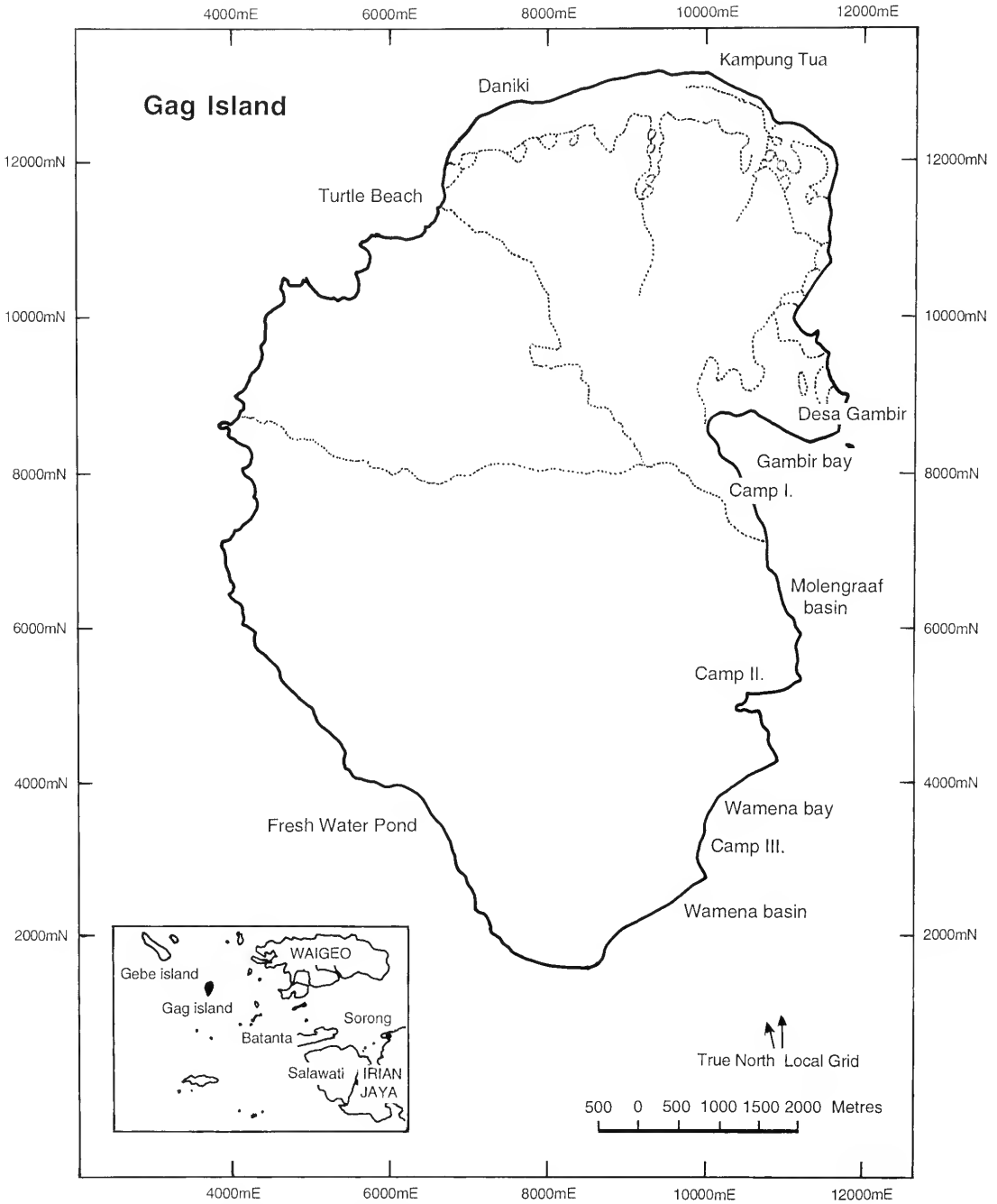


Figure 1 Map of Gag Island showing main features.

around settlements and grassy hills on the south-east corner of island. (Figures 1, 3 and 6).

7. *Mangroves*. Small stand of mangroves occurs at mouth of a creek at Camp Two (south-east side of island). Genera include *Sonneratia*, *Lumnitzera*, *Ceriops*, *Bruguiera*, *Xylocarpus*, *Rhizophora* and *Excoecaria*.

8. *Beach vegetation*. Ranging from dense closed forest to open disturbed or partly cultivated areas. Dominant plants include *Barringtonia*, *Calophyllum*, *Casuarina*, *Scaevola*, *Pandanus*, *Tournefortia*, *Trema*, *Flagellaria*, *Hibiscus* and *Terminalia* (Figure 7).



Figure 2 Gambir Bay, with BHP Camp on right and village backed by kebun on left.



Figure 3 Airstrip with rank herbage and kebun.



Figure 4 Rainforest near pit 8.

9. *Ultra basic valley forest*. Tall rainforest occurring in valleys of southern two-thirds of the island. Dominant trees include *Dillenia*, *Horsfieldia*, *Buchanania*, *Eugenia* and *Clerodendrum* (Figure 4).
10. *Ultrabasic slope forest*. Ranging from dense forest to open forest and scrub and occurring throughout the southern two-thirds of the island. Dominated by Gamau *Ploiarium sessile*, *Calophyllum*, *Symplocos* and *Clerodendrum* sp.
11. *Ultrabasic ridge scrub*. Ranging from areas of open shrubland and woodland to dense thickets. Occurring throughout the southern two-thirds of the island. Dominated by short and sparsely distributed Gamau *Ploiarium sessile*, *Calophyllum articulatum*, *Planchonella oxyedra* and *Clerodendrum* sp.

#### Climate

Gag Island has a tropical monsoon type climate, characterised by year-round moderate temperatures and high relative humidity. Its climate is influenced by the south-east trade winds from May to October and the north-west monsoons from December to April. The wet season (north-west monsoon) begins in October, peaks in December-January and may continue until April. Mean daily temperatures vary between about 21° and 34° C.



Figure 5 Disturbed volcanic forest along track to Turtle Beach.



Figure 6 Grassland of Alang alang south of Camp 2.



Figure 7 Lagoon, south-west corner of island.

### Ornithological History

The ornithological history of Gag Island is rather sparse. The famous naturalist explorer A.R. Wallace spent several days on the island and collected a small number of specimens on Gag Island (Gagie) in early 1860s; Dr H.A. Bernstein also made a small collection on the island in 1863 and 1864; Dr J. Diamond and D. Bishop visited the island for a day in 1986. Apart from their records several species are listed for Gag Island

by Peters (1967) and Sibley and Monroe (1990) in their world distributional lists but their source is however unknown; later F. Crome (1997) compiled a list of 39 species for Gag Island (based on literature records). As visits to Gag Island had been of short duration and very infrequent its avifauna was poorly known. This survey did not record eight of the birds previously listed for the island, but added a further 24 species (see Table 1).

## ANNOTATED SPECIES LIST

Classification and nomenclature follows Andrew (1992) and White and Bruce (1986) and Johnstone (2001).

## Fregatidae

*Fregata minor* Great Frigatebird

Eight birds off Turtle Bay on 11 July, also listed for Gag Island in 1860s.

*Extralimital range.* Widespread in Indian and Pacific Oceans, also south Atlantic Ocean. Moderately common around Ambon and around Kai and Tanimbar Islands. (R.E. Johnstone unpublished data).

*Fregata ariel* Lesser Frigatebird

Four following coast north-west corner of island on 11 July and 10 over southern tip of island on 20 July. These are the first records for Gag Island.

*Extralimital range.* Breeding on tropical islands in Atlantic, Indian and Pacific Oceans. Widespread and moderately common in western Papuan region.

## Sulidae

*Sula sula* Red-footed Booby

A beach washed skeleton found on north-east side of island in July. A wide ranging species occurring throughout tropical seas.

## Ardeidae

*Egretta alba* Great Egret

One feeding on airstrip with two Intermediate Egrets on 14 July. Probably a scarce winter visitor from Australia or New Guinea, recorded patchily in Wallacea, with no evidence of breeding.

*Extralimital range.* Much of Old World from Europe and Africa east to Japan, Philippines, Solomons and New Zealand.

*Egretta intermedia* Intermediate Egret (Lesser Egret)

Moderately common. Single birds and groups (up to four). Mainly feeding on airstrip, edges of sago swamps, open pools, grassy areas around camp and occasionally seashore at creek mouths. Probably winter visitors from Australia. The first records for Gag Island.

*Extralimital range.* Africa south of Sahara and from Pakistan east to Japan, Philippines, Solomons and Australia. Widely distributed in Wallacea and New Guinea but little or no evidence of breeding and presumably most originating from Australia.

*Ardea sacra sacra* Eastern Reef Heron

Moderately common in ones, twos or threes. Resident. Mainly reef flats, rocky shores, beaches and tidal flats. Both white phase and dark phase birds recorded.

*Extralimital range.* Shores of east Indian Ocean and west and central Pacific. Widely distributed in the region including remote atolls.

*Ardea ibis coromanda* Cattle Egret

*Historical records.* Previously listed for Gag Island but not recorded during the July survey. Also recorded from northern Moluccas and Western Papuan, Waigeo and Yamna Islands.

*Extralimital range.* From southern and eastern Asia south-east to northern and eastern Australia and New Zealand. Only recently extended its range to include New Guinea. Records from northern Moluccas and Western Papuan islands. In eastern Wallacea dated specimens fall between September-November.

## Accipitridae

*Pandion haliaetus cristatus* Osprey

Moderately common. Ones and twos recorded over northern end of island, at Gambir Bay, at Camp Two and over lagoon at south-west corner of island. Previously listed for Gag Island and resident judging from a recently used nest in tree near airstrip.

*Extralimital range.* This subspecies ranges from Philippines and Sumatra south-east to Australia and New Caledonia. Widely distributed in coastal areas around New Guinea.

*Taxonomy.* The subspecies *melvillensis* is sometimes recognised for the birds from Indonesia, the Philippines, northern Australia and New Caledonia and *cristatus* for southern Australia and Tasmania. The smaller size of *melvillensis* is however doubtful judging from the wing measurements showing considerable overlap in White and Bruce (1986).

*Aviceda subcristata* Pacific Baza

Status uncertain. Previously listed for Gag Island but not recorded in July.

*Extralimital range.* New Guinea region, Bismarck Archipelago. Solomon Islands and northern Australia. An Australasian species extending into Wallacea with some marked geographical variation; in Moluccas subspecies *A. s. reinwardtii* from Seram, Ambon and Haraku and in western New Guinea *A. s. stenozona*.

*Haliastur indus girrenera* Brahminy Kite

Moderately common, usually in ones, occasionally twos. Coasts especially sheltered bays.

*Extralimital range.* Northern Australia, Moluccas, New Guinea and Bismarcks.

*Taxonomy.* Two forms recognised in Wallacea namely *H. i. intermedius* (Sulawesi and Lesser Sundas) and *H. i. girrenera* (Moluccas, and also eastern end of range).



*Haliaeetus leucogaster* White-bellied Sea-Eagle

Moderately common in ones and twos. Two regularly seen over north end of island and Gambir Bay in July. Recorded over coasts and forest areas.

*Extralimital range.* India, Sri Lanka east to Bismarcks and Australia.

*Accipiter novaehollandiae* Grey Goshawk (Variable Goshawk)

Scarce or uncommon. One over open kebun on 13 July and one over camp on 18 July also previously listed for Gag Island but status on the island uncertain.

*Extralimital range.* Widely distributed in New Guinea, Melanesia and Australia with many local island forms. Eight subspecies recognised for Wallacea including *A. n. griseogularis* from Gebe Island and nine in New Guinea region.

*Aquila gurneyi* Gurney's Eagle

Probably a rare visitor from New Guinea. One observed twice over secondary forest on north end of island. Appeared to be attracted to roost of flying foxes (*Pteropus*). First record for Gag Island.

*Extralimital range.* New Guinea extending west to Moluccas. In Western Papuan islands recorded from Misool and Waigeo.

**Falconidae***Falco moluccensis* Spotted Kestrel

Uncommon. Ones and twos in July also historical records. Mainly open country on and around airstrip; also over cultivated areas and settlements. Easternmost records for Indonesia.

*Extralimital range.* Western Indonesia (Java, Moluccas, Sulawesi, Lesser Sundas).

*Taxonomy.* Two subspecies recognised *F. m. moluccensis* (Moluccas) and *F. m. microbalia* (Sulawesi region and Lesser Sundas). Birds from Gag Island appear most like the darker *moluccensis* populations.

**Anatidae***Tadorna radjah radjah* White-headed Shelduck

Uncommon. Two over beach near creek mouth north-east side of island on 17 July. First record for Gag Island.

*Extralimital range.* Moluccas, New Guinea region and northern Australia. Widely distributed but local on Western Papuan islands including Gebe.

**Megapodiidae***Megapodius freycinet freycinet* Dusky Scrubfowl

Common to very common. Mainly ones and twos occasionally small groups (up to five). Most numerous in beach vegetation especially on north end of island; also disturbed volcanic forest;



Figure 8 Dusky Scrubfowl *Megapodius f. freycinet*.

primary volcanic forest; sago swamps, edge of mangroves and once in dense *Pandanus*. Numerous active mounds in beach vegetation north end of island in July.

*Extralimital range.* Northern Moluccas, Western Papuan Islands (Waigeo, Batanta, Kofiau, Misool, Gebe, Gag) also Geelvink Bay Islands.

*Taxonomy.* The Gag Island population (along with Gebe, Waigeo, Kofiau and Misool) was placed in the nominate subspecies *M. f. freycinet* by Jones *et al.* (1995).

**Rallidae***Rallina tricolor* Red-necked Rail

Scarce or rare. Status uncertain possibly a migrant from New Guinea. One calling and another collected from sago swamp on north end of island. First record for Gag Island.

*Extralimital range.* Moluccas, Lesser Sundas, New Guinea region, Bismarck Archipelago and north-east Queensland. Recorded from Western Papuan islands (Misool and Waigeo).

**Scolopacidae***Numenius phaeopus variegatus* Whimbrel

Scarce visitor. One on rocks south end of island on 20 July. First record for Gag Island. Winter visitor and passage migrant.

*Extralimital range.* Breeding in north-east Siberia, and wintering from east India, Taiwan and Palau south to Australia and New Zealand. Common and widespread in Wallacea and New Guinea region mainly from August to April.

*Tringa hypoleucos* Common Sandpiper

Scarce visitor. Previously listed for Gag Island. In July single birds on rocks and edge of water on north end of island. A winter visitor and passage migrant.

*Extralimital range.* Breeding in Europe and north and central Asia, and wintering in south Europe, Africa, south Asia and from Japan south to Australia. A common passage migrant to Wallacea and New Guinea.

*Arenaria interpres interpres* Ruddy Turnstone

Scarce or casual winter visitor and passage migrant. Two on reef flat north end of island in July. First record for Gag Island.

*Extralimital range.* Breeding in far north of North America, Europe and Asia and wintering from Japan, Hawaii and California south to South Africa, Australia, New Zealand and South America. Widely distributed in Moluccas and New Guinea region from March to November.

### Burhinidae

*Esacus magnirostris* Beach Stone-curlew

Uncommon. Single birds observed on beaches and reef flats in July. First record for Gag Island.

*Extralimital range.* Coastal South-East Asia, New Guinea region to Solomon Islands, northern Australia and New Caledonia.

### Laridae

*Sterna hirundo longipennis* Common Tern

Scarce visitor and passage migrant. Two on stack and later flying north off north-east side of island on 11 July. First record for Gag Island. This subspecies breeds in north-east Asia and winters from east India and Sri Lanka east to New Britain, Solomons and Australia.

*Sterna sumatrana* Black-naped Tern

Moderately common in July in ones, twos and small groups (up to six). Beaches, reef flats and coastal waters. First records for Gag Island.

*Extralimital range.* Breeding on islands in tropical Indian and western Pacific Oceans from Madagascar east to south China, Indonesia, New Guinea, northern Australia and Samoa. Widespread in Wallacea and western New Guinea coastal waters.

*Sterna fuscata* Sooty Tern

Single bird following the shoreline near Camp Two on 19 July 1997. First record for Gag Island.

*Extralimital range.* Breeding on tropical and subtropical islands in Indian Ocean and west Pacific and dispersing widely. Reported in small numbers in Moluccas and western New Guinea seas.

*Sterna albitrons sinensis* Little Tern

Scarce visitor and passage migrant. Three on beach and following shoreline near Turtle Bay on 17 July. First record for Gag Island.

*Extralimital range.* This subspecies occurs around shores of Indian Ocean and west and central Pacific. Moderately common and resident on islets in Wallacea and western New Guinea region.

*Sterna bergii* Crested Tern

Scarce. Single birds (probably this species on size) observed offshore near Camp Two in July. First record for Gag Island.

*Extralimital range.* Shores of Indian Ocean and west and central Pacific. Moderately common and resident on islets in Wallacea and western New Guinea region.

*Anous stolidus* Common Noddy

One edge of water on sandy beach near airstrip on 15 July. First record for Gag Island.

*Extralimital range.* Breeding on islands in tropical and subtropical Indian Ocean and west and central Pacific dispersing widely. Moderately common and resident in Moluccas and western New Guinea waters.

### Columbidae

*Ptilinopus rivoli rivoli* White-bibbed Fruit Dove

Common throughout the island; in ones, twos and occasionally in small groups (up to five) at isolated fruiting trees. Mainly primary volcanic forest disturbed volcanic forest, ultrabasic valley forest and beach vegetation; less frequently in kebun vegetation and ultrabasic slope and ridge scrub. Most often observed feeding in canopy. Attracted to fruiting Gamau *Ploiarium sessile*.

*Extralimital range.* Moluccas including Kai Islands, Western Papuan islands (including Gebe, Gag, Misool) and most coastal islands; Geelvink Bay Islands; Eastern Papuan Islands and Bismarck Archipelago.

*Taxonomy.* Single adult male specimen from Gag Island is smaller (weight 95 g vs two males from Kai Islands 118–120 g), paler on upperparts and has a darker purple lower breast patch than specimens from Kai Islands and may represent a distinct island form. Forms a superspecies with *P. solomonensis*.

*Ptilinopus viridis pectoralis* Claret-breasted Fruit-Dove

Status uncertain. Not recorded in July 1997 but listed for Gag Island in historical data. Possibly very local or only a visitor to Gag Island.

*Extralimital range.* South Moluccas (Buru, Ambon, Saparua, Seram) Western Papuan islands (Kofiau, 'Gag', Gebe, Waigeo and Misool), lowlands of New Guinea, also Solomon Islands (separate subspecies *P. v. lewisii*)

*Ducula myristicivora myristicivora* Spice Imperial Pigeon

Common in ones, twos and small flocks (up to



Figure 9 Spice Imperial Pigeon *Ducula myristicivora*.

eight). Mainly primary volcanic forest, disturbed volcanic forest, ultrabasic valley forest and tall beach vegetation; less frequently in kebum and mangrove forest. Mostly seen feeding in the canopy on fruits and berries. Often observed perched on high bare branches or in powerful direct flight above the forest. Voice a loud guttural 'urwoow'.

A small island species confined to eastern Moluccas, Western Papuan islands (including Gebe, Gag Island and Misool) also Geelvink Bay Islands.

*Macropygia amboinensis* Slender-billed Cuckoo-Dove (Brown Cuckoo-Dove)

Common to moderately common. Mainly in ones and twos occasionally small groups (up to four). Favours edges of forest habitats including primary volcanic forest, disturbed volcanic forest, ultrabasic valley and slope forest, also ultrabasic ridge scrub and beach vegetation. Attracted to fruiting *Ploiarium* in ultrabasic valley and slope forest. Commonly heard calling 'woo up' calls in most forest habitats. Display flights observed and a nest with one egg found in July.

*Extralimital range.* Sulawesi, Moluccas, all New Guinea islands and eastern Australia.

*Taxonomy.* Several well marked local subspecies in Moluccas. Single female from Gag Island does not match description of *M. a. amboinensis* or *M. a. albiceps* and further specimens are needed to confirm the subspecific status of the Gag Island population.

*Chalcophaps indica* Emerald Dove

Moderately common in ones and twos. Most observations in ultrabasic valley forest; primary volcanic forest and beach vegetation; less frequently in ultrabasic slope and ridge scrub and kebum. Favours forest edges and thickets, feeding on the ground on fallen fruits and seeds. First record for Gag Island.

*Extralimital range.* India to South-East Asia, New Guinea, Melanesia and Australia.

*Taxonomy.* This species has two distinct forms. In nominate *indica* males have a white forehead and supercilium and grey crown; *C. i. longirostris* is larger, has a vinous brown crown and front and no supercilium. The grey-crowned nominate form ranges from Kashmir through south and south-east Asia and the Philippines to the Moluccas, some Western Papuan islands (Gebe and Kofiau) and islands in Geelvink Bay (Numfor, Biak, Meos, and Num). The brown-headed form occurs in the Lesser Sunda Islands, eastern New Guinea, some Torres Strait islands and northern and eastern Australia. The two forms intergrade in the Lesser Sunda Islands and birds from Gag Island although most like the nominate race are also intermediate in a number of characters. Further work in the Western Papuan islands would help clarify the taxonomic status of these forms.

*Chalcophaps stephani stephani* Stephan's Ground-Dove

Locally moderately common but generally scarce. Mainly singly, occasionally in twos. Largely confined to beach vegetation and disturbed volcanic forest and edges of primary volcanic forest on north end of island; once edge of kebum. Mostly observed feeding on ground including two flushed regularly from freshly exposed earth and litter on a megapode mound in beach vegetation. First record for Gag Island and one of the few Moluccan islands where this species and *C. indica* are sympatric.

*Extralimital range.* Nominate subspecies *C. s. stephani* ranges from Kai Islands, New Guinea region (Aru Islands, Western Papuan islands (Misool, Salawati, Batanta and Waigeo) also other satellite islands including Admiralty and Bismarck and also Solomon Islands. Another subspecies *C. s. wallacei* in Sulawesi. Its present distribution suggests that it may have once inhabited the Moluccas but has been eliminated through competitive exclusion with *C. indica* which is continuing to expand its range. Further work in this region is needed to define the current distribution and status of these pigeons.

*Caloenas nicobarica nicobarica* Nicobar Pigeon

Scarce. Single birds observed near Camp Two in ecotone between mangroves and valley forest on 17 and 19 July. First record for Gag Island. Highly nomadic favouring small wooded islands and islets.

*Extralimital range.* Widely distributed on small forested islands from the Nicobar Islands, north-east Indian Ocean through the Sunda Islands, Philippines and New Guinea region to western Micronesia and the Solomon Islands. Patchily distributed in Moluccas and on some Western Papuan islands (Pecan Islands, Kofiau, Salawati and Waigeo).

## Psittacidae

*Eos squamata squamata* Violet-necked Lory  
(Moluccan Red Lory)

Common. Mainly in pairs and small flocks (up to 10) occasionally larger flocks (up to 20). Attracted to flowering sago and coconut palms; also flowering and fruiting forest trees and shrubs. Mostly observed in primary volcanic forest, disturbed volcanic forest, kebun (including sago palms) and ultrabasic valley forest; less frequently in slope and ridge scrub. Often seen feeding in canopy taking flowers and fruits. One of the most conspicuous birds on the island.

*Extralimital range.* Northern Moluccas and Western Papuan islands (Batanta, Waigeo, Misool, Gebe and Gag).

*Taxonomy.* Four subspecies recognised namely: *Eos squamata atrocaerulea* (Moluccas); *Eos squamata rinciniata* (Moluccas); *Eos squamata obiensis* (Obi Island); and *Eos squamata squamata* (Western Papuan islands). Gebe Island is the type locality for the nominate subspecies where birds have the best developed collars. There are however slight differences between birds from Gebe Island and those from Waigeo and Misool Islands including a reduction in collar size. Judging from observations birds on Gag Island varied from having a distinct collar to little or no collar and may prove to be intermediate between Gebe and Waigeo populations.

*Micropsitta keiensis* Yellow-capped Pygmy Parrot

Scarce or uncommon. Only observed on north end of island. Two groups of three in and over disturbed volcanic forest on 17 July and two in dense beach vegetation near airstrip on 18 July. Also historical records and possibly seen by Diamond in 1986. These birds are extremely difficult to locate and may be more common than records suggest. Calls include a high pitched insect like 'tseeet'.

*Extralimital range.* Kai Islands, Aru Islands, Western Papuan islands (including Gag Island and Gebe) and western and southern New Guinea.

*Cacatua galerita triton* Sulphur-crested Cockatoo

Uncommon. In July only recorded in northern part of island. Ones and twos in primary volcanic forest and disturbed volcanic forest, also one observed flying over camp in Gambir Bay. Previously recorded for both Gag Island and Gebe Islands. Conspicuous and noisy and often seen perched on dead branches high up in canopy. Pair at nest hollow in huge tree in dense forest above Wapob River in July.

*Extralimital range.* Moluccas, New Guinea region including Aru and Western Papuan islands and Australia.

*Electus roratus polychloros* Eclectus Parrot

Common. Singly and in pairs. Largely confined to forest habitats i.e., primary volcanic forest, disturbed volcanic forest, ultrabasic valley forest, dense beach vegetation and less frequently in kebun and ultrabasic slope forest. Very conspicuous and noisy, often observed flying high above the forest or perched high on dead branches. Several females flushed and returned quickly to hollows in forest north end of island in July.

*Extralimital range.* Moluccas, Lesser Sundas and New Guinea region to Solomon Islands and north-east Australia.

*Taxonomy.* Three subspecies occur in the region namely: *Eclectus roratus riedeli* from Tanimbar Island, *E. r. polychloros* (type locality Gebe Island) restricted to Seram Laut, Tayandu and Kai Islands and some Western Papuan islands, and *E. r. pectoralis* on New Guinea mainland.

*Geoffroyus geoffroyi pucherani* Red-cheeked Parrot

Common. In ones, twos and small groups (up to five). Mainly forest habitats; primary volcanic forest, disturbed volcanic forest, ultrabasic valley forest, dense beach vegetation and less frequently kebun and sago swamps.

*Extralimital range.* Lesser Sundas, Moluccas, New Guinea region and north-east Australia.

*Taxonomy.* Marked geographic variation with 19 subspecies recognised by Peters (1961). The subspecies *G. g. pucherani* occurs in Western Papuan islands (Waigeo, Batanta, Salawati, Gebe, Gag Island and Misool) and north-western New Guinea east to about Etna Bay.

*Tanygnathus megalorhynchus megalorhynchus* Great-billed Parrot

Uncommon. Usually in ones, occasionally twos, once three. Favours forested northern end of island. Primary volcanic forest, disturbed volcanic forest, ultrabasic volcanic forest and once in beach vegetation near airstrip. Also historical records for Gag. Favours small forested islands.

*Extralimital range.* Moluccas, Lesser Sundas and Western Papuan islands.

*Taxonomy.* Seven subspecies recognised. Nominate subspecies occurs on Talaut Islands, Sangir Islands, small islands off northern Sulawesi; northern Moluccas, Western Papuan islands (Waigeo, Batanta, Salawati, Gebe, Gag Island and Misool) and small islands off north-western New Guinea.

## Cuculidae

*Cacomantis variolosus* Brush Cuckoo

Scarce or uncommon. Status uncertain possibly resident or winter visitors from Australia. Ones and twos in open beach vegetation near airstrip,

disturbed volcanic forest and kebun (cultivated areas) in July. Two birds one a speckled immature regularly calling from prominent perch near airstrip in July. Also historical records for Gag Island and Gebe Islands.

*Extralimital range.* Malaya and Sumatra east to Bismarcks, Solomons and Australia.

*Taxonomy.* The nominate subspecies occurs in the region as a winter migrant from Australia; the subspecies *C. v. infaustus* is resident in southern Moluccas and western New Guinea region.

*Chrysococcyx minutillus* Little Bronze Cuckoo

One record. A single bird calling and flushed from sago swamp near camp on 13 July. The first record for Gag Island.

*Extralimital range.* From Malaya and Sumatra east to New Guinea and Australia.

*Taxonomy.* The *Chrysococcyx 'malayanus'* group of bronze cuckoos (including *minutillus*, *russatus*, *rufomerus* and *crassirostris*) contains a number of forms sometimes regarded as separate species. The distribution and taxonomic status of this group requires further study.

*Scythrops novaehollandiae* Channel-billed Cuckoo

Uncommon. In ones and twos. Mainly forested northern parts of island. Recorded in primary volcanic forest, disturbed volcanic forest, ultrabasic valley forest and kebun (cultivated areas). One being attacked by two Torresian Crows (a major host species) on 14 July. Status in region uncertain; breeding resident and also a winter visitor from Australia.

*Extralimital range.* From Sulawesi and Flores east to Bismarcks and northern and eastern Australia.

*Taxonomy.* The Sulawesi and Sula Islands populations are considered to represent an endemic subspecies.

### Caprimulgidae

*Caprimulgus macrurus schlegelii* Large-tailed Nightjar

Locally moderately common but generally uncommon. Resident. In ones and twos (probably pairs). Mainly observed in northern two-thirds of island (including proposed mine site). Recorded in ultrabasic slope forest, ultrabasic ridge scrub, beach vegetation, kebun and sago vegetation and tracks in primary volcanic forest. Flushed during day from grid line tracks and roads with little or no cover and also from small clearings in dense forest. Regularly heard calling at night. Also observed hawking for insects at night around Gambir Bay camp area. First records for Gag Island.

*Extralimital range.* India, South-East Asia, the Greater and Lesser Sundas, Philippines, Moluccas, New Guinea region and northern Australia.

*Taxonomy.* Populations from the Western Papuan islands (Waigeo, Salawati, Batanta) and those from northern Moluccas are combined in the subspecies *C. m. schlegelii*.

### Apodidae

*Collocalia esculenta* Glossy Swiftlet

Scarce. Four circling cliffs near Turtle Bay and several old nests in small cave on coast near Turtle Bay in July. First record for Gag Island.

*Extralimital range.* Bay of Bengal to south-west Pacific.

*Taxonomy.* Considerable geographic variation in Lesser Sundas, Moluccas and New Guinea region. Birds from Western Papuan islands are placed in nominate subspecies *C. esculenta esculenta*.

### Alcedinidae

*Alcedo pusilla* Little Kingfisher

Status uncertain. Not recorded during July survey but collected on Gag Island by Bernstein in 1863. Possibly a scarce visitor to the island. Distribution and status in Moluccas and Western Papuan islands poorly known.

*Extralimital range.* Moluccas south to northern Australia and east to Solomon Islands.

*Taxonomy.* Populations in northern Moluccas often separated from New Guinea birds as race *halmaherae*. Taxonomic status of birds in Western Papuan islands requires review.

### Halcyonidae

*Todiramphus sancta sancta* Sacred Kingfisher

Common winter visitor and passage migrant from Australia. In July recorded throughout the island in nearly all habitats i.e., coasts, beach vegetation, kebun; disturbed volcanic forest; primary volcanic forest; sago vegetation; mangroves; beach vegetation; ultrabasic valley and slope forest; and ultrabasic ridge scrub. Also collected by Wallace in 1860s. In Moluccas the Sacred Kingfisher is a regular, common, winter visitor arriving in April-May-June and departing mid September to mid October (Johnstone unpublished data). A few individuals may stay in their winter quarters.

*Extralimital range.* Breeding in Australia and partly wintering in islands to north, from Borneo and Sumatra east to Bismarcks and Solomons.

*Todiramphus chloris chloris* Collared Kingfisher

Uncommon. Single birds observed at Turtle Bay, also on coast at Kampung Tua on north end of island in July; also collected by Wallace and Bernstein on Gag Island in early 1860s. Favours vicinity of coast but much less frequent than Beach Kingfisher.

*Extralimital range.* From Red Sea east through

south Asia, Philippines, Micronesia, New Guinea region, northern Australia to Samoa and Tonga.

*Taxonomy.* Undergoes profound geographic variation and has been divided into about fifty subspecies. Birds from Western Papuan islands belong to nominate subspecies.

*Todiramphus saurophaga* Beach Kingfisher

Moderately common. Ones and twos. Coastal favouring exposed reefs, rocky slopes, beaches, beach vegetation and coconut groves. Often observed perched on dead branches, driftwood and rocks at edge of seashore.

*Extralimital range.* Moluccas, New Guinea region and North Melanesia. Largely a small island species.

*Taxonomy.* Birds from Western Papuan islands belong to nominate subspecies.

### Meropidae

*Merops ornatus* Rainbow Bee-eater

Moderately common winter visitor and passage migrant from Australia. In July mainly in small parties (up to four) occasionally larger flocks (up to 20). Recorded feeding over kebun areas (coconut plantations); disturbed volcanic forest; beach vegetation and over ultrabasic valley and slope forest and camp area. First record for Gag Island. In Australia moving northwards in February-May and southwards in October-November. Australian birds ranging north in winter to Lesser Sunda Islands, Moluccu region, Western Papuan islands and New Guinea.

### Coraciidae

*Eurystomus orientalis pacificus* Dollarbird

Common in July. Probably a resident and non-breeding migrant from Australia. In July recorded in ones, twos and small flocks (up to 25). Observed in open areas around airstrip; over coconut plantations; forest edges and perched in forest canopy. One flock of 25 circling high over coconut plantation on 12 July. Also noted feeding on flying termites. The first records for Gag Island.

*Taxonomy.* The subspecies *pacificus* breeds in northern and eastern Australia and winters on islands to north (from Sulawesi and Lombok east to New Guinea). Other subspecies, including *E. o. orientalis*, from south and east Asia to Philippines, Bismarcks and Solomons.

### Pittidae

*Pitta sordida* Hooded Pitta

Status uncertain. Not recorded in July 1997 survey but listed for Gag Island by Diamond and Bishop (1986). Possibly very local on Gag Island or perhaps only a casual visitor from nearby Gebe Island or

migrant from Asia. This species favours lowland rainforest and mangroves and is generally silent and inconspicuous during dry season. A visit during the 'wet' would no doubt confirm its status on Gag.

*Extralimital range.* India, south-east Asia, Indonesia, New Guinea region including Western Papuan islands and Bismarck Archipelago.

*Taxonomy.* Forms a superspecies with *P. maxima* (of Moluccas) and *P. superba* (of Bismarck Archipelago).

### Hirundinidae

*Hirundo rustica* Barn Swallow

Not recorded in July 1997, but listed in historical data. A non-breeding migrant from temperate northern hemisphere and likely to occur anywhere in the region. The subspecies *gutturialis* of eastern Asia and Japan winters in south-east Asia, Philippines, Sunda Islands, New Guinea region (including some Western Papuan islands) and northern Australia.

*Hirundo tahitica* Pacific Swallow

Moderately common (probably resident). Ones, twos and small groups (up to six) observed in July. Most frequent around habitation but also foraging over swamps and coastal areas. The first record for Gag Island.

*Extralimital range.* India, South-East Asia, New Guinea region, north-east Australia and Polynesia.

*Hirundo nigricans* Tree Martin

Moderately common. Most birds are probably winter visitors from Australia. In ones, twos and small flocks (up to eight) in July 1997. Mainly over open cultivated areas; coastal areas (including airstrip) and sago swamps. First record for Gag Island.

*Extralimital range.* Breeding in Australia (possibly also some breeding in Wallacea) and wintering in Lesser Sundas, Moluccas and New Guinea region.

*Taxonomy.* Two subspecies recognised namely: *H. n. nigricans* (from Australia) and *H. n. timoriensis* (resident on Timor).

### Campephagidae

*Coracina papuensis papuensis* White-bellied Cuckoo-Shrike

Moderately common resident. Ones, twos and small groups (up to four). Mainly beach vegetation; cultivated areas (including coconut plantations and sago areas) and edges of forest (disturbed volcanic forest and ultrabasic valley forest). Also listed in historical data for both Gag Island and Gebe Islands and Misool, Salawati and Batanta.

*Extralimital range.* Moluccas, northern Australia, New Guinea region, Bismarck Archipelago and Solomon Islands.

*Taxonomy.* The subspecies *C. p. papuensis* occurs in the Moluccas and western and northern New Guinea region.

### Corvidae

#### *Corvus orru* Torresian Crow

Common resident. Mainly in twos and small groups (up to six). Beach vegetation; mangroves; cultivated areas (especially coconut plantations and sago swamps); also open areas and about habitation. Several old nests in tall trees near Turtle Bay. Also historical records for Gag Island and Gebe Islands. Four specimens collected for taxonomic studies.

*Extralimital range.* Northern Moluccas, eastern Lesser Sundas, Australia, New Guinea region and Bismarck Archipelago.

*Taxonomy.* Although Gebe Island birds have been allocated to the nominate subspecies, the taxonomic status of several populations in Moluccas, New Guinea and north-west Australia requires further study. There is considerable variation in calls and morphology (including eye colour) and the species-subspecies limits need further appraisal.

### Pachycephalidae

#### *Pachycephala simplex* Grey Whistler (also known as Grey-headed Whistler *P. griseiceps*)

Common resident, in ones and twos. Mainly forest habitats; primary volcanic forest; disturbed volcanic forest; ultrabasic valley and slope forest; mangroves and dense beach vegetation; less frequently in cultivated areas (coconut plantations and sago swamps). Mostly observed in mid-levels and canopy of forest.

*Extralimital range.* Moluccas, New Guinea region (including Western Papuan islands, Misool, Salawati, Batanta Gebe, Gag Island and Waigeo) and northern Australia.

*Taxonomy.* The Grey Whistler *P. simplex* has been recently treated as conspecific with the Grey-headed Whistler (*P. griseiceps*). However there are some morphological and vocal differences between the two and this situation needs further appraisal. Populations of *simplex-griseiceps* within the Moluccas and Western Papuan islands also show considerable geographic variation; some being yellow on the abdomen and with an olive back, others lacking the yellow and being brown backed. Specimens from Gag Island (*P. griseiceps gagiensis*) are strongly washed with yellow on the underparts and are quite different from the subspecies *P. s. rufipennis* of the Kai Islands. Further study of the species-subspecies limits within this group is required.

### Myiagridae

#### *Monarcha guttulus* Spot-winged Monarch

Common resident. Usually in ones and twos.

Forest habitats; primary volcanic forest; disturbed volcanic forest; ultrabasic valley and slope forest; dense beach vegetation and less frequently in kebun and sago swamps. Favours the middle and lower levels of the forest.

*Extralimital range.* Endemic to New Guinea, the Aru Islands, Western Papuan islands (Misool, Salawati, Sagewin, Batanta, Wageo, Gag Island and Gebe), islands in Geelvink Bay, D'Entrecasteaux Archipelago and Louisiade Archipelago.

#### *Myiagra alecto chalybeocephala* Shining Flycatcher

Uncommon to moderately common resident. Singly and in pairs. Mainly primary volcanic forest; disturbed volcanic forest; beach vegetation; mangroves; overgrown kebun (coconut plantation); sago swamps; and less frequently in ultrabasic valley forest. Often in vicinity of water and forages mainly in the understorey.

*Extralimital range.* Moluccas, New Guinea region including Aru and Western Papuan islands (Kofiau, Misool, Salawati, Batanta, Waigeo, Gebe and Gag). Also Bismarck Archipelago and northern Australia.

*Taxonomy.* Several subspecies recognised within the region namely *M. a. alecto* (northern Moluccas); *M. a. longirostris* (confined to Tanimbar Archipelago); and *M. a. chalybeocephala* (Western Papuan islands and most of New Guinea).

### Muscicapidae

#### *Muscicapa griseicticta* Grey-streaked Flycatcher

Listed for Gag Island by Crome (1997).

Breeds in south-eastern Siberia and winters in southern Asia and east to the Moluccas and western New Guinea. Recorded from several Western Papuan islands including Misool, Salawati, Batanta, Waigeo and Gebe.

### Rhipiduridae

#### *Rhipidura rufiventris gularis* Northern Fantail

Moderately common resident. Usually in ones and twos. Mainly primary volcanic forest; disturbed volcanic forest; ultrabasic valley and slope forest; kebun (coconut plantation); beach vegetation; and sago swamps. Conspicuous and often observed sallying for insects at forest edges.

*Extralimital range.* Moluccas, Western Papuan islands (Salawati, Batanta, Waigeo, Kofiau, Gag, Gebe and Misool), New Guinea, Bismarck and Solomon Islands; Lesser Sunda Islands and northern Australia.

*Taxonomy.* Shows considerable geographic variation throughout the region especially in size and colour intensity; i.e., in width and spotting of the breast band, extent of superciliary spot, colour of outer rectrices and edging of wing coverts. Birds from Gag Island are similar in colouration to *R. r. gularis* of mainland New Guinea.

*Rhipidura leucophrys* Willie Wagtail

Moderately common resident. Usually in ones and twos. Most plentiful in cultivated areas (coconut and sago plantations) and around habitation; also open or lightly wooded areas, beaches, edges of mangroves and around airstrip. One of the most conspicuous birds in the camp area at Gambir Bay. Historical records for both Gag Island and Gebe Islands.

*Extralimital range.* Moluccas, Lesser Sundas, New Guinea region, Solomon Islands and Australia.

*Taxonomy.* Birds from Gag Island match best with the subspecies *melaleuca* of New Guinea and the Solomons.

**Dicaeidae***Dicaeum 'pectorale'* Papuan Flowerpecker (Olive-crowned Flowerpecker)

Status uncertain. Listed in historical records for Gag Island and Gebe Islands (Crome 1997); an unidentified *Dicaeum* seen by Diamond in 1986; and a single *Dicaeum* making the typical 'Tsweet' call of *Dicaeum hirundinaceum* on edge of rainforest on 10 July 1997.

*Extralimital range.* *D. pectorale* occurs throughout New Guinea and most satellite islands.

**Nectariniidae***Nectarinia aspasia* Black Sunbird

Very common resident. Usually singly sometimes in pairs. Occurs throughout the island but favouring forests; primary volcanic forest; disturbed volcanic forest; ultrabasic valley and slope forest; dense beach vegetation; mangroves; and sago swamps; less frequently in ultrabasic ridge scrub and dense plantations. Feeds both in lower levels and canopy of forests. Not listed for Gag Island by most previous workers but listed for the island under *Cinnyris sericea* by Peters (1967), see also Mees (1965).

*Extralimital range.* Sulawesi, Moluccas, Western Papuan islands (Misool, Kofiau, Salawati, Batanta, Waigeo, Gebe and Gag) also throughout New Guinea and its satellite islands (Mees 1965).

*Taxonomy.* Gag Island birds belong to the nominate subspecies *Nectarinia aspasia aspasia* ranging throughout New Guinea and many satellite islands (Mees 1965).

*Nectarinia jugularis frenata* Olive-backed Sunbird

Very common resident. Usually in ones and twos; occasionally small parties at flowering trees and shrubs. Recorded throughout the island but favouring more open habitats than the Black Sunbird, i.e. mostly cultivated areas (kebun including coconut plantations; sago swamps; open beach vegetation and ultrabasic ridge scrub; also edge of forest habitats. Several pairs building nests,

suspended from exposed roots, under low cliffs in July.

*Extralimital range.* South-east Asia, Moluccas and Sunda Islands, New Guinea region, north-eastern Australia and Solomons.

*Taxonomy.* Birds from Gag Island belong to the subspecies *N. j. frenata* occurring on New Guinea and satellite islands (also other subspecies in northern Moluccas and Australia).

**Estrildidae***Lonchura molucca* Black-faced Munia

Scarce. Two feeding on seeds from green grass heads on track in secondary forest near airstrip on 15 July and two in grass edge of airstrip on 19 July. First record for Gag Island and the Western Papuan islands.

*Extralimital range.* Sulawesi, Moluccas, Lesser Sunda Islands and several small islands off Bali and north-east Java.

**Sturnidae***Aplonis metallica* Metallic Starling

Common resident. Mainly in small flocks (up to 35), occasionally larger flocks (up to 50). Recorded in cultivated areas especially coconut plantations, gardens, disturbed volcanic forest, primary volcanic forest, sago vegetation, beach vegetation, ultrabasic forest and scrub areas and in mangroves. Noisy and gregarious. Observed feeding on flowering Albizia, fruits of Gamau *Ploiarium sessile* and flying termites.

*Extralimital range.* Moluccas, New Guinea region including most satellite islands, Solomons and Australia.

*Taxonomy.* Birds from Gag Island belong to the nominate subspecies *A. m. metallica* of Moluccas, New Guinea and north-eastern Australia.

**Artamidae***Artamus leucorhynchus* White-breasted Woodswallow

One over beach vegetation near airstrip on 20 July 1997. First record for Gag Island.

*Extralimital range.* Ranging from India eastward to New Guinea, Australia, New Caledonia and Fiji.

**DISCUSSION**

A total of 62 species (47 non-passerine and 15 passerine) were recorded during this survey. This includes 24 species not previously recorded for Gag Island and several that are important distributional records for the region. Despite its small size (56 km<sup>2</sup>) Gag Island has a relatively rich avifauna with the most conspicuous feature the high proportion of pigeons and parrots. It also contains a number of



species that are restricted to small low islands and a number of species that range widely throughout the Oriental, Australian and New Guinea regions.

Few additional resident species could be expected, however more work during different seasons would no doubt add many visitors to the list. Crome (1997) listed 38 species previously recorded for Gag, and of these eight species were not recorded during this survey namely: Cattle Egret, Pacific Baza, Claret-breasted Fruit-Dove, Little Kingfisher, Hooded Pitta, Olive-crowned Flowerpecker, Barn Swallow and Grey-streaked Flycatcher. Of these the Barn Swallow and Grey-streaked Flycatcher are both visitors from the northern hemisphere and would not be expected during July. The Cattle Egret has only recently expanded its range into the Western Papuan region and has a very patchy distribution. The Pacific Baza, Claret-breasted Fruit-Dove, Little Kingfisher and Hooded Pitta are often also very localised in distribution and may have been overlooked, or they may be only occasional visitors to Gag. The disparities between species previously recorded for Gag Island and the 1997 survey suggest that the land-bird fauna is in a state of flux with some species turnover. On the other hand it is difficult to judge how complete and accurate the historical records are for Gag. Some of the fruit-eating birds, especially the pigeons, are well known for their ability in colonising and moving between small islands to take advantage of flowering and fruiting trees.

Combining all records gives a total of 70 species. As with many islands in the Indonesian and New Guinea region non-passerine species outnumber passerines by a ratio of about 2:1 (Johnstone *et al.* 1996). The ratio in continental Australia and New Guinea is about 1:1. A breakdown of most of the Gag Island avifauna is as follows.

#### 1. Marine species

*Fregata minor*  
*Fregata ariel*  
*Sula sula*  
*Sterna hirundo*  
*Sterna sumatrana*  
*Sterna fuscata*  
*Sterna albifrons*  
*Sterna bergii*  
*Anous stolidus*

#### 2. Non-breeding winter visitors from Palaearctic

*Arenaria interpres*  
*Numenius phaeopus*  
*Tringa hypoleucos*  
*Hirundo rustica*

#### 3. Winter visitors from Australia

*Egretta alba*  
*Egretta intermedia*

*Halcyon sancta*  
*Merops ornatus*  
*Eurystomus orientalis*  
*Hirundo nigricans*

#### 4. Visitors from New Guinea

*Aquila gurneyi*  
*Rallina tricolor*

#### 5. Resident species

*Egretta sacra*  
*Pandion haliaetus*  
*Haliaeetus leucogaster*  
*Accipiter novaehollandiae*  
*Falco moluccensis*  
*Tadorna radjah*  
*Megapodius freycinet*  
*Esacus magnirostris*  
*Macropygia amboinensis*  
*Chalcophaps indica*  
*Chalcophaps stephani*  
*Caloenas nicobarica*  
*Ptilinopus rivoli*  
*Ducula myristicivora*  
*Eos squamata*  
*Cacatua galerita*  
*Micropsitta keiensis*  
*Geoffroyus geoffroyi*  
*Tanygnathus megalorynchos*  
*Eclectus roratus*  
*Cacomantis variolosus*  
*Chrysococcyx minutillus*  
*Scythrops novaehollandiae*  
*Caprimulgus macrurus*  
*Collocalia esculenta*  
*Todiramphus chloris*  
*Todiramphus saurophaga*  
*Eurystomus orientalis*  
*Hirundo tahitica*  
*Coracina papuensis*  
*Rhipidura rufiventris*  
*Rhipidura leucophrys*  
*Monarcha guttulus*  
*Pachycephala simplex*  
*Nectarinia jugularis*  
*Lonchura molucca*  
*Aplonis metallica*  
*Corvus orru*

Gag Island is situated in the transition zone between the Austro-Papuan region to the east and the Wallacean faunal region to the west. Most of the resident species recorded for Gag Island also occur in the adjacent New Guinea lowlands and on other nearby islands. Judging from the distributions and subspecific affinities most of the birds have been derived from New Guinea. A small element including the Spotted Kestrel (*Falco moluccensis*) and Violet-necked Lory (*Eos squamata*) are Wallacean in origin. The zoogeographical

**Table 1** Species distribution in habitats during July 1997 survey

Species	M	KB	DVF	PVF	SA	GR	MA	BV	UVF	USF	URS
<i>Fregata minor</i>		x									
<i>Fregata ariel</i> *	x										
<i>Sula sula</i>	x										
<i>Egretta alba</i>						x					
<i>Egretta intermedia</i> *		x			x	x					
<i>Egretta sacra</i>	x										
<i>Pandion haliaetus</i>	x							x			
<i>Haliastur indus</i>	x	x						x			
<i>Haliaeetus leucogaster</i>	x		x	x							
<i>Accipiter novaehollandiae</i>		x									
<i>Aquila gurneyi</i> *			x								
<i>Falco moluccensis</i>		x					x				
<i>Tadorna radjah</i> *	x				x						
<i>Megapodius freycinet</i>			x	x	x		x	x			
<i>Rallina tricolor</i> *											
<i>Esacus magnirostris</i> *	x										
<i>Arenaria interpres</i> *	x										
<i>Numenius phaeopus</i> *	x										
<i>Tringa hypoleucos</i>	x										
<i>Sterna hirundo</i> *	x										
<i>Sterna sumatrana</i> *	x										
<i>Sterna fuscata</i> *	x										
<i>Sterna albirostris</i> *	x										
<i>Sterna bergii</i> *	x										
<i>Anous stolidus</i> *	x										
<i>Macropygia amboinensis</i>			x	x				x	x	x	x
<i>Chalcophaps indica</i> *		x		x				x	x	x	x
<i>Chalcophaps stephani</i> *		x	x	x				x			
<i>Caloenas nicobarica</i> *							x	x			
<i>Ptilinopus rivoli</i>		x	x	x				x	x	x	x
<i>Ducula myristicivora</i>		x	x	x			x	x	x		
<i>Eos squamata</i>		x	x	x	x				x	x	x
<i>Cacatua galerita</i>			x	x							
<i>Micropsitta keiensis</i>			x								
<i>Geoffroyus geoffroyi</i>		x	x	x	x			x	x		
<i>Tanygnathus megalorhynchus</i>			x	x				x	x		
<i>Ecliptorhynchus roratus</i>		x	x	x				x	x	x	
<i>Cacomantis variolosus</i>		x	x					x			
<i>Chrysococcyx minutillus</i> *					x						
<i>Scythrops novaehollandiae</i>		x	x	x					x		
<i>Caprimulgus macrurus</i> *		x	x		x			x		x	x
<i>Collocalia esculenta</i> *	x										
<i>Todiramphus chloris</i>	x							x			
<i>Todiramphus sancta</i>	x	x	x	x	x		x	x	x	x	x

connections of Gag Island are largely with Waigeo and the western part of the Vogelkop.

Gag Island has no endemic species but contains a number of birds that exhibit significant geographic variation in the region including Grey Goshawk (*Accipiter novaehollandiae*), Dusky Scrubfowl (*Megapodius freycinet*), White-breasted Fruit Dove (*Ptilinopus rivoli*), Slender-billed Cuckoo Dove (*Macropygia amboinensis*), Emerald Dove (*Chalcophaps indica*), Violet-necked Lory (*Eos squamata*), Red-cheeked Parrot (*Geoffroyus geoffroyi*), Little Bronze Cuckoo (*Chrysococcyx*

*minutillus*), Torresian Crow (*Corvus orru*), Grey Whistler (*Pachycephala simplex*), Shining Flycatcher (*Myiagra alecto*) and Northern Fantail (*Rhipidura rufiventris*). Specimens from Gag Island of *Ptilinopus rivoli*, *Macropygia amboinensis*, *Chalcophaps indica*, *Pachycephala simplex-griseiceps* and *Corvus orru* differ from neighbouring New Guinea and Moluccan populations and require further taxonomic assessment. Some of these may prove to be distinct island forms and if so, their future conservation on Gag Island will need to be addressed.

Table 1 (cont.)

Species	M	KB	DVF	PVF	SA	GR	MA	BV	UVF	USF	URS
<i>Todiramphus saurophaga</i>	x	x						x			
<i>Merops ornatus</i>		x	x					x	x	x	
<i>Eurystomus orientalis</i>		x	x	x				x			
<i>Hirundo tahitica</i> *		x			x			x			
<i>Hirundo nigricans</i> *		x			x			x			
<i>Coracina papuensis</i>		x	x		x			x	x		
<i>Rhipidura rufiventris</i>			x	x	x				x	x	x
<i>Rhipidura leucophrys</i>	x	x			x			x			
<i>Monarcha guttulus</i>		x	x	x				x	x	x	
<i>Myiagra alecto</i>		x	x	x	x		x	x	x		
<i>Pachycephala simplex</i>		x	x	x	x		x	x	x	x	
<i>Dicaeum 'pectorale'</i>									x		
<i>Nectarinia aspasia</i>		x	x	x	x		x	x	x	x	x
<i>Nectarinia jugularis</i>		x			x			x			x
<i>Lonchura molucca</i> *			x			x					
<i>Aplonis metallica</i>		x	x	x	x		x	x	x	x	x
<i>Artamus leucorhynchus</i> *								x			
<i>Corvus orru</i>		x			x		x	x			

Legend. M = Marine (coastal seas, stacks, reef flats and sandy and rocky shores); KB = Kebun (cultivated areas especially coconut plantations); DVF = Disturbed volcanic forest; PVF = Primary volcanic forest; SA = Sago swamps; GR = Grassland areas; MA = Mangroves; BV = Beach vegetation; UVF = Ultrabasic valley forest; USF = Ultrabasic slope forest; URS = Ultrabasic ridge scrub.

\* New records for Gag Island.

A breakdown of the avifauna under each of the main habitat types is given below (where the status of a species is similar in two or more habitats it was included in each of them)

1. Beach vegetation: 32 species (12 passerine)
2. Kebun: 29 species (11 passerine)
3. Disturbed volcanic forest: 27 species (8 passerine)
4. Marine: 23 species (1 passerine)
5. Primary volcanic forest: 21 species (6 passerine)
6. Sago: 19 species (11 passerine)
7. Ultrabasic valley forest: 19 species (8 passerines)
8. Ultrabasic slope forest: 13 species (5 passerines)
9. Ultrabasic ridge scrub: 10 species (4 passerine)
10. Mangroves: 9 species (5 passerine)
11. Grassland: 4 species (1 passerine)

This gives an indication of the richness of each habitat type, but more particularly it shows the importance of the northern forest habitats and the ultrabasic valley forests.

Gag Island does support a number of species with high conservation importance (Collar *et al.* 1994) including Dusky Scrubfowl, Nicobar Pigeon, Sulphur-crested Cockatoo, Yellow-capped Pygmy Parrot, Great-billed Parrot and Eclectus Parrot. Most of these have declined in numbers in other parts of Indonesia due to capture for the wild bird market. Gag Island is also part of a region that provides important wintering grounds for many Australian landbirds including the Sacred Kingfisher, Rainbow Bee-eater and Tree Martin.

In order to minimise the impacts of mining on Gag Island it should be a priority for baseline surveys to identify and characterise the threatened habitats; establish and maintain sites for long term

studies; continue to map species ranges and ascertain breeding bird densities in certain habitats and monitor changes in populations. It is also quite clear from this study that next to nothing is known about many of the other small islands in this Archipelago. An expanded programme of biological surveys and studies in the region is urgently needed so that biological information can be integrated into the region's development and conservation planning.

#### ACKNOWLEDGEMENTS

It is a pleasure to express thanks to Warwick Alliston and staff of BHP Gag Island for their help

and hospitality during the July survey. I also gratefully acknowledge the support given by the Western Australian Museum, Perth, the Museum Zoologicum Bogoriense, Bogor and NSR Environmental Consultants Pty Ltd, Melbourne.

#### REFERENCES

- Andrew, P. (1992). *The Birds of Indonesia: a Checklist (Peters sequence)*. Indonesian Ornithological Society, Jakarta.
- Beehler, B.M., Pratt, T.K., and Zimmerman, D.A. (1986). *Birds of New Guinea*. Princeton University Press, Princeton.
- Crome, F. (1997). Ecological and biodiversity issues on Gag Island – results of a desktop study. A Report to NSR Environmental Consultants.
- Collar, N.J., Crosby, M.J. and Stattersfield, A.J. (1994). *Birds to watch 2: the World List of Threatened Birds*. U.K. Birdlife International, Cambridge.
- Gray, G.R. (1862). Remarks on, and descriptions of, new species of birds lately sent by Mr A.R. Wallace from Waigiou, Mysol, and Gagie Islands. *Proceedings of the Zoological Society of London* 1861: 427–438.
- Johnstone, R.E. (1994). Observations of Seabirds and Shorebirds in Nusa Tenggara (Lesser Sundas) and Moluccas, Indonesia. *Western Australian Naturalist* 19: 339–349.
- Johnstone, R.E. and Sudaryanti (1995). The birds of Banda Neira, Moluccas, Indonesia. *Western Australian Naturalist* 20: 15–19.
- Johnstone, R.E., Prawiradilaga, D. and Sudaryanti (1994). Distributional patterns of birds in Eastern Indonesia, particularly Australian-Indonesian seabirds, rainforest and mangal dwellers. Paper and abstract presented to symposium on 'Terrestrial Vertebrate Biodiversity in Indonesia'.
- Johnstone, R.E., Jepson, P., Butchart, S.H.M., Lowen, J.C. and Prawiradilaga, D. (1996). The birds of Sumbawa, Moyo and Sangeang Islands, Nusa Tenggara, Indonesia. *Records of the Western Australian Museum* 18: 157–178.
- Johnstone, R.E. (2001). Checklist of birds of Western Australia. *Records of the Western Australian Museum* Supplement No. 63: 75–90.
- Jones, D.N., Dekker, R.W.R.J. and Reselaar, C.S. (1995). *Birds families of the world The Megapodes Megapodiidae*. Oxford University Press, Oxford.
- Mees, G.F. (1965). A revision of *Nectarinia sericea* (Lesson). *Ardea* 53: 38–56.
- Mees, G.F. (1972). Die Vögel der Insel Gebe. *Zoologische Mededelingen* 46: 69–89.
- Sibley, C.G. and Monroe, B.L. (1990). *Distribution and Taxonomy of Birds of the World*. Yale University Press, New Haven.

# Osteology of the first dorsal fin in two terapontid fishes, *Leiopotherapon unicolor* (Günther, 1859) and *Amniataba caudavittata* (Richardson, 1845), from Western Australia: evidence for hybridisation?

David L. Morgan and Howard S. Gill

Centre for Fish and Fisheries Research, Murdoch University, South Street, Murdoch,  
Western Australia 6150, Australia; Email: d.morgan@murdoch.edu.au

---

**Abstract** – Osteological characters, such as number of supraneural bones anterior to first neural spine, number of spines on first dorsal pterygiophore, position of insertion of first proximal dorsal pterygiophore and number of anterior proximal dorsal pterygiophores inserting between successive neural spines, in conjunction with morphological characters, were used to provide evidence of natural hybridisation between two species of the Terapontidae: the freshwater *Leiopotherapon unicolor* and the marine/estuarine *Amniataba caudavittata*.

## INTRODUCTION

The Terapontidae (commonly called trumpeters or grunters) consists of small to medium-sized fishes represented by approximately 46 species from 16 genera in marine and freshwaters of the Indo-Pacific region (Vari 1978; Nelson 1994; Allen *et al.* 2002). Of these, about 33 are restricted to the freshwaters of New Guinea and Australia where they are often of economic and/or recreational importance (Allen *et al.* 2002). The 16 genera assigned to the group are separated on the basis of the following features: pigmentation; extrinsic swimbladder muscle; swimbladder and intestinal pattern; height of dorsal and anal fin sheath; and osteological characteristics of the posttemporal, tabular, dentary, maxilla, premaxilla, spinous dorsal fin and vertebral column (Vari 1978). The Australian terapontid fauna consists of 25 species which are restricted to freshwaters and a further eight species that are considered predominantly marine or estuarine (Vari 1978; Allen *et al.* 2002).

Two of the most common and widespread terapontids in Australia are the Spangled Perch *Leiopotherapon unicolor* (Günther, 1859) and the Yellowtail Trumpeter *Amniataba caudavittata* (Richardson, 1845). The former is the most widespread freshwater fish species in Australia, occurring in major rivers, isolated drainages and ponds throughout the northern two thirds of Australia, including most river systems north of the Murchison River in Western Australia, the Northern Territory, Queensland, the Lake Eyre/Bulloo drainage systems and those rivers north of the Murray-Darling River in New South Wales (Vari 1978; Allen *et al.* 2002). *Amniataba caudavittata* occurs from the lower west coast of

Western Australia, throughout northern Australia and southern New Guinea to the east coast of northern Queensland (Vari 1978; Allen *et al.* 2002). Whilst *A. caudavittata* is considered to be primarily marine (Vari 1978), in south-western Australia it is essentially restricted to estuaries (Potter *et al.* 1994; Wise *et al.* 1994). It is also able to tolerate both freshwater and hypersaline conditions (Hutchins and Swainston 1986; Morgan and Gill 2004).

*Leiopotherapon unicolor* and *A. caudavittata* both attain total lengths of ca 300 mm and are superficially similar, with considerable overlap occurring in many of the characteristics often used to differentiate between species of fish, e.g., dorsal-fin spines (XI–XIII in *L. unicolor* cf. XII–XIII in *A. caudavittata*); dorsal-fin rays (9–12 cf. 8–10); anal-fin rays (III, 7–10 cf. III, 8–9); pectoral-fin rays (15–16 cf. 13–17); pelvic-fin rays (both I–5); lateral line scales (45–57 cf. 46–54); scales above lateral line (both 7–9); scales below lateral line (16–20 cf. 17–19); caudal scales (3–6 cf. 4–6); and predorsal scales to occiput (15–20 cf. 14–17) (Vari 1978). Notwithstanding the above similarities in these species, *L. unicolor* is readily distinguished from *A. caudavittata* as the fins of the former species are a uniform pale, silvery-grey colour, whereas those of the latter species are yellow and, in the case of the 2<sup>nd</sup> dorsal-fin and caudal-fin, bear prominent black bands (Vari 1978). Furthermore, in *L. unicolor* the row of spots running from the eye to the upper jaw and the row below the eye from the preopercle to the upper jaw are represented by distinct spots, whereas in smaller specimens of *A. caudavittata* these spots coalesce to form two distinct bands (see Figure 1 and photographs on pages 227 and 241 in Allen *et al.* 2002).

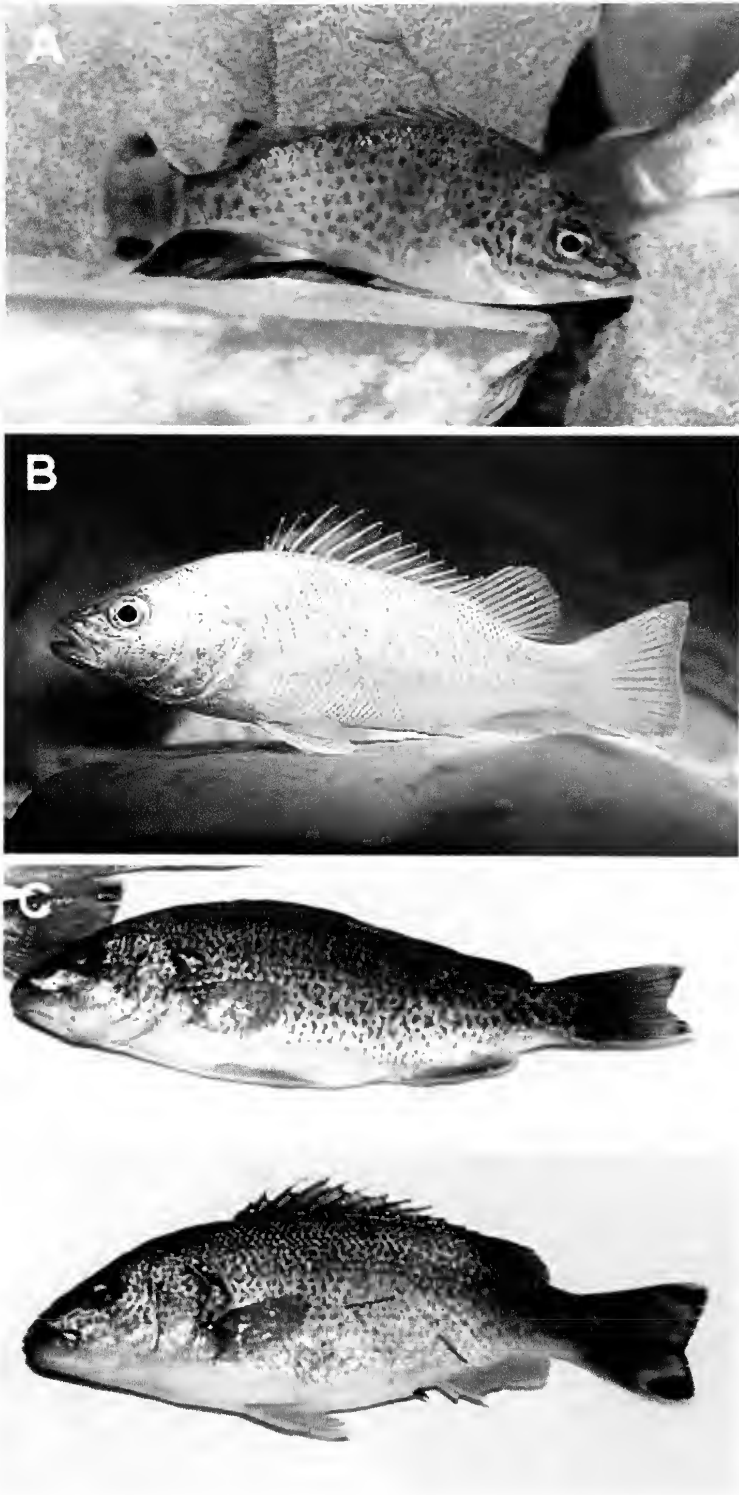
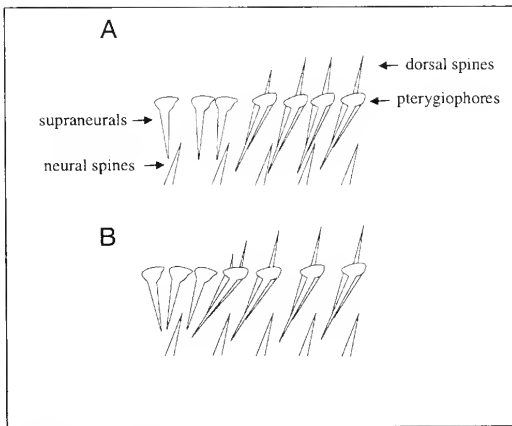


Figure 1 A, *Amniataba caudavittata*. B, *Leiopotherapon unicolor* and C and D, intermediate forms (note bars on caudal fins and rounded snout).

In addition to the clear distinction in coloration between *L. unicolor* and *A. caudavittata*, members of the genus *Leiopotherapon* can be differentiated from those of *Amniataba* using the following osteological criteria: one supraneural bone in front of the first neural spine in *Leiopotherapon* compared to two in *Amniataba*; one spine on first dorsal pterygiophore cf. two; the insertion of the first proximal dorsal pterygiophore between the second and third neural spines cf. its insertion between the first and second; two of the anterior proximal dorsal pterygiophores inserting between successive neural spines cf. one (Figure 2) (Vari 1978).

During a recent survey of the freshwater fishes of the Pilbara (Morgan and Gill 2004) *L. unicolor* and *A. caudavittata* were often observed schooling together up to 300 km inland in the Murchison River. On closer examination, it became apparent that many individuals from these mixed schools possessed combinations of coloration and pattern characteristic of both species. Thus, some individuals had distinct spots that had not coalesced into bands on the snout and cheek (characteristic of *L. unicolor*) but had yellowish fins (characteristic of *A. caudavittata*) and either had no, or one or two weak or strong band(s) on their caudal lobes (characteristics of either *L. unicolor* or *A. caudavittata*, or intermediate between the two) (see Figure 1). It was suspected that these individuals were hybrids.



**Figure 2** Diagrammatic representation of the supraneurals, anterior proximal pterygiophores, anterior neural spines and anterior 1<sup>st</sup> dorsal spines in A, *Leiopotherapon* and B, *Amniataba*. N.B. One supraneural anterior to first neural spine in *Leiopotherapon* (versus 2 in *Amniataba*); one dorsal spine on first anterior pterygiophore in *Leiopotherapon* (versus 2 in *Amniataba*); and second and third anterior pterygiophores inserting between successive neural spines in *Leiopotherapon* (from Vari 1978).

Hybridisation between fish species is not uncommon and Schwartz (1972, 1981) compiled almost 4000 references reporting either natural or artificial hybridisation between various species. Historically, the main methods of detecting hybrids have been through the comparison of morphological characters (e.g., morphometric and meristic data), with the assumption that the hybrid has characters that are intermediate between the parent species (Campton 1987, 1991). In this paper we describe the osteology of the first dorsal fin and, by comparison with the descriptions and diagnoses of the two genera provided by Vari (1978), provide evidence of natural hybridisation in the Terapontidae. In addition, we provide evidence to suggest that the hybrids are reproductively viable.

## MATERIALS AND METHODS

### Murchison River, Western Australia

The Murchison River is located in the Pilbara (or Indian Ocean) Drainage Division of Western Australia and is large by Western Australian standards, draining approximately 120 000 km<sup>2</sup> (Figure 3). Its headwaters arise near Meekatharra, approximately 500 km inland from the mouth at Kalbarri. Precipitation near the river mouth is relatively low and highly seasonal (mean ca 375 mm/annum), with low summer and medium winter falls, while the inland reaches receive relatively marginal and unpredictable rainfall (ca 238 mm/annum) throughout the year (data provided by the Western Australian Bureau of Meteorology). The river is marginally saline throughout its length.

### Sampling localities and environmental variables

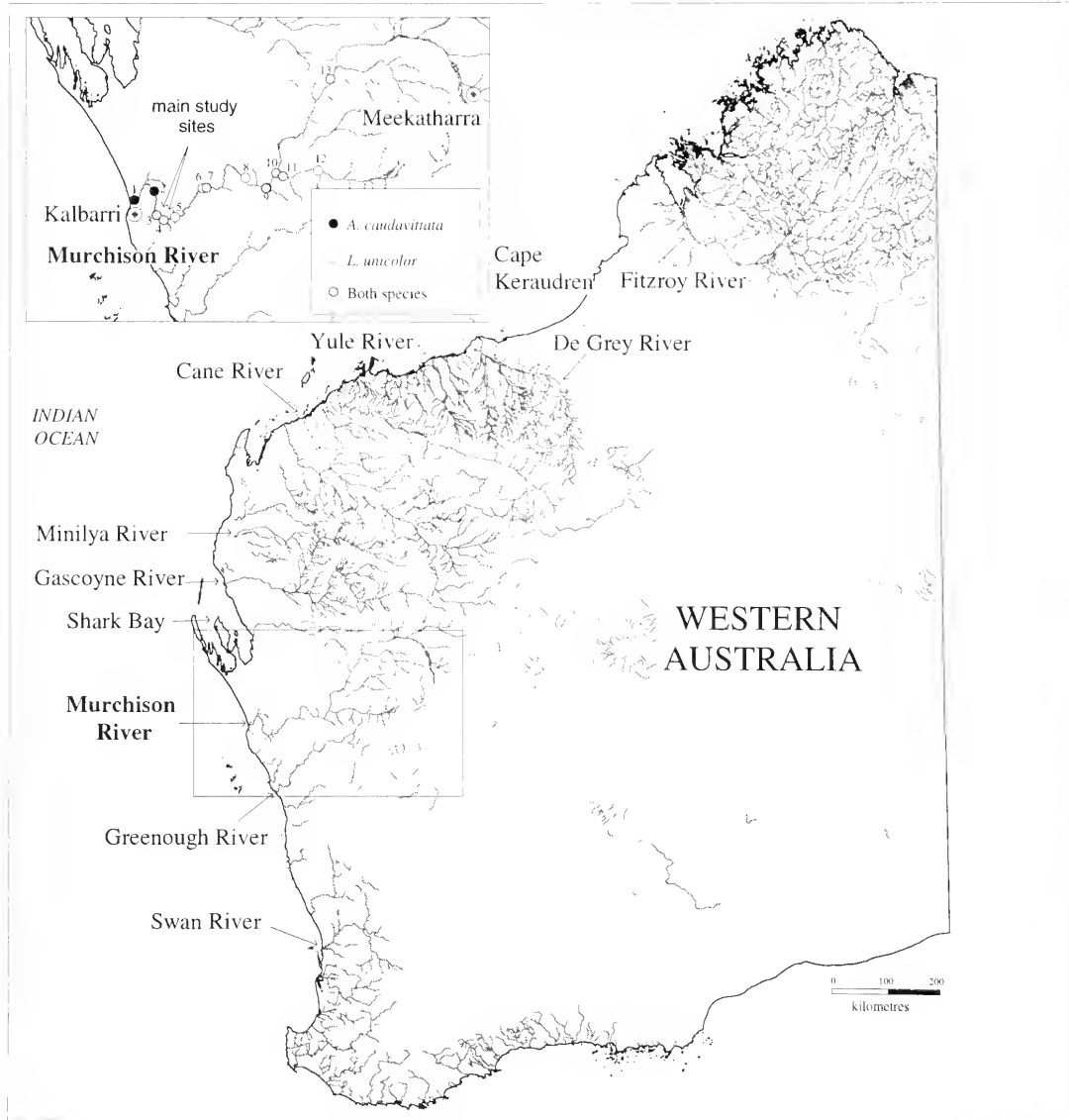
Thirteen sites on the lower, middle and upper Murchison River were sampled using a variety of seine nets and rod and line. The seine nets were comprised of either 3 or 6 mm woven mesh. The main study sites (3 and 4) were situated at the eastern end of the Kalbarri National Park (Figure 3) and the water temperature and conductivity were recorded in each month between December 2000 and November 2001 at site 4. Other sites were sampled on a single occasion and the numbers of each species (that superficially resembled either *L. unicolor* or *A. caudavittata*) were recorded and they were then released immediately. Fish that were kept were euthanased in an ice slurry.

### Morphology and osteology

Each fish retained from the Murchison River was measured to the nearest 1 mm (total length) and a subjective assessment made as to whether the individual superficially resembled more closely *L. unicolor* or *A. caudavittata*; based on fin and body

coloration and patterning, and also overall shape (in *L. unicolor* the body is slender and the snout rounded, whereas the body of *A. caudavittata* is moderately deep and the snout pointed and relatively shorter than that of *L. unicolor*). The vertebral column, and associated supraneurals, pterygiophores and dorsal spines, below the anterior-most section of the first dorsal-fin were then displayed by dissection and the following characteristics determined: number of supraneurals in front of the first neural spine (one or two for *Leiopotherapon* and *Amniataba*, respectively); number of dorsal-fin spines (one or two) on first

dorsal-fin pterygiophore; the position of the insertion of the first proximal dorsal-fin pterygiophore (between second and third or first and second neural spine); and number of anterior proximal dorsal-fin pterygiophores inserting between successive neural spines (one or two) (Vari 1978, and Figure 2). The vertebral column and associated structures were then drawn with the aid of a dissecting microscope and compared to those that comply with either *L. unicolor* or *A. caudavittata* (Vari 1978, and Figures 2 and 4). Dissection, rather than radiography, was used to determine the osteology of the first dorsal-fin as a



**Figure 3** The rivers and embayments (Shark Bay) in Western Australia from which terapontids were examined. The main study sites on the Murchison Rivers, and the major towns, Kalbarri and Meekatharra, are also given.



preliminary investigation demonstrated that radiographs were often difficult to interpret, whereas dissection provided unambiguous and accurate descriptions.

The osteology of individuals of presumptive *L. unicolor* from the Gascoyne (5 specimens), Minilya (4), Cane (5), Yule (5), De Grey (5) and Fitzroy (5) rivers, and *A. caudavittata* from the Swan River (5), Shark Bay (25) and Cape Keraudien (33) were also determined (Figure 3). Specimens of *Leiopotherapon unicolor* in the collections of the Western Australian Museum were also examined (P4336, 4, 56–83 mm TL, Murchison River, 12 October 1958; P5362, 3, 75–100 mm TL, Murchison River, Galena, 27 September 1961).

In order to determine whether a variant pattern (Figure 4) more closely resembled *L. unicolor* or *A. caudavittata* the minimum number of changes required to transform each individual pattern to that of *L. unicolor* and *A. caudavittata* was estimated. In these transformations the following assumptions were made. Firstly, in general, dorsal spines and pterygiophores were not independent, thus the loss, gain, or movement of an individual pterygiophore included a corresponding loss, gain or movement of the associated spine. Secondly, in the case of the first pterygiophore, it was considered that the loss of a second spine on that pterygiophore could occur without losing the pterygiophore and other spine, and that gaining a second spine on the first pterygiophore did not require gaining an additional pterygiophore bearing two spines. It is worth noting that if this second assumption is not made, and transformations require the loss (or gain) of the whole pterygiophore they contain either the same number of steps or require additional steps. Finally, where there are two or more equally short transformations, the one presented in Table 1 maximises movements rather than losses and gains, e.g., in Type 19 the transformation to *Leiopotherapon* presented is: Step 1, move supraneural 2 to between neural spines 1 and 2; Step 2, move supraneural 3 to between neural spines 1 and 2; Step 3, remove 1<sup>st</sup> pterygiophore; Step 4, remove 2<sup>nd</sup> or 3<sup>rd</sup> pterygiophore; Step 5, move new pterygiophore 1 to between neural spines 2 and 3; Step 6, move new pterygiophore 2 to between neural spines 3 and 4. The alternative is: Step 1, move supraneural 2 to between neural spines 1 and 2; Step 2, move supraneural 3 to between neural spines 1 and 2; Step 3, remove 1<sup>st</sup> pterygiophore; Step 4, remove 2<sup>nd</sup> pterygiophore; Step 5, remove 3<sup>rd</sup> pterygiophore; Step 6, gain additional pterygiophore between neural spines 3 and 4. Thus, the first transformation comprises four movements and two losses, whereas the alternative comprises two movements, three losses and one addition.

## Reproductive biology

The gonads of each fish retained from the Murchison River were examined, and the sex and stage of gonadal development determined macroscopically. The stage of gonadal development was based on the following criteria adapted from Laevastu (1965): stage I/II (immature); stages III/IV (maturing); stage V (mature); stage VI (spawning) and stage VII (spent or recently spawned).

## RESULTS

### Environmental variables

The mean water temperature at the main study sites followed a seasonal pattern, peaking in February (*ca* 27°C) and reaching a minimum in August (*ca* 16°C) 2001. The conductivity of the main study sites throughout the year of the study ranged from 1.6–26.8 mScm<sup>-1</sup>, but averaged *ca* 13.2 mScm<sup>-1</sup>.

### Distribution of terapontids in the Murchison River

Terapontids were captured at 13 sites in the Murchison River. Forms that superficially more closely resembled *L. unicolor* were found at all sites except the two most downstream locations (Figure 3). Those resembling more closely *A. caudavittata* were captured at nine sites, ranging from the two downstream sites to the most inland sites. Both 'forms' co-occurred at seven sites.

### Morphology and osteology

Of the 231 terapontids examined for vertebral and first dorsal osteological comparison during this study, 32 different patterns were evident (Figures 2 and 4, Table 1).

In the Murchison River samples collected during the current study, only 24 (30%) of the 80 individuals that superficially more closely resembled *L. unicolor* had an osteological configuration that complies with Vari's (1978) description for *Leiopotherapon* (see also Figures 2 and 4). In the remaining 56 individuals, 20 different osteological patterns unlike those described for any other terapontid, were found (Figure 4, Table 1). The most common of these variant configurations (Type 4, 20 individuals) differs from the configuration diagnostic of *Leiopotherapon* only in having the second pterygiophore arising from between the second and third, rather than the third and fourth, neural spines (Figure 4, Table 1). Of the remaining configurations present in specimens that resembled *L. unicolor*, types 1, 2, 3, and 5 also vary from the pattern diagnostic of *Leiopotherapon* in only requiring the addition or movement of a supraneural or pterygiophore and its spine, whilst Type 7 only requires the addition of a supraneural

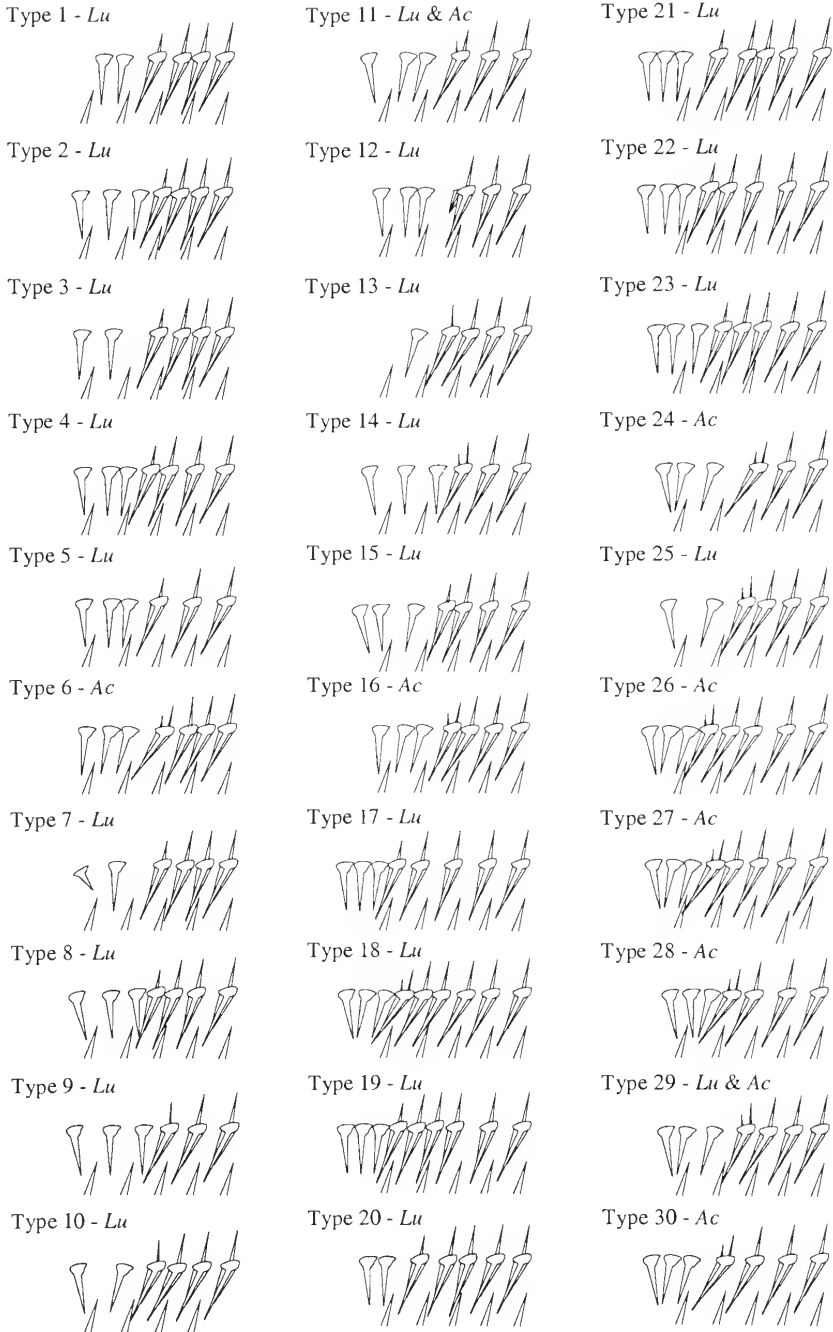


Figure 4 Diagrammatic representation of the osteology of the anterior section of the first dorsal fin for the teraponids examined and whether they superficially resembled *Leiopotherapon unicolor* (Lu) or *Amniataba caudavittata* (Ac).

and a slight increase in the size of the first supraneural. The remaining patterns (types 8, 10, 12, 13, 15, 17-23, 25 and 29) require between two and six transformation steps. Of these patterns, types 1-5, 7, 8, 10, 12 and 13 are closer to the pattern diagnostic of *Leiopotherapon*, types 18-23, 25 and 29 are closer to that of *Amniataba*, and types 15 and 17 are equidistant between the two.

Of the 52 individuals that superficially more closely resembled *A. caudavittata*, 42 (ca 81%) had the osteological pattern characteristic for that genus (Figure 2) (Vari 1978), however, the remaining 10 (ca 19%) displayed nine different osteological configurations unlike those described for any other terapontid (types 6, 11, 16, 24 and 26-30 in Figure 4). Three patterns (28-30) are only one transformation step from that diagnostic of *Amniataba*, whilst the remainder are either two (types 16, 24, 26 and 27) or three (types 6 and 11) steps away. Of these patterns, types 24 and 26-30 are closer to the pattern diagnostic of *Amniataba*, types 6 and 11 are closer to that of *Leiopotherapon*, and Type 16 is equidistant between the two.

Of the *L. unicolor* examined from the collections of the Western Australian Museum, and that all superficially resembled that species, two specimens from 1958 (P4336) conformed to the diagnostic pattern of the genus and the remaining two were of the Type 2 pattern, i.e., one step from the diagnostic pattern, whilst two specimens from 1961 (P5362) were Type 4 and the other was Type 10, i.e., one and two steps from the diagnostic pattern, respectively (Figures 1 and 2, Table 1). All of these patterns are closer to that diagnostic of *Leiopotherapon* rather than that of *Amniataba*.

Of the five *L. unicolor* examined from the Gascoyne River, one conformed to Vari's (1978) description, whilst the others were types 4 (2) and 2 (2), patterns that are both only one transformation step away from the diagnostic pattern. All four of the presumptive *L. unicolor* from the Minilya River had a dorsal osteological pattern unlike that described by Vari (1978), one of these had a Type 2 pattern (one step from the diagnostic pattern) that was also found in fish from the Murchison and Gascoyne Rivers, one had a Type 9 pattern (two steps) and the remaining two individuals had a Type 14 configuration (three steps), these latter patterns were unlike any of the other individuals examined (Figure 4, Table 1). One of the five individuals from the Cane River conformed to *L. unicolor*, whilst the remaining four all exhibited the Type 4 pattern (one step). In the specimens from the Yule River, three individuals had the pattern diagnostic of *L. unicolor*, one had a Type 4 and one a Type 12 pattern, i.e. one and three steps away from the diagnostic pattern, respectively (Figures 2 and 4, Table 1). Of the five *L. unicolor* examined in the De Grey River, two conformed to Vari's (1978)

description, two were Type 4 (one step) and one was Type 11 (two steps). Of the five *L. unicolor* examined from the Fitzroy River one followed Vari (1978), while the others were types 4 (two, one step), 11 (one individual, two steps) or 15 (one, two steps). The Type 11 pattern was also found in a fish from the Murchison River, but in that case the individual more closely resembled *Amniataba* (Figure 4, Table 1). All of these patterns are equal (Type 15) or closer to that diagnostic of *Leiopotherapon* rather than that of *Amniataba*.

All *A. caudavittata* examined from the Swan River (5) and Shark Bay (25), and 30 of 33 examined from Cape Keraudien had a dorsal osteology that conformed to Vari's (1978) description for *Amniataba*. The three individuals that differed in osteological formula from Vari's (1978) description were either types 28 (1) or 30 (2). Both of these patterns only require the movement of a single supraneural to conform to the Vari's (1978) diagnosis for *Amniataba* (Figures 1 and 4, Table 1).

Based on comparisons of the minimum number of steps required for a pattern to transform into those diagnostic of *Leiopotherapon* and *Amniataba*, the fish that superficially more closely resembled *L. unicolor* bore 13 patterns that were more similar to the diagnostic configuration for *Leiopotherapon* (i.e., types 1-5 and 7-14), eight that were more similar to that diagnostic for *Amniataba* (i.e., types 18-23, 25 and 29), whilst two are equidistant between the two diagnostic patterns (i.e., types 15 and 17) (Figures 2 and 4, Table 1). In the case of fish resembling *A. caudavittata*, there were five patterns that more closely resembled that diagnostic for *Amniataba* (i.e., types 24, 26-28 and 30), two were more similar to that of *Leiopotherapon* (i.e., types 6 and 11) and the remaining pattern was equidistant between the two (i.e., Type 16) (Figures 2 and 4, Table 1).

Vari (1978) noted that *Leiopotherapon* and *Amniataba* can be distinguished by the following osteological criteria: one supraneural bone in front of the first neural spine in *Leiopotherapon* versus two in *Amniataba*; one spine on the first dorsal pterygiophore versus two; the insertion of the first proximal dorsal pterygiophore between the second and third neural spines versus its insertion between the first and second; two of the anterior proximal dorsal pterygiophores inserting between successive neural spines versus one. In the current study, of the individuals that superficially most closely resembled *L. unicolor*, six had two supraneurals in front of the first neural spine (types 15 (3), 20, 23 and 29), five had two spines (types 14 (2), 18, 25 and 29), seven had the first proximal dorsal pterygiophore inserting between the first and second neural spines (types 20, 21 (4), 22 and 23) and six individuals had only one of the anterior proximal dorsal pterygiophores inserting between

**Table 1** The minimum number of steps required for each osteological pattern to transform into those considered by Vari (1978) to be diagnostic of *Leiopotherapon* and *Amniataba*. Possible character transforms are provided, with SN = supraneural, PT = pterygiophore, NS = neural spine and FR = fin ray. N.B. Where more than one set of character transformations are possible only one example is provided (see text for examples of other equally parsimonious transformation patterns). M = Murchison River fish this study; WAM = Murchison River fish from the collections of WAM; G = Gascoyne River; Mi = Mimiliya River; C = Cane River; Y = Yule River; DG = De Grey River; F = Fitzroy River; S = Swan River; SB = Shark Bay; CK = Cape Keraudien. Normal font indicates fish that superficially most closely resembled *L. unicolor*, italics represents fish that most closely resembled *A. caudavittata*.

Osteological pattern	Steps to <i>Leiopotherapon</i>	Steps to <i>Amniataba</i>
Type 1 (I, M)	1 - additional SN anterior to NS 1.	5 - 1 <sup>st</sup> SN to anterior of NS 1; additional SN anterior to NS 1; PT 1 to between NS 1 & 2; additional FR on PT 1; additional PT between NS 3 & 4.
Type 2 (5, M; 2, WAM; 2, G; 1, Mi)	1 - SN 3 to between NS 1 & 2.	5 - SN 2 to anterior of NS 1; SN 3 to between NS 2 & 3; PT 1 to between NS 2 & 3; additional FR on PT 1; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT.
Type 3 (3, M)	1 - additional SN anterior to NS 2.	4 - additional SN anterior to NS 1; PT 1 to between NS 1 & 2; additional FR to PT 1; PT 2 to between NS 2 & 3.
Type 4 (20, M; 2, WAM; 2, G; 4, C; 1, Y; 2, DG; 2, F)	1 - PT 2 to between NS 3 & 4	3 - SN 2 to anterior of NS 1; PT 1 to between NS 1 & 2; additional FR on PT 1.
Type 5 (2, M)	1 - additional PT between NS 3 & 4.	3 - SN 2 to anterior of NS 1; add PT between NS 1 & 2; additional FR on new PT 1.
Type 6 (I, M)	1 - rem. FR on PT 1.	3 - SN 2 to anterior of NS 1; PT 1 to between NS 1 & 2; PT 2 to between NS 2 & 3.
Type 7 (I, M)	2 - inc. size of SN 1; additional SN between NS 1 & 2.	5 - inc. size of SN 1; additional SN anterior of NS 1; PT 1 to between NS 1 & 2; additional FR on PT 1; PT 2 to between NS 2 & 3.
Type 8 (I, M)	2 - SN 3 to between NS 1 & 2; PT 2 to between NS 3 & 4.	4 - SN 2 to anterior of NS 1; SN 3 to between NS 1 & 2; PT 1 to between NS 1 & 2; additional FR on PT 1.
Type 9 (I, Mi)	2 - SN 3 to between NS 1 & 2; additional PT between NS 3 & 4.	4 - SN 2 to anterior of NS 1; SN 3 to between NS 1 & 2; additional PT between NS 1 & 2; additional FR on new PT 1.
Type 10 (6, M; 1, WAM)	2 - additional SN between NS 2 & 3; PT 2 to between NS 3 & 4	3 - additional SN anterior to NS 1; additional FR on PT 1; PT 1 to between NS 1 & 2.
Type 11 (I, DG; 1, F; I, M)	2 - rem. FR on PT 1; additional PT between NS 3 & 4	3 - SN 2 to anterior of NS 1; PT 1 to between NS 1 & 2; additional PT between NS 2 & 3.
Type 12 (I, M; 1, Y)	3 - inc. size of PT 1; add FR to PT 1; PT 2 to between NS 3 & 4.	5 - SN 2 to anterior of NS 1; inc. size of PT 1; PT 1 to between NS 1 & 2; add 2 FRs to PT 1.
Type 13 (2, M)	3 - additional SN anterior to NS 1; additional SN between NS 2 & 3; PT 2 to between NS 3 & 4.	4 - additional 2 SNs anterior to NS 1; PT 1 to between NS 2 & 3; additional FR on PT 1.
Type 14 (2, Mi)	3 - SN 3 to between NS 1 & 2; rem. FR on PT 1; additional PT between NS 3 & 4.	4 - SN 2 to anterior of NS 1; SN 3 to between NS 1 & 2; PT 1 to between NS 1 & 2; additional PT to between NS 2 & 3.
Type 15 (2, M; 1, F)	2 - SN 2 to between NS 1 & 2; PT 2 to between NS 3 & 4.	2 - PT 1 to between NS 2 & 3; additional FR on PT 1.

Type 16 (I, M)	2 – rem. FR on PT 1; PT 2 to between NS 3 & 4.	2 – SN 2 to anterior of NS 1; PT 1 to between NS 1 & 2.
Type 17 (I, M)	4 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 3; rem. 1 <sup>st</sup> PT; rem. 2 <sup>nd</sup> PT.	4 – SN 3 to between NS 1 & 3; rem. 1 <sup>st</sup> or 2 <sup>nd</sup> PT; remaining PT to between NS 1 & 3; additional FR on PT 1.
Type 18 (I, M)	5 – SN 1 to between NS 1 & 2; SN 2 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT; new PT 1 to between NS 2 & 3.	4 – SN 3 to between NS 1 & 2; PT to between NS 1 & 2; rem. 2 <sup>nd</sup> PT; rem. 3 <sup>rd</sup> PT.
Type 19 (I, M)	6 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT; new PT 1 to between NS 2 & 3; new PT 2 to between NS 3 & 4.	4 – SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT; additional FR on new PT 1.
Type 20 (I, M)	4 – 2 <sup>nd</sup> SN to between NS 1 & 2; additional SN between NS 1 & 2; rem. PT 1; new PT 2 to between NS 3 & 4.	3 – additional SN between NS 1 & 2; additional FR to PT 1; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT.
Type 21 (4, M)	4 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; new PT 2 to between NS 3 & 4.	3 – SN 3 to between NS 1 & 2; additional FR on PT 1; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT.
Type 22 (I, M)	5 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> or 2 <sup>nd</sup> PT; (new) PT 1 to between NS 2 & 3; (new) PT 2 to between NS 3 & 4.	3 – SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> or 2 <sup>nd</sup> PT; additional FR on new PT 1.
Type 23 (I, M)	3 – SN 2 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; new PT 2 to between NS 3 & 4.	2 – additional FR on PT 1; rem. 2 <sup>nd</sup> or 3 <sup>rd</sup> PT.
Type 24 (I, M)	3 – SN 2 to between NS 1 & 2; rem. FR on PT 1; additional PT between NS 3 & 4.	2 – PT 1 to between NS 1 & 2; additional PT between NS 2 & 3.
Type 25 (I, M)	3 – additional SN between NS 2 & 3; lose FR 1 on PT 1; PT 2 to between NS 3 & 4.	2 – additional SN anterior to NS 1; PT 1 to between NS 1 & 2.
Type 26 (I, M)	5 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 2; rem. 1 <sup>st</sup> PT; 2 <sup>nd</sup> PT to between NS 2 & 3; 3 <sup>rd</sup> PT to between NS 3 & 4.	2 – SN 3 to between NS 1 & 2; rem. 2 <sup>nd</sup> PT.
Type 27 (I, M)	6 – Same as Type 27, plus increase size of NS 4.	2 – Same as Type 27, plus increase size of NS 4.
Type 28 (I, M; I, CK)	2 – rem. PT 1; additional PT between NS 3 & 4.	1 – SN 2 to anterior of NS 1.
Type 29 (I M; I, M)	3 – SN 2 to between NS 1 & 2; rem. FR on PT 1; PT 2 to between NS 3 & 4.	1 – PT 1 to between NS 2 & 3.
Type 30 (2, M; 2, CK)	4 – SN 2 to between NS 1 & 2; SN 3 to between NS 1 & 2; rem. PT 1; additional PT between NS 3 & 4.	1 – SN 3 to between NS 1 & 2.

successive neural spines (types 5 (2), 9, 14 (2) and 17). In the case of individuals that superficially most closely resembled *A. caudavittata*, five had only one supraneural in front of the first neural spine (types 6, 11, 16 and 28 (2)), four had the first proximal dorsal pterygiophore inserting between the second and third neural spines (types 6, 11, 16 and 24) and four individuals had two of the anterior proximal dorsal pterygiophores inserting between successive neural spines (types 6, 16, 26 and 27). All individuals that superficially resembled *A. caudavittata* had two spines on the first dorsal pterygiophore.

### Reproductive biology

Individuals exhibiting characteristics of both species had lengths ranging from 39–253 mm TL, while those representing *L. unicolor* and *A. caudavittata* ranged in length from 47–211 and 29–206 mm, respectively. Of the 13 fish greater than 200 mm TL, 11 exhibited characteristics of both species.

From the macroscopic staging of the gonads of all fish dissected, including those with characteristics of both species, it was evident that many were either mature, spawning or had recently spawned. The peak spawning period for the two species and the fish exhibiting characteristics of both species in the Murchison River appeared to be in late summer/early autumn.

The sex ratio in the individuals that exhibited both characteristics was ca 1.8 females:1 male, whereas for *L. unicolor* and *A. caudavittata* it was 2:1 and 1.6:1, respectively.

### DISCUSSION

Of the 161 terapontids collected from the riverine sites during the current study, the characteristics of the first dorsal/neural spine matrix resembled *L. unicolor* in about 20% of cases and *A. caudavittata* in about 26% of cases. The remaining 54% of fish had first dorsal/neural spine osteological characteristics unlike any of those described for terapontids by Vari (1978). Whilst many of the novel patterns described in the current study are very similar to those described by Vari (1978) as diagnostic for the two genera, others bear little resemblance to the diagnostic patterns. Vari (1978), who examined 10 specimens from the Murchison River, 76 from the De Grey River and over 100 from the Fitzroy River, made no mention of the osteological variability evident in the current study for these species. Furthermore, he noted no variation in the patterns of other members of these genera considering the two patterns to be diagnostic for *Leiopotherapon* and *Amniataba*. Although it is not known how many individual *L. unicolor* or *A. caudavittata*, or specimens of other

species within these two genera, Vari radiographed or cleared and stained for osteological examination (Vari personal communication), given such a high occurrence of different pterygiophore patterns (i.e., 54% were unusual), it could be expected that he would have noticed some exceptions. However, our preliminary use of radiographs suggested that it was often difficult to discern minor variations in pattern using this method. Thus, although not noted by Vari (1978), it is likely that some minor natural variations in pterygiophore pattern occur in these species. For example, of the 63 specimens of *A. caudavittata* examined from the Swan River, Shark Bay and Cape Keraudien, i.e., estuarine and marine sites at which *L. unicolor* does not exist, the three that did not conform to the pattern diagnostic for that genus only differed in the position of the second or third supraneural. Furthermore, although variations in pterygiophore pattern were evident in some specimens of *L. unicolor* examined from the Western Australian Museum, these variations were minor and all specimens exhibited the coloration of that species.

Notwithstanding that some minor differences in the anterior dorsal-fin pterygiophore pattern occur naturally, the level of variation in the first dorsal/neural spine patterns and the fact that many specimens exhibited coloration and shape characteristics of both *L. unicolor* and *A. caudavittata* suggests that in the Murchison River these two species can readily hybridise. This is further highlighted by the fact that in many instances it was very difficult to decide whether fish superficially resembled *L. unicolor* or *A. caudavittata*. Furthermore, as only seven of the 25 presumptive *L. unicolor* examined from the Minilya, Cane, Yule, De Grey and Fitzroy Rivers were actually *L. unicolor* as described by Vari (1978), and as each river had at least two specimens that did not conform to the diagnostic pattern, it is possible that hybridisation between terapontids is not restricted to the Murchison River. It is also worth noting that the related barred grunter (*Amniataba percooides*) is present in some of these rivers and that Dr Barry Hutchins of the Western Australian Museum believes that hybridisation between terapontids may be quite common in the rivers of the Kimberley (Hutchins pers. com., see also Hutchins 1981).

In addition to proposing that much of the variation in coloration and anterior pterygiophore patterns described in the current study is the result of hybridisation, we also suggest that, in the Murchison River at least, (1) hybridisation has been occurring for at least the last few breeding seasons, (2) hybrids are reproductively viable and (3) some individuals may have been hybrids of hybrids. These further hypotheses are based on the facts that fish from the Murchison River that exhibited such

variations included, several distinct size-classes (length-range 39–253 mm TL), individuals that had spawned or were spawning and individuals with configurations very different and not intermediate to the parent species (see Campton 1987, 1991).

In considering Campton's (1987) criteria that increase the likelihood of hybridisation, it is evident that, (1) competition for spawning sites, (2) weak ethological isolating mechanisms, (3) unequal abundance of parent species and (4) susceptibility to secondary contact between recently evolved forms, may all be applicable when considering why hybridisation of *L. unicolor* and *A. caudavittata* apparently occurs so readily in the Murchison River. For example, (1) the river is generally narrow, its waters shallow (generally < 2 m deep), with spawning sites likely to be in the algal beds that characterise the littoral zones. Furthermore, spawning activity of both species overlaps and is confined to the warmer summer/autumn months (see also Beumer 1979; Potter *et al.* 1994 for spawning periods of these species in other systems), when the river may be comprised of small disconnected pools. (2) Both species readily school together, grow to a similar size, and have a similar diet (Morgan unpublished data). (3) Initially, *L. unicolor* may have been the dominant species, however, as salinity increased during land clearing in the middle catchment, *A. caudavittata* may have been drawn further upstream, thereby (4) facilitating secondary contact between recently evolved forms, which may not have developed mechanisms to isolate the species when sympatric (Hubbs 1961).

In regards to points (3) and (4) above it is pertinent to note that whilst *A. caudavittata* is essentially a marine/estuarine species, an increase in the salinity of previously freshwater stretches may have enabled this species to colonise a large proportion of Murchison River catchment. Such an increase in the salt content of previously freshwater stretches is likely the result of the large scale land clearing that has occurred in the middle of the catchment, a situation not uncommon in Western Australia. For example, in south-western Western Australia, where salinities in many rivers (e.g., Swan-Avon River, Blackwood River) have increased greatly as a result of excessive land clearing, a number of estuarine species are now entrenched in the waters a long distance from their normal estuarine environ (e.g., Western Hardyhead *Leptatherina wallacei* and the goby *Pseudogobius olorum*) (Morgan *et al.* 1998, 2003; Morgan and Gill 2000). Although *Amniataba caudavittata* has not yet moved long distances inland in any of the rivers of south-western Western Australia, it is found a considerable distance inland in the salt-affected Greenough River (Figure 3, Morgan and Gill 2004).

In summary, we believe that the results of the

current study support the view that, in the Murchison River at least, *L. unicolor* and *A. caudavittata* hybridised. We further propose that the considerable differences in the osteology of these hybrids compared with the parent species, their dominance in terms of numbers and the fact that many had recently spawned indicate that they are reproductively viable. Increases in the salinity of the Murchison River (through land clearing) are likely to have permitted the upstream movement of the marine/estuarine *A. caudavittata* into areas previously only inhabited by *L. unicolor*. Once these species became sympatric, the considerable overlap in spawning period, similarity in habitat utilisation, behaviour and diets, as well as their restriction to small pools during the summer spawning period would enhance the likelihood of hybridisations occurring. Genetic studies would be useful in verifying that the intermediary forms described in the current study are indeed hybrids, whilst further reproductive studies would allow us to determine the viability of such hybrids. If genetic studies confirm that these intermediary forms are hybrids, the examination of the osteological characteristics from museum specimens and other rivers could then be used to determine whether hybridisation is a recent phenomenon that is facilitated by increasing salinity levels and if it is occurring between terapontids in other river systems of Australia. The collection of these genetic, and spatial and temporal data is crucial. If, as we suspect, the increase of salinities in our rivers has facilitated hybridisation by removing an isolating barrier, then the effect of salinisation is far more insidious than merely the loss of habitat available to freshwater species, it may result in the loss of species through their replacement by hybrids.

#### ACKNOWLEDGEMENTS

Thanks to the Natural Heritage Trust, Department of Fisheries Western Australia, Water and Rivers Commission Western Australia and Murdoch University for providing funds for the project. Thanks to the Department of Conservation and Land Management for providing access to the Kalbarri National Park. Thanks to Charlotte Morgan, Stephen Beatty, Mark Allen and Steven Head for help in the collection of fish.

#### REFERENCES

- Allen, G.R., Midgley, S.H. and Allen, M. (2002). *Field Guide to the Freshwater Fishes of Australia*. Western Australian Museum, Perth.
- Beumer, J.P. (1979). Reproductive cycles of two Australian freshwater fishes: the spangled perch, *Therapon unicolor* Gunther, 1859 and the East Queensland rainbowfish, *Nematocentris splendida* Peters, 1866. *Journal of Fish Biology* **15**: 111–134.

- Campton, D.E. (1987). Natural hybridization and introgression in fishes – methods of detection and genetic interpretations. In N. Ryman and F. Utter (eds), *Population Genetics & Fishery Management*, pp. 162–192. University of Washington Press, Seattle.
- Campton, D.E. (1991). Application of biochemical and molecular genetic markers to analysis of hybridization. In D.H. Whitmore (ed.), *Electrophoretic and Isoelectric Focusing Techniques in Fisheries Management*, pp. 241–263. CRC Press, Boston.
- Hubbs, C.L. (1961). Isolating mechanisms in the speciation of fishes. In W.F. Blair (ed.), *Vertebrate Speciation*, pp. 5–23. University of Texas Press, Austin.
- Hutchins, J.B. (1981). Freshwater fish fauna of the Mitchell Plateau Area, Kimberley, Western Australia. In *Biological survey of Mitchell Plateau and Admiralty Gulf, Kimberley, Western Australia*. Western Australian Museum, Perth.
- Hutchins, B. and Swainston, R. (1986). *Sea Fishes of Southern Australia*. Swainston Publishing, Perth.
- Laevastu, T. (1965). *Manual of Methods in Fisheries Biology*. FAO, Rome.
- Morgan, D.L. and Gill, H.S. (2000). Fish associations within the different inland habitats of lower south-western Australia. *Records of the Western Australian Museum* 20: 31–37.
- Morgan, D.L. and Gill, H.S. (2004). Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia – evidence for three subprovinces. *Zootaxa* 636: 1–43.
- Morgan, D.L., Gill, H.S. and Potter, I.C. (1998). Identification, distribution and biology of the freshwater fishes in south-western Australia. *Records of the Western Australian Museum*, Supplement 56: 1–97.
- Morgan, D.L., Thorburn, D.C. and Gill, H.S. (2003). Salinization of south-western Western Australian rivers and the implications for the inland fish fauna – the Blackwood River, a case study. *Pacific Conservation Biology* 9: 161–171.
- Nelson, J.S. (1994). *Fishes of the World*. 2nd edn. J. Wiley, New York.
- Potter, I.C., Neira, F.J., Wise, B.S. and Wallace, J.H. (1994). Reproductive biology and larval development of the terapontid *Amniataba caudavittata*, including comparisons with the reproductive strategies of other estuarine teleosts in temperate Western Australian. *Journal of Fish Biology* 45: 57–74.
- Schwartz, F.J. (1972). World literature to fish hybrids, with an analysis by family, species, and hybrid. *Publications of the Gulf Coast Research Laboratory Museum* 3: 328pp.
- Schwartz, F.J. (1981). World literature to fish hybrids, with an analysis by family, species, and hybrid: supplement 1, NOAA technical report. NMFS SSRF-750. Washington DC: US Department of Commerce.
- Vari, R.P. (1978). The terapon perches (Percoidei, Teraponidae). A cladistic analysis and taxonomic revision. *Bulletin of the American Museum of Natural History* 159 (5): 175–340.
- Wise, B.S., Potter, I.C. and Wallace, J.H. (1994). Growth, movements and diet of the terapontid *Amniataba caudavittata* in an Australian estuary. *Journal of Fish Biology* 45: 917–931.

---

*Manuscript received 12 November 2003; accepted 16 September 2005*



# The wolf spider genus *Venatrix* Roewer: new species, synonymies and generic transfers (Araneae, Lycosidae)

Volker W. Framenau

Department of Terrestrial Invertebrates, Western Australian Museum, Locked Bag 49,  
Welshpool DC, Western Australia 6986, Australia

**Abstract** – Three species in the wolf spider genus *Venatrix* Roewer, 1960 are described as new: *V. amnicola* sp. nov. from south-east Australia, *V. tinfos* sp. nov. from Western Australia and *V. palau* sp. nov. from Queensland, the Federated States of Micronesia and Palau. *Venatrix kosciuskoensis* (McKay, 1974) comb. nov., *V. summa* (McKay, 1974) comb. nov., and *V. ornatula* (L. Koch, 1877) (= *V. forsteri* Framenau and Vink, 2001, new synonymy) are transferred from *Lycosa* to *Venatrix*, and *V. magkasalubonga* (Barrion and Litsinger, 1995) comb. nov. (= *Pardosa daniloi* Barrion and Litsinger, 1995, new synonymy; = *Pardosa sacayi* Barrion and Litsinger, 1995, new synonymy; = *Pardosa hawakana* Barrion and Litsinger, 1995, new synonymy) is transferred from *Pardosa*. *Allocosa percauta* (Simon, 1909), *Lycosa marcentior* Simon, 1909 and *Lycosa propitia* Simon, 1909 are considered junior synonyms of *V. pullastra*. *Venatrix goyderi* (Hickman, 1944) and *Lycosa howensis* McKay, 1979 are considered junior synonyms of *Venatrix konei* (Berland, 1924) comb. nov. *Arctosa konei epiana* (Berland, 1938) is elevated to species status, *Arctosa epiana* (Berland, 1938), stat. nov. The male of *V. kosciuskoensis* and the female of *V. archookoora* are described for the first time. Notes on the type material are provided for *V. furcillata* (L. Koch, 1867) and *V. brisbanae* (L. Koch, 1878).

## INTRODUCTION

The wolf spider genus *Venatrix* Rower, 1960 is a representative of the wolf spider subfamily Lycosinae, which is currently defined by male pedipalps with a transverse tegular (= median) apophysis carrying a ventrally directed spur and a sinuous channel on its dorsal surface (Dondale 1986). The Lycosinae are the most dominant subfamily of wolf spiders in Australia, in addition to an undescribed subfamily represented by, amongst other unnamed genera, *Artoria* Thorell, 1877 and *Tetralycosa* Roewer, 1960 (e.g., Framenau 2002a, 2005; Framenau *et al.* in press) and the Venoniinae, including *Allotrochosina* Roewer, 1960, *Anomalosa* Roewer, 1960, *Venonia* Thorell, 1894 and *Zoica* Simon, 1898. Most Australian Lycosinae are currently listed in the genus *Lycosa* Latreille, 1804, however, recent studies suggest this to be an exclusively Northern Hemisphere genus (Zyuzin and Logunov 2000). It appears that most Australian lycosines, with the exception of *Venatrix* and *Tuberculosa* Framenau and Yoo in press, represent a monophyletic group (Murphy *et al.* in press; Framenau and Yoo in press) and current and forthcoming revisions place the Australian representatives of this subfamily in a variety of endemic genera, such as *Dingosa* Roewer, 1955a, *Hoggicosa* Roewer, 1960, *Mainosa* Framenau (in press), *Tasmanicosa* Roewer, 1959 and *Venator* Hogg, 1900.

*Venatrix* was recently revised in Australia and New Zealand to include 22 species (Framenau and Vink 2001). Since this review, a large amount of material has been examined as part of a comprehensive revision of the Australian wolf spider fauna. This study provides an update of the *Venatrix* revision with the description of three new species, the transfer of some species formerly included in *Lycosa* and *Pardosa* to *Venatrix*, and the descriptions and illustrations of hitherto unknown sexes. In addition, some new synonymies are established. This study also includes material from outside the former known range of *Venatrix*, Australia and New Zealand, as original descriptions of some wolf spider species from the Philippines, New Caledonia and Vanuatu suggested the presence of *Venatrix* in these countries (e.g., Barrion and Litsinger 1995; Berland 1924). This study increases the number of *Venatrix* to 27 species, of which 12 are treated here (Table 1).

## METHODS

Descriptions are based on specimens preserved in 70% ethanol. Internal female genitalia were cleared for examination by submersion in lactic acid at room temperature for 2–24 hrs. For clarity, the setae have been omitted from the illustrations of epigyna and male pedipalps. The morphological

nomenclature follows Framenau and Vink (2001). All type material was examined unless otherwise stated. All measurements are in millimetres (mm).

### Eyes

Abbreviations: anterior (AE), anterior median (AME), anterior lateral (ALE), posterior (PE), posterior median (PME), posterior lateral (PLE).

### Australian States and Territories

Abbreviations: Australian Capital Territory (ACT), New South Wales (NSW), Northern Territory (NT), Queensland (Qld), South Australia (SA), Tasmania (Tas), Victoria (Vic), Western Australia (WA).

### Collections

Abbreviations: Australian Museum, Sydney (AM); Australian National Insect Collection Canberra (ANIC); Natural History Museum, London (BMNH); Bernice Pauahi Bishop Museum, Honolulu, Hawaii (BPBM); International Rice Research Institute, Entomology Division, Manila (IRR); Museum National d'Histoire Naturelle Paris (MNHP); Museum National d'Histoire Naturelle, Troyes (France) (MHNT); Museum Victoria Melbourne (MV); Museum and Art Gallery of the Northern Territory, Darwin (NTMAG); Queensland Museum, Brisbane (QM); South Australian Museum, Adelaide (SAM); Western Australian Museum, Perth (WAM); Museum für Naturkunde, Zentralinstitut der Humboldt-Universität Berlin (ZMB); Zoologisches Institut und Zoologisches Museum, Universität Hamburg (ZMH).

## SYSTEMATICS

### Family Lycosidae Sundevall, 1833

#### Subfamily Lycosinae Sundevall, 1833

#### *Venatrix* Roewer, 1960

#### Type species

*Venator fuscus* Hogg, 1900. By original designation (Roewer 1960).

*Venator fuscus* is a junior synonym of *Venatrix funesta* (C.L. Koch 1847) (Framenau and Vink 2001).

#### Diagnosis

Within the Lycosinae, *Venatrix* can be identified by the presence of a characteristic pattern on the ventral side of the abdomen, consisting of two longitudinal light bands on a dark surface. Sometimes, these bands are reduced to two or more light spots (e.g., in the *pictiventris*-group) or missing due to an overall light colouration of the

venter (e.g., *V. lapidosa*, *V. fontis*, and *V. arenaris*). In some species, this pattern is absent but may be visible in juvenile specimens (e.g., *V. arenaris*) (Framenau and Vink 2001). Males of *Venatrix* are characterised by a tubercle on the outer edge of the fangs and the presence of claw-like macrosetae on the tip of the cymbium (Framenau and Vink 2001). The female epigyne is usually inverted-T or anchor-shaped, however, some species, such as *V. goyderi* Hickman, 1944 and species in the *V. pictiventris*-group, deviate from this pattern (Framenau and Vink 2001). In species without the characteristic colouration of the venter it may be difficult or impossible to identify females as *Venatrix* due to the conservative morphology within the Lycosinae. In this case, generic identification may require the examination of males collected with the females.

#### Remarks

Recent morphological investigations showed, that *Venatrix hoggi* Framenau and Vink, 2001 does not belong to the genus *Venatrix* due to the presence of unique modified setae on the ventral side of the third coxae in males and a distinct morphology of the male pedipalp with a reduced terminal apophysis (Framenau and Yoo in press). This species is therefore not included in our list of *Venatrix* (Table 1).

#### *Venatrix amnicola* sp. nov.

Figures 1A–E, 2, 3

*Venatrix arenaris* (Hogg, 1905): Framenau and Vink 2001: ♀60–9e2, figures 40A–F, 41 (misidentification).

#### Types

*Holotype* male, Australia, Victoria, Avon River near Valencia Creek, 37°48'24"S, 146°57'14"E, 21 May 1907, V.W. Framenau, riparian gravel bank (WAM T55406).

*Paratypes*: 2 males, 1 female, Australia, Victoria, Avon River at Stratford, 37°58'23"S, 147°04'40"E, 29 December 2003, V.W. Framenau, M.L. and J. Thomas, riparian gravel bank (WAM T56082).

#### Etymology

The specific epithet is an adjective in apposition (Latin, *amnicolus* – growing beside a river) and refers to the habitat of this species, the riverbanks of the Great Dividing Range.

#### Other material examined

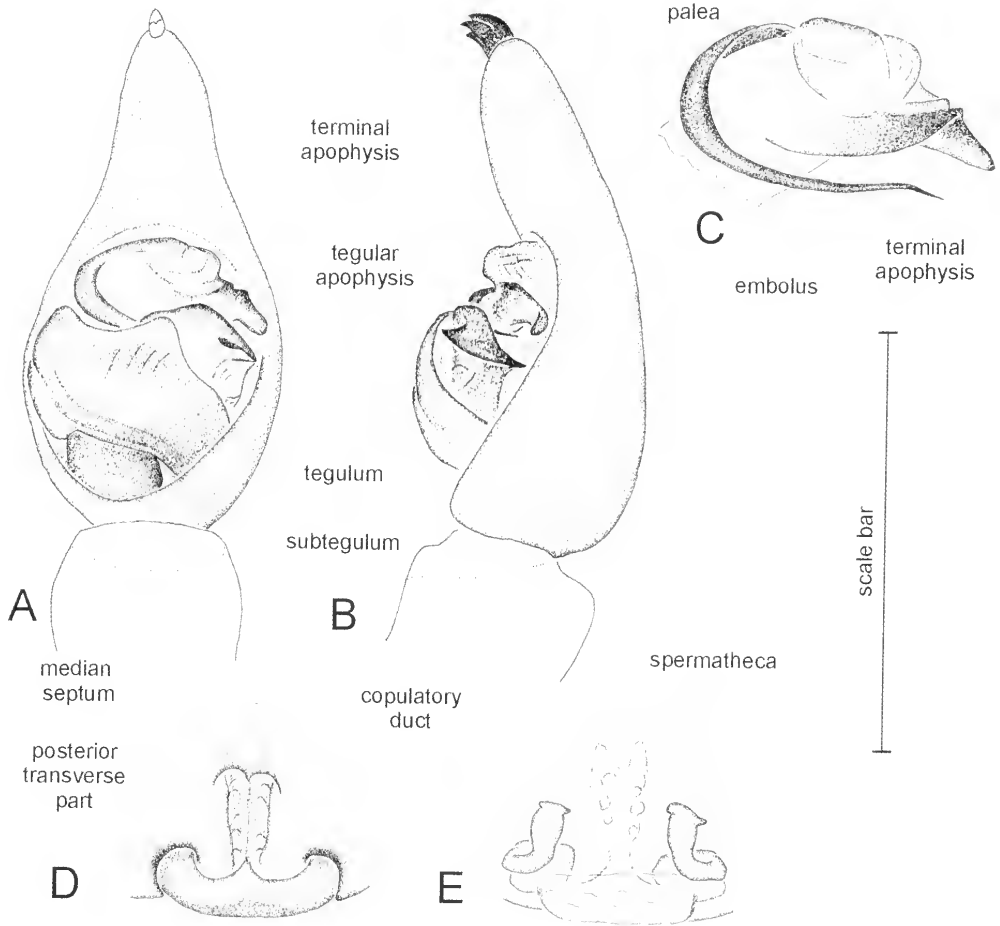
**Australia: New South Wales:** 4 males, 2 females, Honeysuckle Creek, Fish River, 34°46'S, 149°19'E, 22 November 1900, J. A. Thorpe (AM KS85164); 1 male, 1 female, Clarence River, Tabulam, 28°53'S, 152°34'E, 21 April 1973, D. Gleeson, on rocks near

creek (QM W3914). **Queensland:** 6 males, 6 females Gayndah, 25°37'S, 151°37'E, R. J. McKay, V. E. Davies, 1 December 1973, dry river sand (QM W5064); 1 female, Goodnight Scrub, 24°45'S, 152°24'E, no collector, at edge of water; eggs laid 30 July 1990 (QM S66813); 1 female, Mingo Crossing, Burnett River, 25°24'S, 151°47'E, 2 December 1973, R. J. McKay (QM S66816); 3 females, Mitchell River and Desaille Creek junction, Mt Carbine, 16°32'S, 145°08'E, 12 May 1973, R. J. McKay, wet river sands (QM W3912); 2 males, 1 female, Pine Creek Dam, Texas, 28°51'S, 151°10'E, 8 November 1973, at edge of creek (QM W3913). **Victoria:** 4 males, 3 females, Avon River at Stratford, 37°58'S, 147°04'E, 10 April 1997, V. W. Framenau, riparian gravel bank (MV K7454); 3 males, 1 female, same location, 26 March 2002, V. W. Framenau, riparian gravelbank (WAM T47300); 9 males, 10 females, same location, V. W. Framenau, riparian gravel bank (AM KS58429, KS58432, KS58436, KS69914-9); 2 males, 1 female, Avon River at Stratford, under highway bridge, 37°58'23"S, 147°4'40"E, 12 February 1997, V. W. Framenau, riparian gravel bank (WAM T55400); 1 female, same location, 29 December 2003, V. W. Framenau, M. L. and J. Thomas, riparian gravel bank (WAM T56081); 3 males, 2 females, Avon River at Weirs Crossing, 37°55'S, 147°00'E, V. W. Framenau, riparian gravel bank (AM KS58430, KS58433, KS58437, KS69920-5); 15 males, 9 females, Avon River near Valencia Creek, 37°48'24"S, 146°27'14"E, V. W. Framenau, riparian gravel bank (AM KS58431, AM KS58434-5, AM KS69926-33); 2 males, same location, 10 April 1997, V. W. Framenau, riparian gravel bank, gravel bank '3' (WAM T55402); 1 male, 2 females, Cann River at Leslies Track, 37°28'S, 149°11'E, 3 December 1998, V. W. Framenau, riparian gravel bank (AM KS58422); 1 male, 1 female, Cann River at Princess Highway bridge, 37°34'S, 149°09'E, 3 December 1998, V. W. Framenau, riparian gravel bank (AM KS58420); 1 female, Ensay, 37°22'S, 147°50'E, January 1972, A. Fischer (SAM NN10231); 4 males, 2 females, Mitchell River at Wuk Wuk Bridge, 37°47'S, 147°26'E, 26 November 1998, V. W. Framenau, riparian gravel bank (AM KS58419, KS69886); 5 males, 1 female, Mitchell River near Angusvale, 37°36'S, 147°21'E, 26 November 1998, V. W. Framenau, riparian gravel bank (AM KS58418); 1 female, Mitta Mitta River, 8km NW of Dartmouth Dam, 36°34'S, 147°28'E, 4 November 1976, A. A. Calder (MV K7448); 3 males, 1 female, Ovens River near Wangaratta, 36°23'S, 146°22'E, 6 December 1998, V. W. Framenau, riparian gravel bank (AM KS58424); 3 males, 2 females, Ovens River near Wangaratta, Ovens Billabong, 36°23'S, 146°22'E, 6 December 1998, V. W. Framenau, riparian gravel bank (AM KS58432); 1 female with eggsac, Snowy and Broadbent Rivers junction, 37°20'S, 148°21'E, early December 1947, C. W. Brazenoor (MV K7439).

## Description

**Male** (based on holotype, WAM T55406). **Carapace:** Brown, with irregular but distinct and wide light brown median band in the anterior two thirds of carapace, which is constricted at about half its length; carapace margins black; light brown submarginal bands represented by three irregular spots; covered with mainly black and a few white setae; white setae in median and submarginal bands; brown bristles around eyes, in particular between PME. **Sternum:** Dark brown, margins yellow-brown; narrow yellow-brown median band in anterior half; black-brown setae increasing in length and density towards margins. **Labium:** Brown, base very dark; front end truncate and white. **Chelicerae:** Reddish-brown, white setae and fewer brown bristles mainly in basal half; three retromarginal teeth of nearly equal size; three promarginal teeth, with the middle one largest. **Pedipalp** (Figures 1A–C): Terminal apophysis triangular with rounded tip that is bent ventrally, embolus sickle-shaped (Figure 1C). **Abdomen:** Light yellow-brown with dark and irregular olive-grey, mottled pattern; indistinct orange lanceolate heart mark; colour of setae corresponding to pigmentation, heart mark with very dense whitish setae; few brown macrosetae; venter yellow-brown, indistinct olive-grey pattern medially; covered with white setae and fewer brown macrosetae; spinnerets brown with darker base. **Legs:** Leg formula IV > I > II > III; brown, with the apical segments darker; very distinct dark annulations; spination of leg I: femur: 3 dorsal, 2 prolateral, 3 retrolateral; patella: 1 prolateral; tibia: 3 ventral pairs, 2 prolateral, 2 retrolateral; metatarsus: 3 ventral pairs, 2 prolateral, 1 retrolateral, 1 apicoventral, 1 apicoprolateral, 1 apicoretrolateral.

**Female** (based on paratype, WAM 56082). **Carapace:** As male, less white setae. **Sternum:** As male, but darker and with additional few white setae. **Labium:** As male. **Chelicerae:** Very dark reddish-brown; setae and dentition as male. **Epigyne** (Figures 1D, E): Ventral view: medium septum inverted T-shaped (Figure 1D); dorsal view: spermathecae elongate oval; copulatory ducts S-shaped and connect posteriorly to spermathecae (Figure 1E). **Abdomen:** Mottled yellow-brown and dark olive-grey; some lighter patches in two rows medially; lanceolate heart mark very indistinct, discernable only by dense silver-grey setae; covered with silver-grey and brown setae and fewer brown macrosetae; venter and spinnerets as male. **Legs:** Leg formula IV > I > II > III; colouration as male; weak scopulous setae on tarsi and metatarsi of leg I and tarsi and apical half of metatarsi of leg II: femur: 3 dorsal, 2 retrolateral (3 on right leg), 1 apicoprolateral; tibia: 3 ventral pairs, 2 prolateral; metatarsus: 3 ventral pairs, 1 prolateral, 1 apicoventral.



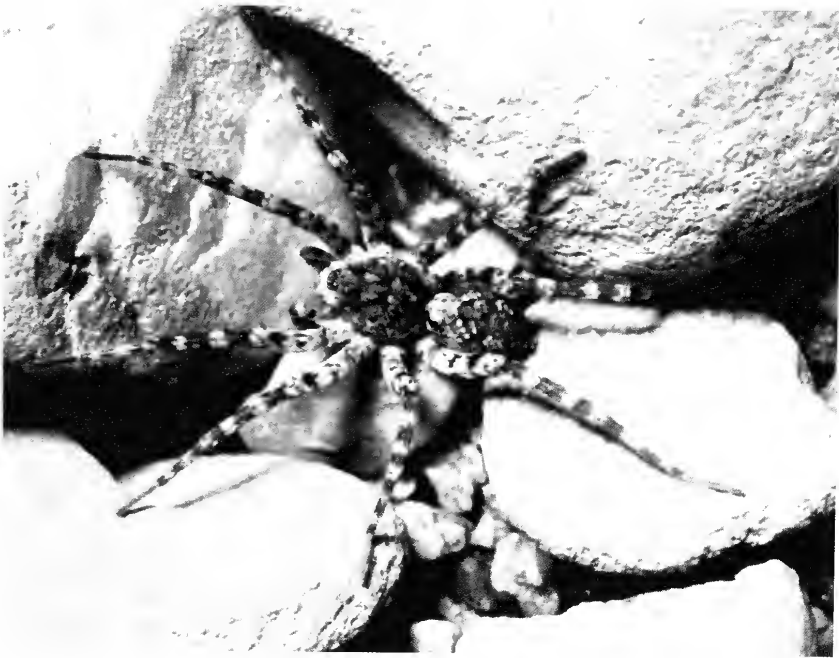
**Figure 1** *Venatrix amnicola* sp. nov., holotype male (WAM T55406, from the Avon River near Valencia Creek, Victoria); A, left pedipalp, ventral view; B, left pedipalp, retrolateral view; C, left pedipalp, apical part of bulbus. Female (WAM T56082, from the Avon River at Stratford, Victoria): D, epigyne, ventral view; E, epigyne, dorsal view. Scale bar: A, B = 1.01 mm; C = 0.57 mm; D, E = 1.32 mm.

**Measurements.** Male holotype, WAM T55406 (female paratype, WAM T56082): TL 7.24 (8.46), CL 3.95 (4.70), CW 2.82 (3.48). Eyes: AME 0.17 (0.19), ALE 0.11 (0.14), PME 0.28 (0.35), PLE 0.26 (0.28). Row of eyes: AE 0.67 (0.91), PME 0.75 (0.91), PLE 1.03 (1.22). Sternum (length/width) 1.97/1.41 (2.16/1.79). Labium (length/width) 0.45/0.55 (0.68/0.64). AL 3.38 (3.76), AW 2.26 (3.01). Legs: Lengths of segments (femur + patella/tibia + metatarsus + tarsus = total length): Pedipalp 1.50+1.41+ - +1.13 = 4.04, I 2.91+3.67+2.44+1.69 = 10.71, II 2.91+3.57+2.40+1.60 = 10.48, III 2.73+3.10+2.54+1.41 = 9.78, IV 3.38+4.04+3.48+1.88 = 12.78 (Pedipalp 1.69+1.88+ - +1.13 = 4.70, I 3.48+4.04+2.63+1.88 = 12.03, II 3.38+3.76+2.54+1.79 = 11.47, III 3.10+3.38+3.01+1.69 = 11.18, IV 3.95+4.70+4.23+2.07 = 14.95).

**Variation.** Males (females)(range, mean  $\pm$  s.d.): TL 7.20 - 8.40, 7.76  $\pm$  0.52; CL 3.75 - 5.10, 4.42  $\pm$  0.50; CW 2.82 - 3.75, 3.25  $\pm$  0.39; n = 7 (TL 8.46 - 11.55, 10.12  $\pm$  1.56; CL 4.70 - 5.10, 4.97  $\pm$  0.23; CW 3.48 - 3.86, 3.69  $\pm$  0.18; n = 3). Live spiders do have a mottled, cryptic colouration, which provides camouflage in their natural environment, sandy and gravel banks of rivers (Figure 2).

#### Remarks

This species was previously regarded as a morphological variety of *V. arenaris* (Framenau and Vink 2001). The recent examination of additional material in combination with molecular data, however, indicated that *V. amnicola* represents a distinct species. Specimens of *V. amnicola* from the Avon River (Victoria) showed 33% fixed differences



**Figure 2** *Venatrix amnicola*, male from the Avon River at Valencia Creek, Victoria. Body length ca. 8 mm.

in allele frequencies compared with *V. arenaris* specimens from artesian springs in South Australia (Gotch 2003).

In the key to *Venatrix* (Framenau and Vink 2001), males and females of *V. amnicola* will key out to *V. arenaris* (Hogg, 1905). The diagnosis above will serve to differentiate both species.

#### Life history and habitat preferences

*Venatrix amnicola* has only been found on the sandy and gravel riverbanks of the Great Dividing Range and was subject to a major investigation of this habitat, then misidentified as *V. arenaris* (Framenau 1998, 2002b; Framenau *et al.* 2002). It inhabits the lowland floodplains of alpine rivers

where a number of ecological factors such as altitude, degree of shade, gravel size and gravel bank size appear to determine the arthropod community structure (Framenau *et al.* 2002). In Victoria, *V. amnicola* completes its life cycle in one year; juveniles hatch in spring, mature by autumn and reproduce the following spring (Framenau 1998).

#### Distribution

New South Wales, Queensland, and Victoria (Figure 3).

#### *Venatrix archookoora* Framenau and Vink, 2001

Figures 4A–B, 5

*Venatrix archookoora* Framenau and Vink, 2001: 940–942, figures 14a–c, 15.

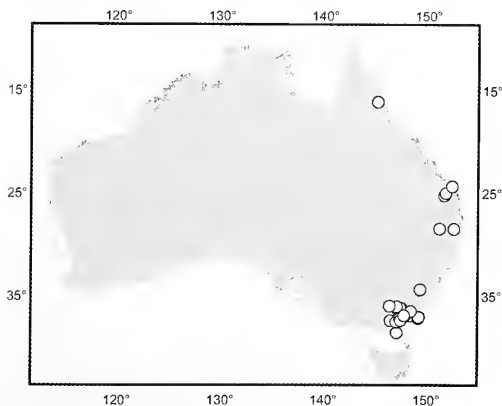
#### Types

*Holotype* male of *Venatrix archookoora*, Australia, Queensland, Archookoora State Forest, via Kumbia, 26°43'S, 151°47'E, 17 October 1976, G.B. and S.R. Monteith (QM S45307). Examined.

*Paratype* male, Australia, Queensland, Amiens, near Stanthorpe, 28°35'S, 151°49'E (QM S45294). Examined.

#### Diagnosis

Males of *V. archookoora* are similar to those of *V. australiensis*, *V. roo* and *V. mckayi*, but differ in the shape of the tegular apophysis which is uniquely



**Figure 3** Records of *Venatrix amnicola* sp. nov.

triangular in ventral view with a small pointed protrusion on its apical edge (Framenau and Vink 2001). The epigyne of female *V. archookoorra* resembles that of *V. arenaris*, *V. amnicola* and *V. palau*, and the species will key out to *V. arenaris* in the key of the genus in Framenau and Vink (2001). However, *V. archookoorra* differs distinctly in its dark reddish-brown carapace and overall colouration from the above species with their light brown mottled pattern.

#### Other material examined

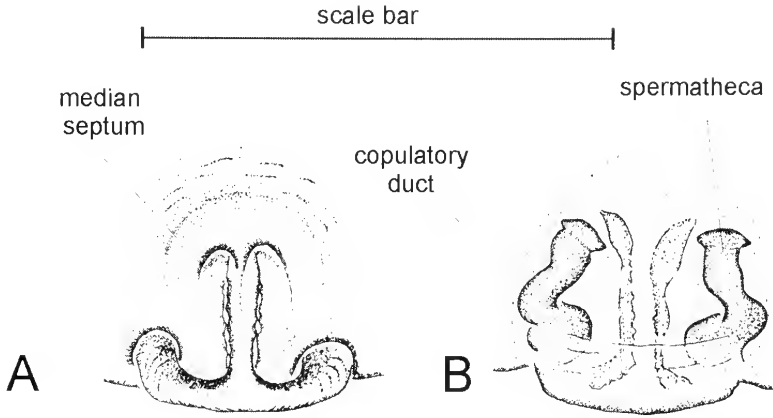
**Australia: Queensland:** 2 males, Binjour Plateau, Swains Road, 25°32'S, 151°30'E, 23 September – 21 December 1997, G. Monteith, D. Cook, 340m, vine scrub (QM S44305); 2 males, same location, 20 December 1997 – 26 April 1998, G. Monteith, vine scrub (QM S46395); 1 female, Boat Mountain summit Environmental Park., 26°09'S, 151°59'E, 9 September – 15 December 1994, G. Monteith, vine scrub (QM S66674); 2 males, Brigooda, Koy Property, 26°16'S, 151°25'E, 15 December 1994 – 26 January 1995, G. B. Monteith, vine scrub, bottom site (QM S57043); 1 male, 1 female, same location, 26 January – 20 April 1995, G. B. Monteith, vine scrub, top site (QM S31603); 1 male, Coalston Lakes, 26°11'S, 152°04'E, 26 March – 5 September 1997, G. and S. Monteith, vine scrub, GM72A/3 (QM S66674); 1 female, same location, 29 August – 13 December 1976, G. and S. Monteith, GM72A/1 (QM S66670); 4 males, Cobbs Hill, 26°03'S, 151°54'E, 19 December 1992 – March 1993, S. Hamlet, site 1 (QM S27402); 2 males, same location, S. Hamlet, site 2 (QM S27413); 4 males, 1 female, Crater National Park, Atherton Tableland, 17°26'S, 145°29'E, 28 December 1990, G. B. Monteith, 950m (QM S41641); 2 males, 2 females, Expedition Range National Park, 'Amphitheatre' scrub, 25°13'S, 148°59'E, 25 September – 17 December 1997, G. Monteith, D. Cook, vine forest (QM S66669); 2 males, Gurgeena Plateau, 25°27'S, 151°23'E, 27 January – 2 June 1999, G. Monteith, G. Thompson, 360m, open forest (QM S50718); 2 males, same location, 20 August – 9 October 1998, G. B. Monteith, 360m, rainforest (QM S59225); 1 male, same location, 27 January – 2 June 1999, G. Monteith, G. Thompson, open forest (QM S66673); 1 male, Hurdle Gully, 13km WSW Monto, 24°51'S, 151°00'E, 23 September – 20 December 1997, G. Monteith, D. Cook, 350m, semi-evergreen vine thicket (QM S44397); 1 male, 1 female, Hurdle Gully, 10.8km WSW Monto, 24°54'S, 151°01'E, 23 September – 20 December 1997, intercept trap, G. Monteith, D. Cook, vine scrub (QM S32531); 1 male, Keysland, 26°12'S, 151°44'E, 29 September 1994 – 15 December 1994, G. B. Monteith, open forest (QM S37742); 5 males, Nangur State Forest, 26°08'S, 151°59'E, 29 July 1995 – 23 October 1995, G. B. Monteith, 320m, rainforest, second site (QM S41636, S41649); 4 males, 2 females, same location, 24

October – 24 November 1995, G. B. Monteith, 320m, rainforest, first site (QM S51084); 1 male, 1 female, same location, 24 October – 24 November 1995, G. B. Monteith, 320m, rainforest, second site (QM S43799); 12 males, 2 females, 1 female with eggsac, same location, 24 November 1995 – 3 February 1996, G. B. Monteith, rainforest, first site (QM S37653); 1 male, 3 females, Nipping Gully, 25°41'S, 151°26'E, 9 October – 18 December 1998, G. Monteith, C. Gough, 200m, rainforest, site 2 (QM S49534); 2 males, 1 female, same location, 25 January – 2 February 1999, G. Monteith, G. Thompson, 240m, rainforest (QM S52029); 1 male, same location, 26 January – 2 June 1999, G. Monteith, G. Thompson, 300m, rainforest, site 2 (QM S51948); 2 males, same location, 18 December 1998 – 25 January 1999, G. Monteith, C. Gough, rainforest, site 5 (QM S34857); 2 females, 'Pearlinga', via Mundubbera, 25°36'32"S, 151°7'51"E, 20 July – 20 December 2000, D. Cook, G. Monteith, 160m, semi-evergreen vine thicket (QM S57727); 2 males, same location, 20 December 2000 – 23 March 2001, D. Cook, G. Monteith, vine scrub (QM S66672); 1 male, The Bluff, Keysland, 26°15'S, 151°43'E, 29 July – 23 October 1995, G. B. Monteith, 530m, vine scrub (QM S51077); 3 males, same location, 24 October – 24 November 1995, G. B. Monteith, 530m, vine scrub (QM S51079); 3 males, same location, 24 November 1995 – 3 February 1996, G. B. Monteith, vine scrub (QM S37662); 1 female, Wetherston, 3km SW, 25°34'S, 151°42'E, 10 October – 19 December 1998, G. Monteith, C. Gough, vine scrub (QM S66671); 4 males, Wonga Hills, 26°4'07"S, 150°49'29"E, 10 October – 11 December 2001, G. Monteith, D. Cook, 500m, softwood scrub, site 2 (QM S57108); 8 males, Woodmillar (East), 25°41'S, 151°36'E, 25 January – 2 June 1999, G. Monteith, G. Thompson, 350m, vine scrub (QM S51912); 7 males, same location, 21 August – 10 October 1998, G. Monteith, vine scrub (QM S66668).

#### Description

**Male.** See Framenau and Vink (2001). The size variation of a larger number of males is given below.

**Female** (based on paratype, WAM T56082). **Carapace:** Reddish-brown, with dark radial pattern; orange-brown median band, widest posteriorly of PLE and narrowing continuously; two small brown spots in median band between PLE and fovea; very indistinct lighter submarginal band; head flanks distinctly darker; white and black setae, but only white setae in median band and eye region and mainly black setae on dark head flanks; a band of white setae from below the PLE to carapace margin; brown-black bristles around eye region some in median band anterior of fovea; six long bristles below AE, one long bristle between AME. **Sternum:** Reddish-brown with indistinct lighter, narrow



**Figure 4** *Venatrix archookoora* Framenau and Vink, 2001, female (QM 32531, from Hurdle Gully, Queensland): A, epigyne of, ventral view; B, epigyne, dorsal view. Scale bar: A, B = 1.30 mm.

median band in anterior half; covered with black setae and bristles which are longer towards margin. *Labium*: Brown-black, front end truncate and white. *Chelicerae*: Black-brown, light brown setae in basal third, black setae apically, fewer longer brown bristles mainly medially. *Epigyne* (Figures 4A, B): Ventral view: medium septum inverted T-shaped, longitudinal part with slightly serrated edges (Figure 4A); dorsal view: spermathecae and copulatory ducts of similar width, spermathecae with apical hood-like structure (Figure 4B). *Abdomen*: Olive-grey, medially lighter with two pairs of darker spots in posterior half; brown and white setae, fewer brown macrosetae; venter uniformly very dark olive-grey, brown setae; spinnerets dark brown. *Legs*: Leg formula IV > I > II > III; orange brown, femora and tibiae with indistinct light annulations through rings of white setae; spination of leg I: femur: 3 dorsal, 3 retrolateral, 2 apicoprolateral; patella: 1 prolateral;

tibia: 3 ventral pairs, 2 prolateral, 2 retrolateral; metatarsus: 3 ventral pairs, 2 prolateral, 1 retrolateral, 1 apicoventral, 1 apicoprolateral, 1 apicoretrolateral.

*Measurements*. Female, QM S32531: TL 12.41, CL 6.58, CW 4.79. Eyes: AME 0.25, ALE 0.18, PME 0.53, PLE 0.45. Row of eyes: AE 1.22, PME 1.22, PLE 1.63. Sternum (length/width) 2.44/2.26. Labium (length/width) 0.87/0.99. AL 4.89, AW 4.14. Legs: Lengths of segments (femur + patella/tibia + metatarsus + tarsus = total length): Pedipalp 2.44+2.26+ - +1.88 = 6.58, I 4.70+5.64+3.57+2.16 = 16.07, II 4.42+5.08+3.29+2.07 = 14.86, III 4.14+4.61+3.38+1.79 = 13.92, IV 5.45+6.20+5.83+2.26 = 19.74.

*Variation*. Males (females)(range, mean  $\pm$  s.d.): TL 7.95 – 10.50, 9.27  $\pm$  0.65; CL 4.50 – 6.00, 5.15  $\pm$  0.40; CW 3.15 – 4.50, 3.76  $\pm$  0.34; n = 21 (TL 10.50 – 15.00, 12.39  $\pm$  1.36; CL 4.95 – 7.80, 6.33  $\pm$  0.86; CW 3.45 – 6.00, 4.61  $\pm$  0.78; n = 12).

#### Remarks

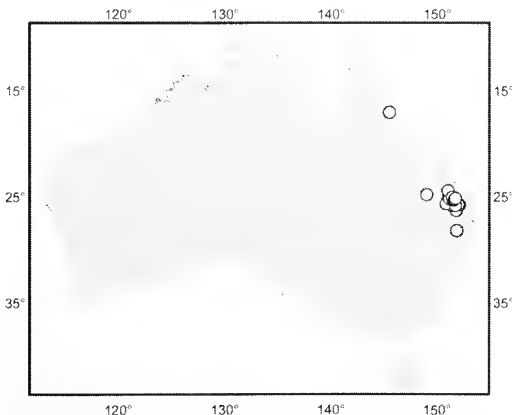
When Framenau and Vink (2001) described *V. archookoora*, the species was only known from two males. The hitherto unknown female is here described for the first time.

#### Life history and habitat preferences

The activity of males judged by pitfall trap periods, appears to be highest from October to January (spring and early summer) and females appear in lower numbers and slightly later. The species appears to inhabit a variety of shady habitats, such as open forest, vine forest and scrub, and rainforest. It was found at elevations between 150 and 900m.

#### Distribution

Queensland (Figure 5).



**Figure 5** Records of *Venatrix archookoora* Framenau and Vink, 2001.

*Venatrix brisbanae* (L. Koch, 1878)

*Lycosa brisbanae* L. Koch, 1878: 976–978, plate 85, figures 4, 4a, 4b; Rainbow 1911: 266; McKay 1985: 75.

*Pirata brisbanae* (L. Koch); Roewer 1955b: 286; McKay 1973: 381.

*Lycosa brisbanensis* L. Koch; Bonnet 1957: 2636.

*Venatrix brisbanae* (L. Koch); Framenau and Vink 2001: 953–954, figures 30A–F, 31.

**Type**

*Holotype* female of *Lycosa brisbanae*, Australia, Queensland, Brisbane, 27°28'S, 153°01'E (MHNT AR0820). Examined.

**Remarks**

The identification of *V. brisbanae* in Framenau and Vink (2001) was solely based on the original description as the whereabouts of the type material was not known. The recent discovery and examination of the holotype in the Museum National d'Histoire Naturelle, Troyes (France) confirmed the identity of this species as diagnosed and revised in Framenau and Vink (2001).

*Venatrix furcillata* (L. Koch, 1867)

*Lycosa furcillata* L. Koch, 1867: 201–202; L. Koch 1877: 903–906, plate 78, figures 1a–b, 2a–b; Rainbow 1911: 268; Rack 1961: 37; McKay 1973: 379; McKay 1974a: 15–18, figure 3c, d, k–m; McKay 1985: 77; Platnick 1993: 487.

*Allocosa furcillata* (L. Koch); Roewer 1955b: 206.

*Venatrix furcillata* (L. Koch); Framenau and Vink 2001: 957–959, figures 36A–D, 37.

**Type**

*Holotype* immature (?) of *Lycosa furcillata*, Australia, Queensland, Brisbane, 27°28'S, 153°01'E, Queensland. Whereabouts unknown. Not examined.

**Remarks**

*Venatrix furcillata* was originally described from a single specimen (holotype) collected by Amalie Dieterich in Brisbane and deposited in the collection of the Museum Godeffroy (L. Koch 1867). This specimen may have been a juvenile since the description does not mention male or female genitalia as in other species of the same publication. Subsequently, L. Koch (1877) redescribed and illustrated males and females of *V. furcillata*, listing numerous specimens from Bowen, Brisbane, Port Mackay, Gayndah (all Queensland) and Sydney (New South Wales)

deposited in the Museum Godeffroy, but also specimens in the Museum National d'Histoire Naturelle, Troyes (France) from Brisbane and some specimens from Sydney in the Bradley Collection. More recently, a catalogue of the material in the ZMH mistakenly listed a 'syntype' of *V. furcillata* from Sydney (Rack 1961) most likely referring to the series of species on which L. Koch's (1877) redescription (but not original description) was based. McKay (1974a) designated a lectotype from what he also presumed to be syntypes, all from the Godeffroy Museum, collected in Sydney and deposited in the Natural History Museum, London. Framenau and Vink (2001) expanded this list with additional paralectotypes. All references to syntypes and the designation of a lectotype series of *V. furcillata* must be considered invalid, since the original description of this species was based on a single specimen, i.e., a holotype.

I have examined all major collections which today house material from the Museum Godeffroy (BMNH, ZMB, ZMH) but could not find a specimen that agrees with the description of the holotype of *V. furcillata* and was collected or labelled 'Brisbane'. Therefore, I consider the holotype of *V. furcillata* lost. However, due to L. Koch's (1877) accurate redescription, there is no doubt about the identity of this species as revised in McKay (1974a) and Framenau and Vink (2001).

*Venatrix konei* (Berland, 1924), **comb. nov.**

*Lycosa albosparsa sensu* Hogg, 1896: 314, 351; not L. Koch 1876: 886, plate 76, figure 4 (misidentification, *L. albosparsa* considered *nomen dubium* in Framenau and Vink 2001).

*Lycosa konei* Berland, 1924: 245–246, figures 197–199; Bonnet 1957: 2648.

*Lycosa goyderi* Hickman, 1944: 33–34, plate 2, figure 20; McKay 1985: 78. **New synonymy.**

*Mustelicosa goyderi* (Hickman, 1944); Roewer 1955b: 280.

*Arctosa konei* (Berland, 1924); Roewer 1955b: 230.

*Piratosia goyderi* (Hickman, 1944); Roewer 1960: 915; Platnick 1993: 506.

*Arctosa goyderi* (Hickman, 1944); McKay 1973: 380.

*Lycosa howensis* McKay, 1979a: 237–238; figures 1a–e; McKay 1985: 78; Platnick 1989: 371. **New synonymy.**

*Venatrix goyderi* (Hickman, 1944); Framenau and Vink 2001: 963–965, figures 44A–E, 45; Vink 2002: 39, figures 5, 33, 40, 67, 94, map 27; Framenau *et al.* in press: figures 15–17.



**Types**

*Lectotype* female (designated here) of *Lycosa konei*, New Caledonia, labelled 'Vallée Tiaouka' (= ?Tiwaka) [Berland (1924) states 'Station au bord du fleuve Koné'], 21°05'S, 164°48'E (coordinates for Koné River), 23 August 1911, Roux and Sarasin (MHNP). Examined.

*Paralectotype* female (penultimate) of *Lycosa konei*, data as lectotype (MHNP). Examined.

*Paralectotype* female of *Lycosa konei*, New Caledonia, Bopope, 20°55'S, 165°04'E, August 1911 (listed as 'cotype' by Berland, 1924) (MHNP?, not received with other type material). Not examined.

*Holotype* female of *Lycosa goyderi*, Australia, South Australia, Goyders Lagoon Bore, 27°01'S, 138°54'E, 1939, Simpson Desert Expedition, coll. 647 (AM KS49705). Examined.

*Holotype* female of *Lycosa howensis*, Australia, New South Wales, Lord Howe Island, Lagoon Road, North of Blinky Beach Road turnoff, 31°32'30"S, 159°04'30"E, 3 February 1971, M. R. Gray, Station 25 (AM KS60). Examined.

*Paratypes* of *Lycosa howensis*, 3 males, 4 juv., data as holotype (AM KS 61-63). Examined.

**Diagnosis**

Males of *V. konei* can be separated from all other species in the genus by the unique shape of the terminal apophysis, that forms a roof over the resting embolus. The hoods of the female epigyne touch centrally and the median septum is only weakly sclerotised (see diagnosis of *V. goyderi* in Framenau and Vink 2001).

**Remarks**

*Venatrix goyderi* had recently been recorded from New Caledonia (C.J. Vink, personal communication, Framenau *et al.* in press) and an assessment of original descriptions of New Caledonian spiders (e.g., Berland 1924) suggested *Lycosa konei* to have very close affinities to *V. goyderi*. Subsequent examination of the type material of *L. konei* showed no distinct differences in genitalic and somatic characters of both species. Therefore, *V. goyderi* and its synonym *Lycosa howensis* (Framenau and Vink 2001) are here considered junior synonyms of *L. konei* and the species is transferred to *Venatrix*. The syntype series consists of 'types', a female and a penultimate female, and an adult female 'cotype' (Berland 1924). A lectotype is designated here to stabilise the taxonomic concept of *V. konei*.

Berland (1938) subsequently described a new subspecies of *V. konei*, *Lycosa konei* var. *epiana* Berland, 1938, currently listed in *Arctosa* (Platnick 2005). The types of *Lycosa konei* var. *epiana* are not present in the MHNP (C. Rollard personal communication) where, as part of the collection of Mr and Mrs Aubert de la Ruë, they should be

housed (Berland 1938). However, the original description of *A. konei* var. *epiana* clearly shows that this species is not conspecific with *V. konei*. The male pedipalp, illustrated in Berland (1938), has a sickle-shaped terminal apophysis and is not similar to the roof-shaped structure that is very characteristic for *V. konei*. In addition, the female epigyne of *A. konei* var. *epiana* is inverted T-shaped without the distinct separate anterior hoods of *V. konei*. Consequently, the subspecies *A. konei* var. *epiana* is removed from its synonymy with *V. konei* and elevated to species status, *Arctosa epiana* (Berland 1938), stat. nov. It is retained in its current genus *Arctosa*, pending an examination of the type material.

***Venatrix kosciuskoensis* (McKay, 1974)**

comb. nov.

Figures 6A–C, 7

*Lycosa kosciuskoensis* McKay, 1974b: 31–34, figures 1d–f, j–l; Brignoli 1983: 450; McKay 1985: 79.

**Types**

*Holotype* female of *Lycosa kosciuskoensis*, Australia, New South Wales, Mt Kościuszko near Lake Albina, 36°27'S, 148°16'E, 6 January 1929, A. Musgrave (AM KS628). Examined.

*Paratypes* of *Lycosa kosciuskoensis* (all from Australia, New South Wales): 1 female, data as holotype (AM KS629); 1 female, 2 juveniles, Mt Kościuszko, 36°27'S, 148°16'E, 7 January 1929, A. Musgrave, H.O. Fletcher, 7000ft (AM KS625, KS630); 1 female, Mt Kościuszko, 36°27'S, 148°16'E, A. Musgrave, H.O. Fletcher, 7000ft (AM KS632); 3 females, Mt Kościuszko, 36°27'S, 148°16'E, 7 January 1929, A. Musgrave, H.O. Fletcher (KS627); 3 females, 2 juveniles, Mt Kościuszko, summit, 36°27'S, 148°16'E, 11 January 1929, A. Musgrave, H.O. Fletcher, 7328ft (AM KS626); 1 juvenile, Mt Kościuszko near Lake Coatapatamba, 36°27'S, 148°16'E, 7 January 1929, A. Musgrave, H.O. Fletcher (AM KS631). All examined.

**Diagnosis**

*Venatrix kosciuskoensis* can be distinguished from all other species of *Venatrix* by its unique ventral pattern displaying a pair of white spots in the posterior half on a dark surface. Due to this unique pattern the key to the species of *Venatrix* (Framenau and Vink 2001) fails in the first couplet to identify this species.

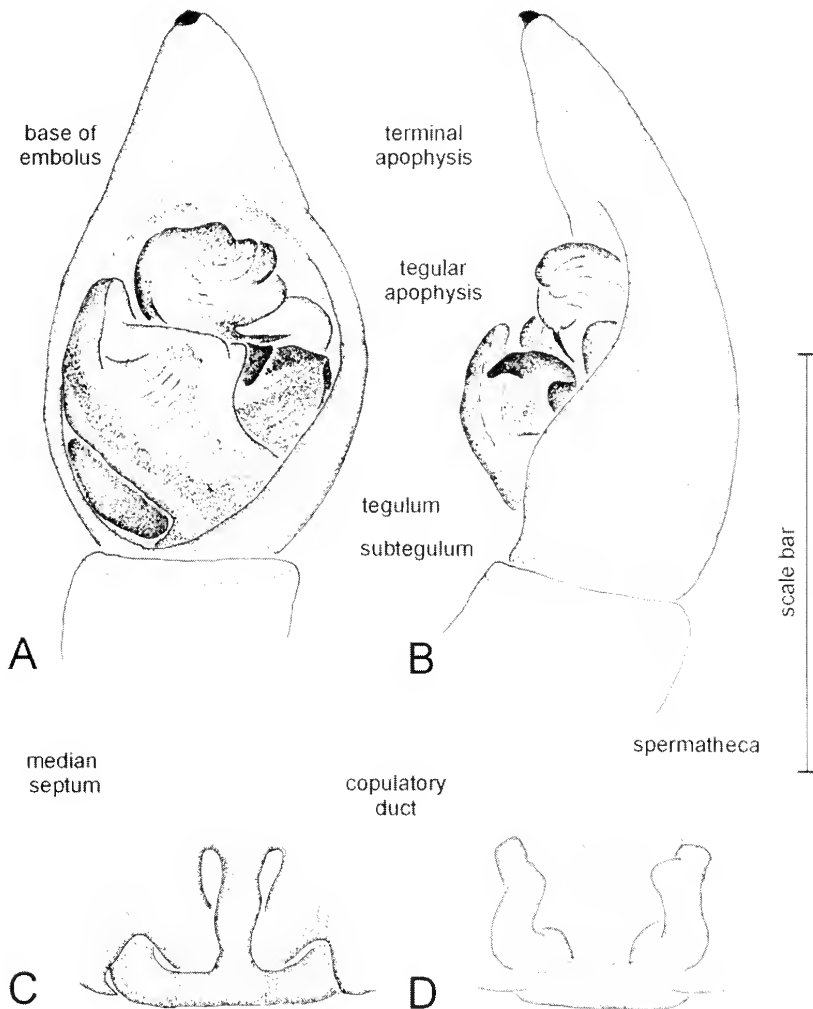
**Other material examined**

**New South Wales:** 1 female, Mt Kościuszko National Park, 3km NE of Mt Twynham, 28 December 1981, B.E. Roberts, walking on ground, daytime (MV K7436); 1 female, Rock Creek, Mt Kościuszko, 36°27'S, 148°16'E, 25 November 1952,

A. Musgrave, 1833m, among snow grass against rocks (AM KS85153); 1 female, Spencers Creek, Mt Kościuszko, 36°21'S, 148°32'E, 22 November 1952, A. Musgrave, 5–6000ft (AM KS70011); 1 female, Wilsons Valley, Mt Kościuszko, Boonbar, 5000ft (AM KS85152); 1 female, Mt Coruthers, Maria Range, 100m E of junction Blue Lake Track with Lakes Track on Maria Range, 36°23'S, 148°19'E, 26 February 1934, fen vegetation (ANIC). **Victoria:** 1 male, Falls Creek, 39°53'S, 147°16'E, 13 December 1992, J. Dawson, alpine grassland (QM S21161); 1 female, Mt Buller Ski Resort, 37°08'S, 146°27'E, 5 May 1975, V. Salitrini (QM S66445); 1 female, Suggan Buggan – Thredbo track, 36°57'S, 148°19'E, 29 December 1976, V. Salitrini (QM S66444).

### Description

**Male** (based on QM S21161). **Carapace:** Dark reddish-brown with distinct and wide orange-brown median and submarginal bands; submarginal bands reach to frontal margin of carapace; carapace covered with black setae, except in median and submarginal bands which have white setae; dark brown bristles mainly around PME, one long brown bristle between AME, six long brown bristles below AE. **Sternum:** Black; black setae increasing in length towards margins. **Labium:** Black; front end truncate and white. **Chelicerae:** Very dark reddish-brown, patch of dense orange setae in basal half; three retromarginal teeth, with the middle one largest; three



**Figure 6** *Venatrix kosciuskoensis* (McKay, 1974), male (QM S21161 from Falls Creek, Victoria): A, left pedipalp, ventral view; B, left pedipalp, retrolateral view. Female (QM S66444 from Suggan Buggan, Thredbo track, Victoria): C, epigyne, ventral view; D, epigyne, dorsal view. Scale bar: A, B = 1.22 mm; C, D = 1.17 mm.

promarginal teeth, with the middle one largest. *Pedipalp* (Figures 6A–B): Cymbium tip with small claw-like macrosetae; tegular apophysis forms a large triangle with the retrolateral tip bent ventrally. *Abdomen*: Dark brown with a distinct light brown median band; brown-black lanceolate patch in anterior half of longitudinal band; laterally a narrow light band along whole carapace; setae black, except in median and lateral bands where they are white. Venter black, with two white spots in posterior half. Spinnerets brown. *Legs*: Leg formula IV > I > II > III; dorsally brown, ventrally very dark brown; spination of leg I: Femur: 3 dorsal pairs, 2 apicoprolateral; patella: 1 prolateral, 1 retrolateral; tibia: 3 ventral pairs, 1 dorsal, 2 prolateral, 2 retrolateral; metatarsus: 3 ventral pairs, 3 prolateral, 2 retrolateral, 1 apicoventral.

*Measurements*. TL 9.87, CL 5.92, CW 4.23. Eyes: AME 0.23, ALE 0.18, PME 0.45, PLE 0.38. Row of eyes: AE 1.06, PME 1.13, PLE 1.55. Sternum (length/width) 2.26/2.07. Labium (length/width) 0.71/0.77. AL 4.42, AW 3.20. Legs: Lengths of segments (femur + patella/tibia + metatarsus + tarsus = total length): Pedipalp 2.16+2.16+ - +1.60 = 5.92, I 3.67+4.61+3.20+2.26 = 13.74, II 3.57+4.32+3.01+2.07 = 12.97, III 3.38+3.76+3.20+1.88 = 12.22, IV 4.23+4.79+4.70+2.26 = 15.95.

*Female*. See in McKay (1974b). External and internal genitalia of a female from Suggan Buggan-Thredbo track (QM S66444) are depicted here to illustrate diagnostic features (Figures 6C, D).

*Variation*. A female from Mt Buller, Victoria (QM S66445) lacks the two light ventral spots on the abdomen.

### Remarks

The hitherto unknown male of *V. kosciuskoensis* is described here and although the illustrated specimen was not collected with a female, matching somatic characters, in particular the ventral pattern, and the alpine habitat strongly suggest that the

male described here is conspecific with *V. kosciuskoensis*. Male and female genitalia and colouration, and in particular the presence of claw-like macrosetae on the tip of the cymbium and a tubercle on the outer edge of the fangs in males clearly identify *V. kosciuskoensis* as belonging to the genus *Venatrix*. Consequently, this species is here transferred from the *Lycosa* to *Venatrix*.

The original specific epithet is based on “Mt Kosciusko”, an anglicisation and former spelling of the highest mountain in Australia. The spelling Mt Kościuszko (original Polish spelling of T. Kościuszko after who the mountain was named) was officially adopted only in 1997 by the New South Wales Board of Geographic Names.

### Distribution

New South Wales and Victoria (Figure 7).

*Venatrix magkasalubonga* (Barrion and Litsinger, 1995), comb. nov.  
Figures 8A–D, 9

*Pardosa magkasalubonga* Barrion and Litsinger, 1995: 394–396, figures 235a–h; Platnick 1998: 570.

*Pardosa daniloi* Barrion and Litsinger, 1995: 398–399, fig 237a–h; Platnick 1998: 566. **New synonymy**.

*Pardosa sacayi* Barrion and Litsinger, 1995: 399–402, figures 238a–l; Platnick 1998: 575. **New synonymy**.

*Pardosa hawakana* Barrion and Litsinger, 1995: 402, figures 239a–j; Platnick 1998: 567. **New synonymy**.

### Types

*Holotype* female of *Pardosa magkasalubonga*, Philippines, Luzon Island, Quezon Province, Real, Llavac Village, 14°26'29"N, 121°26'43"E, 4 January 1985, A.T. Barrion, M. Perez (IRRI). Examined.

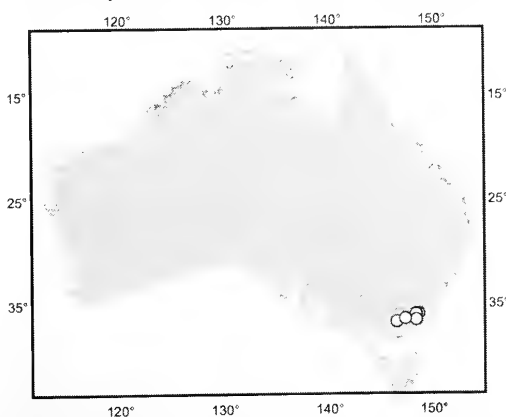
*Paratypes* of *Pardosa magkasalubonga*, 2 males, 1 female, data as holotype (IRRI). Examined.

*Holotype* male of *Pardosa daniloi*, Philippines, Luzon Island, Laguna Province, Siniloan, Magsaysay Village, 14°26'N, 121°29'E, 18 July 1984, A.T. Barrion (IRRI). Not examined.

*Paratype* male of *Pardosa daniloi*, data as holotype, labeled “palp on slide #33” (IRRI). Examined.

*Holotype* male of *Pardosa sacayi*, Philippines, Luzon Island, Cagayan Province, Solana, Iriga Village, 13°25'30"N, 123°25'04"E, 28 July 1980, A.T. Barrion (IRRI). Examined.

*Paratypes* of *Pardosa sacayi*, 2 males, Philippines, Luzon Island, Isabela Province, Alicia, 16°46'41"N 121°42'05"E, 23 October 1981, A.T. Barrion (IRRI). Not examined.



**Figure 7** Records of *Venatrix kosciuskoensis* (McKay 1974).

*Holotype* male of *Pardosa hawakana*, Philippines, Mindanao Island, Agusan del Sur, Claveria, Kalingagan, 8°30'N, 125°50'E, 15 September 1987, A.T. Barrion (IRRI). Examined.

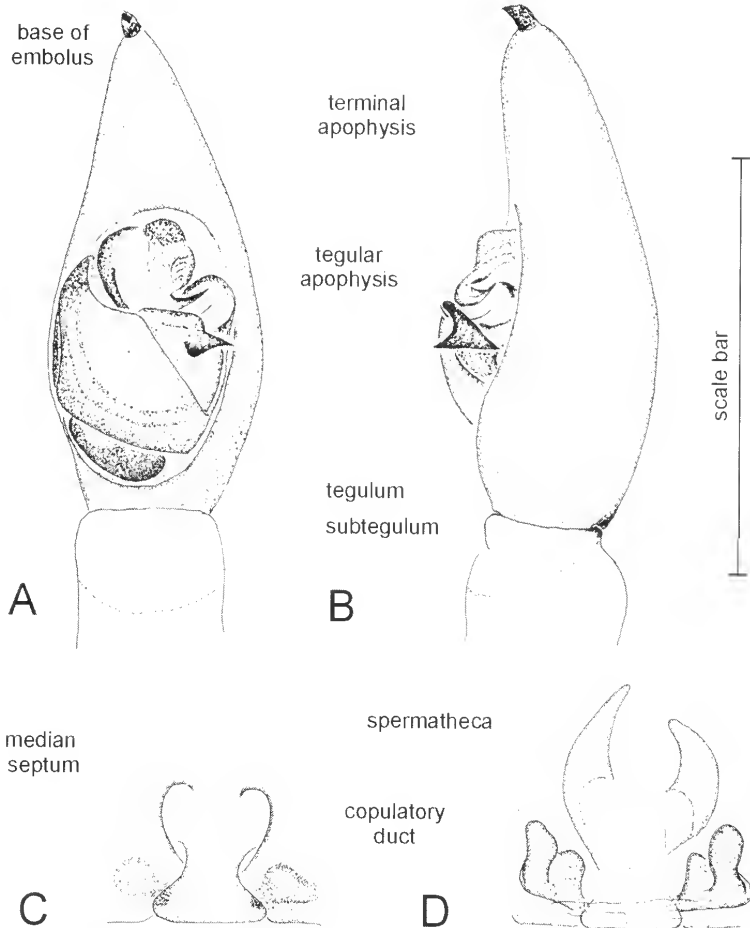
### Diagnosis

*Venatrix magkasalubonga* is very similar and keys out to *V. fuscillata* in the key to the genus *Venatrix* (Framenau and Vink 2001) due to the distinct submarginal bands on the carapace. However, males differ in the shape of the tegular apophysis which is apically notched in *V. fuscillata* but not in *V. magkasalubonga*. The median septum of the female epigyne of *V. magkasalubonga* does not have the distinct median transverse parts that are present in *V. fuscillata*. The species seems to be widespread in rice fields of the Philippines (Figure 9).

### Remarks

The lycosine structure of the male pedipalp (Dondale 1986) in combination with the presence of a tubercle on the outer edge of the fangs in males and a claw-like macroseta on the tip of the cymbium identifies *V. magkasalubonga* as belonging to *Venatrix*. Consequently, this species is here transferred from *Pardosa*. The species was recently described in detail (Barrion and Litsinger 1995) and only the pedipalp of one of the paratype males (Figure 8A–B), the epigyne of the holotype female (Figure 8C) and the internal genitalia of a paratype female (Figure 8D) are depicted here to illustrate diagnostic features.

I could not find any genitalic or somatic characters that separate *Pardosa daniloi* Barrion and Litsinger, 1995, *Pardosa sacayi* Barrion and Litsinger, 1995 and *Pardosa hawakana* Barrion and



**Figure 8** *Venatrix magkasalubonga* (Barrion and Litsinger, 1995), male paratype (IRRI) from Real, Llavac Village, Philippines): A, left pedipalp, ventral view; B, left pedipalp, retrolateral view. Female (IRRI, holotype from Real, Llavac Village, Philippines): C, epigyne, ventral view; female (IRRI, paratype from Real, Llavac Village): D, epigyne, dorsal view. Scale bar: A, B = 0.84 mm; C, D = 0.91 mm.

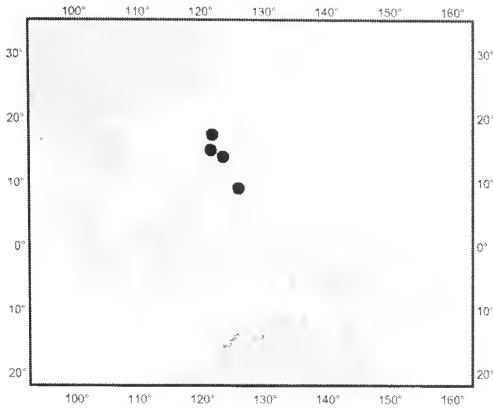


Figure 9 Records of *Venatrix magkasalubonga* (Barrion and Litsinger 1995).

Litsinger, 1995 from *V. magkasalubonga*. The pedipalp structure of all males (pedipalps missing in *P. daniloi*, see below) and the epigynes of all females are identical, and the type material of all specimens shows very similar colouration. Barrion and Litsinger (1995) did not provide diagnostic features to separate the species. Consequently, *P. daniloi*, *P. sacayi* and *P. hawakana* are considered junior synonyms of *V. magkasalubonga*.

The holotype of *V. daniloi* could not be located in the collection of the IRRI, and the microscopic slides containing the pedipalps of the paratype male are missing (G. Jahn, personal communication). However, the tubercles on the outer edge of the fangs and somatic characters such as eye arrangement, carapace shape and colouration clearly match the type material of all other species described by Barrion and Litsinger (1995). In addition, the material examined included non-type females of *V. daniloi* from the type locality, which agree with the females of *V. magkasalubonga*.

***Venatrix ornatula* (L. Koch, 1877) comb. nov.**

*Lycosa ornatula* L. Koch, 1877: 902–903, plate 77, figures 6, 6a–b; Hogg 1900: 76; Rainbow 1911: 270; Bonnet 1957: 2656; McKay 1973: 379; McKay 1985: 81.

*Allocosa ornatula* (L. Koch, 1877); Roewer 1955b: 206; Rack 1961: 38.

*Venatrix forsteri* Framenau and Vink, 2001: 955–956, figures 32a–f, 33. **New synonymy.**

**Types**

*Syntype* female of *Lycosa ornatula*, Australia, Queensland, Rockhampton, 150°30'E, Museum Codeffroy Nr. 14555 (ZMH, Rack (1961) catalog 471). Examined.

*Syntype* female of *Lycosa ornatula*, Australia, Queensland, Bowen, 20°00'S, 148°14'E (BMNH 1919.9.18.712). Examined.

*Holotype* male of *Venatrix forsteri*, Australia, Queensland, Berwah Forestry Reserve, 26°51'S, 152°59'E, 31 October 1990, pitfall trap, M. Glover, heath (QM S45533). Examined.

*Paratypes* of *Venatrix forsteri*, 3 males, 5 females, 10 juv., data as holotype (QM S19146–7, S19151, S19454, S19176, S19178, S19437, S19447). All examined.

**Diagnosis**

*Venatrix ornatula* (as *V. forsteri*) was diagnosed in Framenau and Vink (2001). The species is most similar to *V. brisbanae*, but differs in the carapace colouration. The flanks of the cephalic area and the posterior carapace margin are considerably darker than in *V. brisbanae*. In addition, the tegular apophysis of males of *V. ornatula* only consists of a single part (two distinct parts in *V. brisbanae*) and the median septum of the female epigyne is distinctly wider (Framenau and Vink 2001).

**Remarks**

A recent detailed examination of the type material of *Lycosa ornatula* revealed no differences in somatic and genitalic characters to *Venatrix forsteri* Framenau and Vink, 2001. Consequently, *V. forsteri* is considered a junior synonym of *L. ornatula* and the species is transferred from *Lycosa* to *Venatrix*.

***Venatrix palau* sp. nov.**

Figures 10A–F, 11

**Types**

*Holotype* male, Palau, Kayangel Atoll, 8°03'50"N, 134°42'00"E, 23 May 1973, J. Berry (BPBM).

*Paratypes*: 1 male, data as holotype (WAM T62719); 1 female, data as holotype (BPBM).

**Diagnosis**

*Venatrix palau* is very closely related to *V. amnicola* and *V. arenaris*, but can be distinguished by the different colour pattern. The edges of the median band on the carapace are much smoother and do not form a star-shaped pattern in the anterior half. *Venatrix palau* is also distinctly smaller than *V. amnicola* and *V. arenaris*. In addition, males of all three species can be distinguished by the shape of the terminal apophysis of the pedipalp, which uniquely curves around the tip of the embolus in *V. palau*.

**Etymology**

The species name refers to the type locality of this species, the Palau Islands. It is a noun in apposition.

**Other material examined**

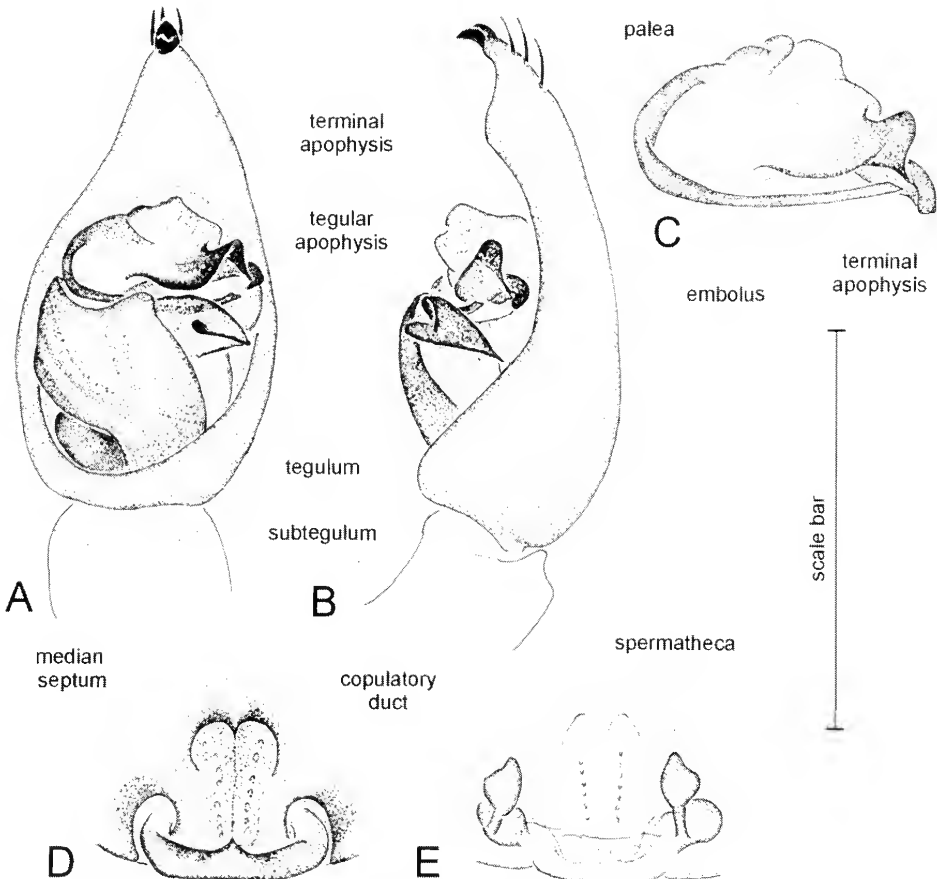
**Australia: Queensland:** 1 male, Aspley Creek,

Andagrove, Mackay, 21°05'S, 149°12'E, 6 July 1983, D.S. Jones, landward salt flat, at margin near land vegetation (WAM T53855); 1 female, Corio Bay, Yeppoon, 23°07'S, 150°44'E, 6 July 1974, P. Davie, edge of salt march at mangrove edge (QM S66814). **Federated States of Micronesia:** 1 female, 1 female with eggsac, Yap, Map Island (Cho'ol), 9°35'25"N, 138°10'12"E, 12 April 1980, E. Berry (BPBM); 1 female, Yap, Wanyan, 9°32'50"N, 138°11'49"E, among short beach grass, 17 April 1980, E. Berry (WAM T62721). **Palau:** 1 female, Kayangel Atoll, 8°03'50"N, 134°42'00"E, May 1973, J.W. Berry, night collecting, coconut forest (BPBM).

### Description

**Male** (based on holotype, BPBM). **Carapace:** Light brown with indistinct brown radial pattern; distinct yellow-brown median band, widening slightly behind PLE and then narrowing towards the posterior end; wide yellow-brown submarginal

bands; carapace mainly covered with white setae, which are particularly dense in the median and submarginal bands; brown setae in darker parts of carapace in posterior half; two brown bristles behind PLE, one long brown bristle between AME, four long brown bristles below AE. **Sternum:** Yellow-brown; brown bristles increasing in length towards margins. **Labium:** Brown, basally darker; front end truncate and white. **Chelicerae:** Light brown; sparsely covered with brown setae; three retromarginal teeth, with the middle one largest and the apical one shortest; three promarginal teeth, with the middle one largest. **Pedipalp** (Figures 10A-C): Terminal apophysis curves around strong and sickle-shaped embolus (Figure 10C). **Abdomen:** Yellow-white with guanine crystals shining through the integument; yellow lanceolate heart-mark; mottled brown patches at anterior border of abdomen, as a pair of large spots in the middle of the abdomen and pairs of smaller spots in posterior



**Figure 10** *Venatrix palau* sp. nov., male (WAM T62719, from Kayangel Atoll, Palau): A, left pedipalp, ventral view; B, left pedipalp, retrolateral view; C, left pedipalp, apical part of bulb. Female (WAM T62721, from Yap, Wanyan, Federated States of Micronesia): D, epigyne, ventral view; E, epigyne, dorsal view. Scale bar: A, B = 0.78 mm; C = 0.53 mm; D, E = 0.75 mm.

half; mainly covered with white setae, except in brown spots where there are brown setae; venter yellow-white (guanine); covered with white and few brown setae; spinnerets yellow-brown. *Legs*: Leg formula IV > I > II > III; light brown; spination of leg I: femur: 3 dorsal, 3 retrolateral, 1 apicoprolateral; patella: 1 prolateral; tibia: 3 ventral pairs, 2 prolateral, 2 retrolateral; metatarsus: 3 ventral pairs, 3 prolateral, 3 retrolateral, 1 apicoventral.

Female (based on paratype, BPBM). *Carapace*: As male, but overall darker and the submarginal bands are narrower and not continuous. *Sternum*: Orange-brown, setae as male. *Labium*: Dark brown, basally darker; front end truncate and white. *Chelicerae*: Reddish-brown, setae as male. *Epigyne* (Figures 10D, E): Ventral view: inverted T-shaped (Figure 10D); dorsal view: spermathecae narrowing anteriorly, copulatory ducts narrow and straight, connecting posteriorly to spermathecae (Figure 10E). *Abdomen*: As male, but generally darker (no guanine) and more brown patches; venter orange-brown, setae as male; spinnerets orange-brown. *Legs*: Leg formula IV > I > II > III; light brown, femora III and IV with indistinct grey annulations, which are most distinct laterally; spination of leg I: Femur: 3 dorsal, 1 apicoprolateral; tibia: 3 ventral pairs, 2 prolateral; metatarsus: 3 ventral pairs, 1 apicoprolateral, 1 apicoventral.

*Measurements*. Male holotype, BPBM (female paratype, BPBM): TL 4.98 (6.11), CL 2.82 (2.91), CW 2.07 (1.88). Eyes: AME 0.16 (0.13), ALE 0.09 (0.10), PME 0.27 (0.27), PLE 0.22 (0.21). Row of eyes: AE 0.57 (0.64), PME 0.63 (0.65), PLE 0.82 (0.82). Sternum (length/width) 1.41/1.08 (1.32/1.13). Labium (length/width) 0.28/0.35 (0.32/0.38). AL 2.26 (3.01), AW 1.50 (2.26). *Legs*: Lengths of segments (femur + patella/tibia + metatarsus + tarsus = total length): Pedipalp 0.94+1.03+ - +0.95 = 2.92, I 2.07+2.44+1.69+1.18 = 7.38, II 1.97+2.26+1.55+1.13 =

6.91, III 1.88+1.97+1.69+0.94 = 6.48, IV 2.44+2.82+2.54+1.27 = 9.07 (Pedipalp 1.03+1.03+ +0.75 = 2.81, I 1.88+2.16+1.32+0.95 = 6.31, II 1.69+2.07+1.27+0.94 = 5.97, III 1.65+1.88+1.50+0.85 = 5.88, IV 2.21+2.63+2.44+1.13 = 8.41).

*Variation*. Males (females) (range, mean  $\pm$  s.d.): TL 4.23 – 4.98, 4.67  $\pm$  0.39; CL 2.44 – 2.85, 2.70  $\pm$  0.23; CW 1.69 – 2.25, 1.94  $\pm$  0.28; n = 3 (TL 5.81 – 7.14, 6.39  $\pm$  0.66; CL 2.91 – 3.48, 3.12  $\pm$  0.25; CW 1.88 – 2.44, 2.18  $\pm$  0.22; n = 5). In contrast to the paratype female described above, most other females also show distinct guanine crystals shining through the integument of the abdomen.

### Life history and habitat preferences

This species has only been found sandy habitats, in particular beaches. In Australian it appears to be winter-mature as adults have been found in July. In contrast, spiders from the Pacific were collected in April and May.

### Distribution

Queensland, Federated States of Micronesia, and Palau (Figure 11).

### *Venatrix pullastra* (Simon, 1909)

*Lycosa pullastra* Simon, 1909: 184–185, figure 2; Rainbow 1911: 272; Bonnet 1957: 2660; McKay 1973: 379; McKay 1974a: 6–12, figures 2a–p; McKay 1985: 82; Platnick 1993: 488.

*Lycosa marcentior* Simon, 1909: 185, figure 3; Rainbow 1911: 270; Bonnet 1957: 2652; McKay 1973: 379; McKay 1985: 80; Platnick 1989: 372; Moritz 1992: 319; Platnick 1993: 488. **New synonymy.**

*Lycosa segregis* Simon, 1909: 186, figure 4; Rainbow 1911: 272; Bonnet 1957: 2663; McKay 1973: 379; Moritz 1992: 325.

*Lycosa propitia* Simon, 1909: 186, figure 5; Rainbow 1911: 271; Bonnet 1957: 2659; McKay 1973: 379; McKay 1985: 81; Moritz 1992: 323. **New synonymy.**

*Lycosa percauta* Simon, 1909: 187; Rainbow 1911: 271; Bonnet 1957: 2657; McKay 1973: 379; McKay 1985: 81; Moritz 1992: 321. **New synonymy.**

*Allocosa propitia* (Simon, 1909); Roewer 1955b: 206; Rack 1961: 38.

*Allocosa percauta* (Simon, 1909); Roewer 1955b: 206.

*Hogna pullastra* (Simon, 1909); Roewer 1955b: 253.

*Hogna segregis* (Simon, 1909); Roewer 1955b: 253.

*Hogna marcentior* (Simon, 1909); Roewer 1955b: 253.

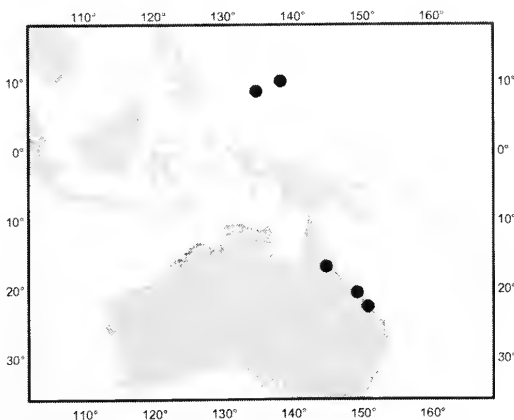


Figure 11 Records of *Venatrix palau* sp. nov.

not *Lycosa marcentior* Simon, 1909 *sensu* McKay 1979b: 263–264, figures 8A–D (misidentification).

*Lycosa pullastra* Simon, 1909; Moritz 1992: 323 (misspelled).

*Venatrix pullastra* (Simon); Framenau and Vink 2001: 962–963, figures 42A–D, 43.

### Types

*Syntype* of *Lycosa pullastra*, female, Australia, Western Australia, Kings River, 9 mi N of Albany, 34°52'S, 117°53'E, 'Hamburger südwest-australische Forschungsreise' Station 164, 17 October 1905, mountainous forest with swamp (ZMB 11099). Examined.

*Syntypes* of *Lycosa pullastra*, 1 male, 1 female, labeled 'Austr. occid. (Michaelsen)', most likely (see remarks below): Australia, Western Australia, Mundaring Weir, 30°04'S, 121°55'E, 'Hamburger südwest-australische Forschungsreise', Station 101, 9 August 1905, mountainous bushland (MHNP 24355). Examined.

*Syntypes* of *Lycosa marcentior*, 1 male, 1 female, labeled 'Swan River (Michaelsen)' (MHNP 24357). Examined.

*Syntype* female (penultimate) of *Lycosa marcentior*, labeled 'Australia occid. (Mich.)' (MHNP 24359). Examined.

*Syntype* female (penultimate) of *Lycosa marcentior*, Australia, Western Australia, Boyanup, 33°29'S, 115°43'E, 'Hamburger südwest-australische Forschungsreise', Station 146, 1/3 August 1905, mountainous forest and cultivated landscape (ZMB 11084). Examined.

*Syntype* immature of *Lycosa marcentior*, Australia, Western Australia, Dongara, 29°15'S, 114°55'E, 'Hamburger südwest-australische Forschungsreise', Station 84, 17 July 1905, dunebush (ZMH, Rack (1961)-catalogue 466). Examined.

*Holotype* female of *Lycosa segregis*, Australia, Western Australia, Fremantle Harbour, 32°03'S, 115°45'E, 'Hamburger südwest-australische Forschungsreise', Station 37, 17 May 2005, on pylons (ZMB 11101). Examined.

*Syntypes* of *Lycosa propitia*, male, penultimate female, labeled 'Austr. occid. (Mich.)', most likely (see remarks below): Australia, Western Australia, Cannington, 32°01'S, 115°56'E, 'Hamburger südwest-australische Forschungsreise', Station 123, 28 June 1905, swamp with lakes (MHNP 24354). Examined.

*Syntype* female (penultimate) of *Lycosa propitia*, Australia, Western Australia, Cannington, 32°01'S, 115°56'E, 'Hamburger südwest-australische Forschungsreise', Station 123, 28 June 1905, swamp with lakes (ZMH, Rack (1961)-catalog 475). Examined.

*Syntype* female (penultimate) of *Lycosa propitia*, Australia, Western Australia, Cannington, 32°01'S,

115°56'E, 'Hamburger südwest-australische Forschungsreise', Station 123, 28 June 1905, swamp with lakes (ZMB 11098). Examined.

*Syntype* immature of *Lycosa propitia*, Australia, Western Australia, Cannington, 32°01'S, 115°56'E, 'Hamburger südwest-australische Forschungsreise', Station 123, swamp with lakes (WAM 11/4302). Examined.

*Holotype* female of *Lycosa percauta*, Australia, Western Australia, Rottneest Island, 31°59'S, 115°32'E, 'Hamburger südwest-australische Forschungsreise', Station 121, 6/13 October 1905, dense bush with dunes (ZMB 11094). Examined.

### Remarks

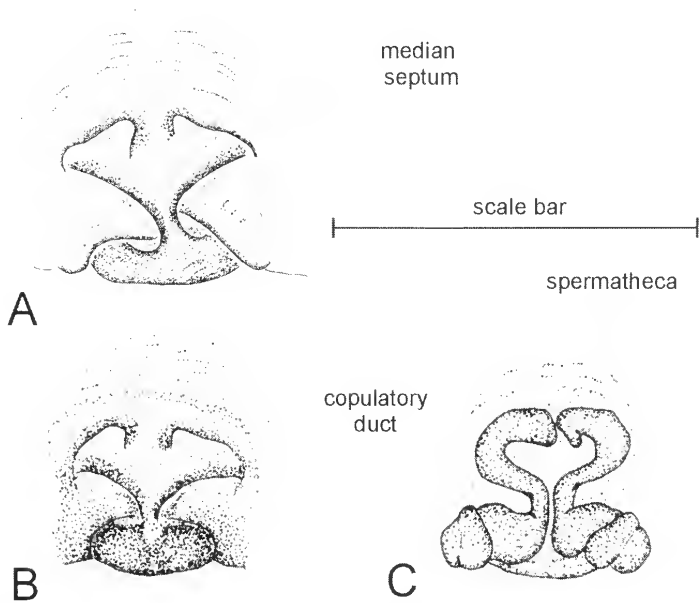
*Venatrix pullastra* was redescribed in detail by McKay (1974a) (herein also synonymised with *Lycosa segregis* Simon, 1909) and Framenau and Vink (2001). Recent examination of the type material of *Lycosa marcentior* Simon, 1909, *Lycosa propitia* Simon, 1909 and *Lycosa percauta* Simon, 1909 revealed no differences in somatic or genitalic characters to *V. pullastra*. Therefore, all three species are here considered junior synonyms of *V. pullastra*.

The type localities of the syntypes of *Lycosa pullastra* Simon, 1909 are Mundaring Weir (Station 101) and Kings River, 9 mi N Albany (Station 164) (Michaelsen and Hartmeyer, 1907; Simon, 1909). Since the syntype in the ZMB is from near Albany, the syntypes in the MHNP, only labeled 'Austr. occid. (Michaelsen)', are almost certainly from Mundaring Weir.

*Lycosa marcentior* Simon, 1909 was based on material from two localities. Dongara (Station 84), ca. 350km north of Perth and Boyanup (Station 146), near Bunbury, ca. 200 km south of Perth (Michaelsen and Hartmeyer, 1907; Simon, 1909). The only mature specimens of *Lycosa marcentior* are a male and female lodged at the MHNP labeled 'Swan River (Michaelsen)' without station number or other locality data. Despite the dubious locality data, I consider these specimens part of the syntype series since there were clearly identified as *L. marcentior* by E. Simon and contain the only mature female of which he illustrated the epigyne (Simon 1909). Consequently, McKay's (1979b) redescription of *L. marcentior*, which is based on a different species collected at the type locality Dongara, is erroneous. Apparently, he did not examine the male and female types of this species lodged in the MHNP.

Similarly, the only mature syntype of *Lycosa propitia* Simon, 1909 is a male (together with a penultimate female) lodged at the MNHP and simply labeled 'Austr. occid. (Mich.)'. Since this species was described only from Cannington (Station 123) (Michaelsen and Hartmeyer 1907; Simon 1909), there is no doubt about the collection data of these specimens. Simon (1909) illustrated





**Figure 12** *Venatrix summa* (McKay, 1974), female holotype (AM KS635, from Mt Kościuszko, New South Wales): A, epigyne, ventral view; female paratype (AM KS 634, from Mt Kosciuszko, New South Wales): B, epigyne, dorsal view. Scale bar: A, B, C = 0.20 mm.

the epigyne of *Lycosa propitia* and it appears that this illustration represents a penultimate female. The immature syntype lodged in the ZMH was mistakenly listed as the holotype by Rack (1961).

***Venatrix summa* (McKay, 1974) comb. nov.**  
 Figures 12A–B, 13

*Lycosa summa* McKay, 1974b: 28–31, figures 1a–c, g–i; Brignoli 1983: 450; McKay 1985: 83–84.

**Types**

*Holotype* female of *Lycosa summa* McKay, 1974, Australia, New South Wales, Mt Kościuszko, 36°27'S, 148°16'E, 7 January 1929, A. Musgrave, H. O. Fletcher (AM KS 635). Examined.

*Paratypes* of *Lycosa summa* McKay, 1974: 5 females, 9 juv., data as holotype (AM KS633-4, KS 636-8). Examined.

**Diagnosis**

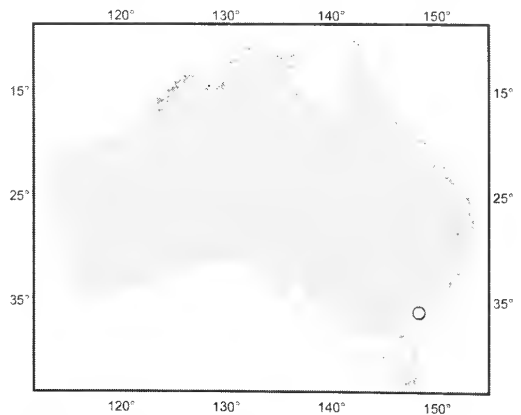
*Venatrix summa* appears to be closely related to *V. kosciuskoensis*, however, females differ in the colouration of carapace and abdomen (McKay 1974b). In addition, the median septum of the female epigyne in *V. summa* widens anteriorly, whereas it is of similar width along its whole length in *V. kosciuskoensis*.

**Remarks**

When McKay (1974b) described both *V.*

*kosciuskoensis* and *V. summa* from alpine New South Wales, he suggested that they may be part of the 'arenaris-group', which contained species that have been subsequently transferred to *Venatrix* (Framenau and Vink 2001). I agree with McKay (1974b), based on the anchor-shaped median septum of the epigyne (Figure 12) and the colour pattern of the abdomen, and transfer this species from *Lycosa* to *Venatrix*. The species is only known from the type locality, Mt Kościuszko (Figure 13). The male is unknown.

This species keys out to *V. roo* Framenau and Vink, 2001 or *V. australiensis* Framenau and Vink, 2001 using the key to the genus *Venatrix* (Framenau



**Figure 13** Records of *Venatrix summa* (McKay 1974).

and Vink 2001). However, *V. summa* differs distinctly in the abdominal pattern, which shows a conspicuous dark lanceolate heart mark in a light median band. This lanceolate heart mark is much less conspicuous in the two other species.

***Venatrix tinfos* sp. nov.**

Figures 14A–F, 15

**Types**

*Holotype* male, Australia, Western Australia, Lake Bryde West Nature Reserve, Lake Bryde Road, 33°21'40"S, 118°48'14"E, 15 October 1999 – 1 February 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site P13 (WAM T61661).

*Paratypes*: 7 males, 3 females, data as holotype (WAM T47210, T47280); 2 females, Australia, west of Scaddan, west of Dalyup Road, 33°23'09"S, 121°34'56"E, 15 October 1999 – 1 November 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site GP8 (WAM T47276).

**Diagnosis**

*Venatrix tinfos* is very similar to *V. fontis* from South Australia with a similar unusual leg formula of  $IV > I > III > II$ , i.e. the third leg is longer than the second leg (all other *Venatrix* have  $IV > I > II > III$ ). The male pedipalps of both species are extremely similar. However, the inner edge of the ventral process (see Figure 14A) of the tegular apophysis forms a right angle with the tegular apophysis in *V. tinfos* when viewed from the tip of the cymbium. This angle is distinctly smaller than 90° in *V. fontis*, i.e. the ventral process appears much more acute. Females can be distinguished by the anchor-shape of the median septum in comparison to the inverted T-shaped median septum of *V. fontis*.

**Etymology**

The specific name is an anagram of *fontis*, as *V. tinfos* is very similar to *V. fontis*.

**Other material examined**

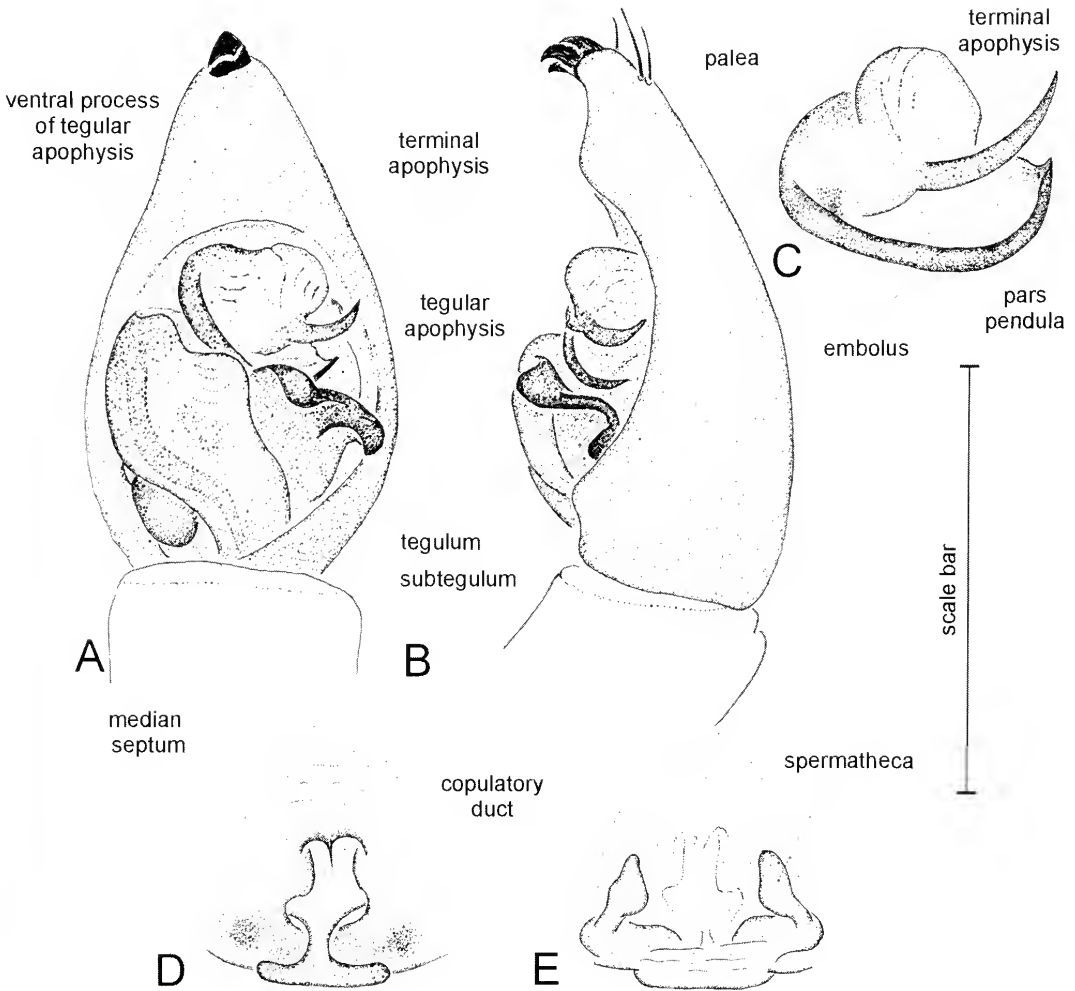
**Australia: Western Australia:** 1 female, Chinocup Reserve, 4 miles E of Pingrup, 33°28'S, 118°26'E, 11 – 17 February 1972, W. H. Butler (WAM 72/331); 1 male, Coolinup Nature Reserve, 33°43'53"S, 122°17'59"E, 15 October 1999 – 2 May and 29 November 2000, wet pitfall trap, P. van Heurck, CALM Salinity Action Plan, site ES12 (WAM T47272); 1 male, Dead Mans Swamp Nature Reserve, 33°30'02"S, 116°57'10"E, 15 October 1999 – 1 November 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site DA7 (WAM T47278); 2 females, Fitzgerald River (no exact location), 11 July 1970, R. Humphries, J. Gilbert, black soil swamp (WAM 71/492-3); 1 female, Lake

Bryde West Nature Reserve, Lake Bryde Road, 33°21'20"S, 118°54'26"E, 15 October 1999 – 1 November 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site PI4 (WAM T47273); 18 males, 5 females, near Lort River, North Rollands Road, 33°12'20"S, 121°18'08"E, 15 October 1999 – 24 May and 26 November 2000, wet pitfall trap, L. King, CALM Salinity Action Plan, site GP7 (WAM T47284); 9 males, 7 females, SW of Scaddan, Speddingup West Road, W of, 33°30'30", 121°28'01"E, 15 October 1999 – 1 November 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site GP10 (WAM T47275, T47283); 1 female, W of Scaddan, N of South Griffiths Road, 33°27'13"S, 121°15'01"E, 15 October 1999 – 1 November 2000, wet pitfall trap, P. van Heurck *et al.*, CALM Salinity Action Plan, site GP11 (WAM T47281)

**Description**

*Male* (based on holotype, WAM T62661). *Carapace*: Brown with darker margins and indistinct darker radial pattern; narrow light brown median band; covered with black setae, but white setae in median band and between PE; black bristles lateral of PE, one long brown bristle between AME, four long brown bristles below AE. *Sternum*: Light brown; brown bristles increasing in length towards margins. *Labium*: Brown; front end truncate and white. *Chelicerae*: Brown; covered with silver-white setae, a few black setae medially; three promarginal teeth with the median one largest, two retromarginal teeth of similar size. *Pedipalp* (Figures 14A–C): Lateral tip of tegular apophysis pointing basally, terminal apophysis and embolus sickle-shaped, pars pendula very broad (Figure 14C). *Abdomen*: Dark olive-grey and covered with black setae; indistinct light median band in which guanine crystals shine through anteriorly and medially; indistinct brown-grey heart mark in anterior half; median band and heart mark covered with silver-grey setae; venter grey-brown, covered with short brown setae; spinnerets brown. *Legs*: Leg formula  $IV > I > III > II$ ; light brown, with indistinct darker annulations; apical segments somewhat darker; spination of leg 1: Femur: 3 dorsal, 3 dorsolateral, 2 apicoprolateral; patella: 1 prolateral, 1 retrolateral; tibia: 3 ventral pairs, 2 prolateral, 2 retrolateral; metatarsus: 3 ventral pairs, 2 prolateral, 1 retrolateral, 1 apicoventral, 1 apicoretrolateral.

*Female* (based on WAM T47276). *Carapace*: As male, some white setae in brown areas. *Sternum*: Light brown, with dark grey pigmentation, setae as male. *Labium*: Dark brown, front end truncate and white. *Chelicerae*: Dark reddish-brown, setae and dentition as male. *Epigyne* (Figures 14D, E): Ventral view: Medium septum inverted anchor-shaped (Figure 14D); dorsal view: short copulatory ducts,



**Figure 14** *Venatrix tinfos* sp. nov., male (WAM T61661 from Lake Bryde West Nature Reserve, Western Australia): A, left pedipalp, ventral view; B, left pedipalp, retrolateral view; C, left pedipalp, apical part of bulbus. Female (WAM T47276 from West of Scadden, Western Australia): D, epigyne, ventral view; E, epigyne, dorsal view. Scale bar: A, B = 1.08 mm; C = 0.40 mm; D, E = 0.91 mm.

elongated spermathecae (Figure 14E). *Abdomen*: Light brown with grey pigmentation, pattern as male but less distinct; venter yellow-brown, short brown setae; spinnerets yellow-brown. *Legs*: Leg formula IV > I > III > II; colouration as male, but annulations very indistinct; spination of leg I: Femur: 2 dorsal, 2 apicoprolateral; tibia: 3 ventral pairs, 1 prolateral (only on left leg); metatarsus: 3 ventral pairs, 1 apicoventral.

*Measurements*. Male holotype, WAM T62661 (female, WAM T47276): TL 8.20 (8.84), CL 4.32 (4.04), CW 3.29 (2.63). Eyes: AME 0.19 (0.15), ALE 0.12 (0.09), PME 0.87 (0.30), PLE 0.27 (0.25). Row of eyes: AE 0.77 (0.67), PME 0.87 (0.72), PLE 1.16

(1.00). Sternum (length/width) 1.97/1.50 (1.60/1.22). Labium (length/width) 0.64/0.60 (0.56/0.55). AL 3.48 (5.36), AW 2.16 (2.82). Legs: Lengths of segments (femur + patella/tibia + metatarsus + tarsus = total length): Pedipalp 1.77+1.69+ - +1.32 = 4.78, I 3.10+3.95+2.73+1.88 = 11.66, II 2.91+3.67+2.07+1.69 = 10.34, III 2.82+3.29+2.73+1.60 = 10.44, IV 3.57+4.51+3.85+2.07 = 14.00 (Pedipalp 1.22+1.22+ - +0.85 = 3.29, I 2.26+2.91+1.69+1.08 = 7.94, II 2.16+2.73+1.60+1.03 = 7.52, III 2.26+2.54+1.79+1.03 = 7.62, IV 2.73+3.76+3.01+1.32 = 10.82).

*Variation*. Males (females) (range, mean  $\pm$  s.d.): TL 7.50 - 10.20, 8.50  $\pm$  0.86; CL 4.35 - 5.85, 4.88  $\pm$  0.44; CW 3.30 - 4.50, 3.78  $\pm$  0.33; n = 11 (TL 8.70 -

16.65, 11.76 ± 2.66; CL 4.05 – 7.50, 5.39 ± 1.11; CW 3.00 – 6.00, 4.20 ± 1.01; n = 12).

### Life history and habitat preferences

The majority of the specimens of *V. fontis* were collected during a survey of the Western Australian agricultural zone conducted by the Department of Conservation and Land Management (CALM) (e.g., Keighery 2004; Harvey *et al.* 2004). The long opening periods of the pitfall traps do not allow an interpretation of the life cycle of this species. *Venatrix tinfos* was taken in open, moderately moist habitats.

### Remarks

The male of *V. tinfos* keys out to *V. fontis* and the female to *V. pullastra* using the identification key to the species of *Venatrix* in Framenau and Vink (2001). Males can be distinguished using the diagnosis above, whereas females clearly differ in their leg formula.

### Distribution

Southwestern Western Australia (Figure 15).

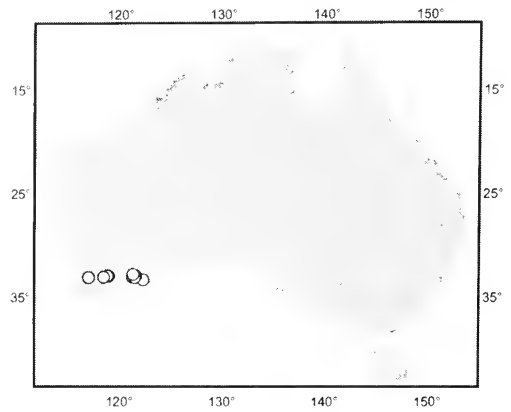


Figure 15 Records of *Venatrix tinfos* sp. nov.

### ACKNOWLEDGEMENTS

I am grateful to the staff of all the museums who provided access to their collections in the form of loans or while visiting their institutions: Graham Milledge and Mike Gray (AM), Bruce Halliday (ANIC), Janet Beccaloni (BMNH), Pascal Leblanc

Table 1 Distribution of all species of the genus *Venatrix*. Species treated in this study are indicated with an asterisk (\*). For abbreviations of Australian states, see 'Methods'.

Species	Distribution
<i>Venatrix allopectiventris</i> Framenau and Vink, 2001	NSW, QLD
* <i>Venatrix amnicola</i> sp. nov.	NSW, QLD, VIC (Figure 3)
* <i>Venatrix archookoorra</i> Framenau and Vink, 2001	QLD (Figure 5)
<i>Venatrix arenaris</i> (Hogg, 1905)	NSW, NT, QLD, SA, WA
<i>Venatrix australiensis</i> Framenau and Vink, 2001	NSW, QLD
* <i>Venatrix brisbanae</i> (L. Koch, 1878)	NSW, QLD
<i>Venatrix esposita</i> Framenau and Vink, 2001	NSW <sup>1</sup> , SA, TAS, VIC, NT <sup>2</sup>
<i>Venatrix fontis</i> Framenau and Vink, 2001	NSW <sup>1</sup> , SA, VIC
<i>Venatrix funesta</i> (C. L. Koch, 1847)	ACT, NSW, SA, TAS, VIC
* <i>Venatrix furcillata</i> (L. Koch, 1867)	NSW, QLD, TAS <sup>1</sup> , VIC
<i>Venatrix hickmani</i> Framenau and Vink, 2001	NSW, QLD
* <i>Venatrix konei</i> (Berland, 1924)	NSW, NT, QLD, SA, VIC, WA, New Caledonia <sup>1</sup> , New Zealand
<i>Venatrix koori</i> Framenau and Vink, 2001	VIC
* <i>Venatrix kosciuskoensis</i> (McKay, 1974)	NSW, VIC (Figure 7)
<i>Venatrix lapidosa</i> (McKay, 1974)	NSW, QLD, VIC
* <i>Venatrix magkasalubonga</i> (Barrion and Litsinger, 1995)	Philippines (Figure 9)
<i>Venatrix mckayi</i> Framenau and Vink, 2001	ACT, NSW, VIC
* <i>Venatrix ornatula</i> (L. Koch, 1877)	NSW, QLD
* <i>Venatrix palau</i> sp. nov.	QLD, Micronesia, Palau (Figure 11)
<i>Venatrix penola</i> Framenau and Vink, 2001	SA, VIC <sup>1</sup>
<i>Venatrix pictiventris</i> (L. Koch, 1877)	ACT, NSW, QLD, SA, TAS, VIC
<i>Venatrix pseudospeciosa</i> Framenau and Vink, 2001	ACT, NSW, SA, TAS, VIC
* <i>Venatrix pullastra</i> (Simon, 1909)	WA
<i>Venatrix roo</i> Framenau and Vink, 2001	SA
<i>Venatrix speciosa</i> (L. Koch, 1877)	ACT, NSW, QLD, SA, VIC
* <i>Venatrix summa</i> (McKay, 1974)	NSW (Figure 13)
* <i>Venatrix tinfos</i> sp. nov.	WA (Figure 15)

<sup>1</sup> Range extension on state or country level in comparison to Framenau and Vink (2001)

<sup>2</sup> Single, record outside the normal range of the species.

(MNHT), Ken Walker, Peter Lillywhite and Richard Marchant (MV), Owen Seeman and Robert Raven (QM), David Hirst (SAM), Mark Harvey and Julianne Waldoock (WAM), Jason Dunlop and Shahin Nawai (ZMB), Josie Catindig and Gary Jahn (IRRI), Gavin Dally (NTMAG), and Hieronymus Dastych (ZMH). I am in particular grateful to Tracey Churchill (Darwin) and Barbara Baehr and Robert Raven (Brisbane) for their hospitality during recent visits to the NTMAG and QM and to James W. Berry for sending me his collection of Pacific Island lycosids for systematic studies. Julianne Waldoock, Melissa Thomas, Mark Harvey and Robert Raven provided helpful comments on earlier drafts of this manuscript.

This study forms part of a revision of Australian wolf spiders funded by the Australian Biological Resources Study (ABRS) to M. Harvey (Western Australian Museum) and A. Austin (The University of Adelaide).

#### REFERENCES

- Barrion, A.T. and Litsinger, J.A. (1995). *Riceland Spiders of South and Southeast Asia*. CAB International, Wallingford, pp. 1–736.
- Berland, L. (1924). Araignées de la Nouvelle-Calédonie et des Îles Loyalty. *Nova Caledonia Zoologie* 3: 159–255.
- Berland, L. (1938). Araignées des Nouvelles-Hébrides. *Annales de la Société Entomologique de France* 107: 121–190.
- Bonnet, P. (1957). *Bibliographia Araneorum*, Tome II (3<sup>me</sup> partie: G–M), Doulaoure, Toulouse, pp. 1926–3026.
- Brignoli, P.M. (1983). *A Catalogue of the Araneae described between 1940 and 1981*. Manchester University Press in association with The British Arachnological Society, Butler and Tanner Ltd, Frome and London. 755pp.
- Dondale, C.D. (1986). The subfamilies of wolf spiders (Araneae: Lycosidae). *Actas X Congreso Internacional de Aracnología, Jaca, España* 1: 327–332.
- Framenau, W.W. (1998). Life cycles of *Lycosa lapidosa* McKay, 1974, and *Lycosa arenaris* (Hogg, 1905), two riparian wolf spiders from south-eastern Australia. In P. A. Selden (ed.) *Proceedings of the 17<sup>th</sup> European Colloquium of Arachnology, Edinburgh 1997*. pp. 227–234 Burnhem Beeches, Bucks.
- Framenau, V.W. (2002a). Review of the wolf spider genus *Arteria* Thorell (Araneae: Lycosidae). *Invertebrate Systematics* 16: 209–235.
- Framenau, V.W. (2002b). *Taxonomy, Life History Characteristics, and Ecology of Riparian Wolf Spiders (Araneae, Lycosidae) in the Victorian Alps, South-east Australia*. Ph.D. thesis, The University of Melbourne, 237pp.
- Framenau, V.W. (2005). The wolf spider genus *Arteria* Thorell in Australia: new synonymies and generic transfers (Araneae, Lycosidae). *Records of the Western Australian Museum* 22: 265–292.
- Framenau, V.W. (in press). *Mainosa*, a new genus for the Australian ‘Shuttlecock Wolf Spider’ (Araneae, Lycosidae). *Journal of Arachnology*.
- Framenau, V.W. and C.J. Vink (2001). Revision of the wolf spider genus *Venatrix* Roewer (Araneae: Lycosidae). *Invertebrate Taxonomy* 15: 927–970.
- Framenau, V.W., Manderbach, R. and Baehr, M. (2002). Riparian gravel banks of upland and lowland rivers in Victoria (south-east Australia): arthropod community structure and life-history patterns along a longitudinal gradient. *Australian Journal of Zoology* 50: 103–123.
- Framenau, V.W., Gotch, T.B. and Austin, A.D. (in press). The wolf spiders of artesian springs in arid South Australia, with a revalidation of *Tetra lycosa* (Araneae, Lycosidae). *Journal of Arachnology*.
- Framenau, V.W. and Yoo, J.-C. (in press). Systematics of the new Australian wolf spider genus *Tuberculosa* (Araneae, Lycosidae). *Invertebrate Systematics*.
- Gotch, T.B. 2003. The dispersal, colonization and genetic variation of mound spring lycosids. *Australasian Arachnology* 66: 8–14.
- Harvey, M.S., Waldoock, J.M., Guthrie, N.A., Durrant, B.J. and McKenzie, N.L. (2004). Patterns in the composition of ground-dwelling araneomorph spider communities in the Western Australian wheatbelt. In G. J. Keighery, S. A. Halse, M. S. Harvey and N. L. McKenzie (eds), *A Biodiversity Survey of the Western Australian Agricultural Zone. Records of the Western Australian Museum*, Supplement 67: 257–292.
- Hickman, V.V. (1944). The Simpson Desert Expedition, 1939 – Scientific Reports No. 1, Biology – Scorpions and Spiders. *Transactions of the Royal Society of South Australia* 68: 18–48.
- Hogg, H.R. (1896). Araneidae. In B. Spencer (ed.) *Report of the Horn Expedition to Central Australia. Pt. 2. Zoology*. pp. 309–356. Melville, Mullen and Slade, Melbourne.
- Hogg, H.R. (1900). A contribution to our knowledge of the spiders of Victoria; including some new species and genera. *Proceedings of the Royal Society of Victoria* 8: 67–123.
- Hogg, H.R. (1905). On some South Australian spiders of the family Lycosidae. *Proceedings of the Zoological Society London* 1905: 569–590.
- Keighery, G.J. (2004). State salinity strategy biological survey of the Western Australian wheatbelt: background In G. J. Keighery, S. A. Halse, M. S. Harvey and N. L. McKenzie (eds) *A Biodiversity Survey of the Western Australian Agricultural Zone. Records of the Western Australian Museum, Supplement 67*: 1–6.
- Koch, C.L. (1847). *Die Arachniden. 14. Band. Zeh’sche Buchhandlung, Nürnberg*.
- Koch, L. (1867). Beschreibung neuer Arachniden und Myriapoden. *Verhandlungen der kaiserlich-königlich zoologisch-botanischen Gesellschaft in Wien* 17: 173–250.
- Koch, L. (1876). *Die Arachniden Australiens, nach der Natur beschrieben und abgebildet*. Bauer and Raspe, Nürnberg, pp. 741–888.
- Koch, L. (1877). *Die Arachniden Australiens, nach der Natur beschrieben und abgebildet*. Bauer and Raspe, Nürnberg, pp. 889–968.
- Koch, L. (1878). *Die Arachniden Australiens, nach der*

- Natur beschrieben und abgebildet.* Bauer and Raspe, Nürnberg, pp. 969–1044.
- Latreille P.A. (1804). Tableau méthodique des insectes. *Nouveau Dictionnaire d'Histoire Naturelle Paris* 24, 129–295.
- McKay, R.J. (1973). The wolf spiders of Australia (Araneae: Lycosidae): 1. The *bicolor* group. *Memoirs of the Queensland Museum* 16: 375–398.
- McKay, R.J. (1974a). The wolf spiders of Australia (Araneae: Lycosidae): 2. The *arenaris* group. *Memoirs of the Queensland Museum* 17: 1–19.
- McKay, R.J. (1974b). The wolf spiders of Australia (Araneae: Lycosidae): 4. Three new species from Mount Kosciusko, N.S.W. *Memoirs of the Queensland Museum* 17: 27–36.
- McKay, R.J. (1979a). The wolf spiders of Australia (Araneae: Lycosidae): 11. A new species from Lord Howe Island. *Memoirs of the Queensland Museum* 19: 237–240.
- McKay, R.J. (1979b). The wolf spiders of Australia (Araneae: Lycosidae): 12. Descriptions of some Western Australian species. *Memoirs of the Queensland Museum* 19: 241–275.
- McKay, R.J. (1985). Lycosidae. In D. W. Walton (ed.) *Zoological Catalogue of Australia, Vol. 3. Arachnida, Mygalomorphae, Araneomorphae in Part, Pseudoscorpionida, Amblypygida, Palpigradi*. pp. 73–88. Australian Government Publishing Service, Canberra.
- Michaelsen, W. and Hartmeyer, R. (1907). Reisebericht. In W. Michaelsen and R. Hartmeyer (eds) *Die Fauna Südwest-Australiens. Ergebnisse der Hamburger südwest-australischen Forschungsreise 1905*. pp. 1–116. Gustav Fischer, Jena.
- Moritz, M. (1992). Die Typen der Arachniden-Sammlung des Zoologischen Museums Berlin. X. Araneae: Lycosidae. *Mitteilungen des Zoologischen Museums Berlin* 68: 309–329.
- Murphy, N.P., Framenau, V.W., Donellan, S.C., Harvey, M.S., Park, Y.-C. and Austin, A.D. (in press). Phylogenetic reconstruction of the wolf spiders (Araneae, Lycosidae) using sequences from 12S rRNA, 28S rRNA and NADH1 genes: implications for classification, biogeography and the evolution of web-building behavior. *Molecular Phylogenetics and Evolution*.
- Platnick, N.I. (1989). *Advances in Spider Taxonomy, 1981–1987*. Manchester University Press, Manchester, 673 pp.
- Platnick, N.I. (1993). *Advances in Spider Taxonomy, 1988–1991. With Synonymies and Transfers 1940–1980*. New York Entomological Society in association with the American Museum of Natural History, New York, 846 pp.
- Platnick, N.I. (1998) [imprint date 1997]. *Advances in Spider Taxonomy, 1992–1995. With Redescriptions 1940–1980*. New York Entomological Society in association with the American Museum of Natural History, New York, 976 pp.
- Platnick, N.I. (2005). The World Spider Catalog, Version 5.5 <http://research.amnh.org/entomology/spiders/catalog/INTRO1.html>. American Museum of Natural History.
- Rack, G. (1961). Die Entomologischen Sammlungen des Zoologischen Staatsinstituts und Zoologischen Museums Hamburg, II. Teil Chelicerata II: Araneae. *Mitteilungen des Hamburgischen Zoologischen Museums und Instituts* 59: 1–60.
- Rainbow, W.J. (1911). A census of Australian Araneidae. *Records of the Australian Museum* 9: 107–319.
- Roewer, C.F. (1955a). Die Araneen der Österreichischen Iran-Expedition 1949/50. *Sitzungsberichte der Österreichischen Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Klasse* 164: 751–782.
- Roewer, C.F. (1955b) [imprint date 1954]. *Katalog der Araneae von 1758 bis 1940. Vol. 2a*. pp. 1–923. Institut Royal des Sciences Naturelles de Belgique, Bruxelles.
- Roewer, C.F. (1959). Araneae Lycosiformae II (Lycosidae). *Exploration du Parc National de l'Upemba – Mission GF de Witte* 55: 1–518.
- Roewer, C.F. (1960) [imprint date 1959]. Araneae Lycosiformae II (Lycosidae) (Fortsetzung und Schluss). *Exploration du Parc National de l'Upemba – Mission GF de Witte* 55: 519–1040.
- Simon, E. (1909). Araneae, 2me partie. In W. Michaelsen and R. Hartmeyer (eds) *Die Fauna Südwest-Australiens. Ergebnisse der Hamburger südwest-australischen Forschungsreise 1905*. pp. 155–212. Gustav Fischer, Jena.
- Sundevall, J.C. (1833). *Conspectus Arachnidum*. C. F. Berling, Lund (Sweden), 1–39.
- Thorell, T. (1877). Studi sui Ragni Malési e Papuani. *Annali di Museo Civico di Storia Naturale 'Giacomo Doria', Genova* 10: 341–634.
- Vink, C.J. (2002). *Fauna of New Zealand. Number 44. Lycosidae (Arachnida: Araneae)*. Manaaki Whenua Press, Lincoln (New Zealand), pp. 1–94.
- Zyuzin, A.A. and Logunov, D.V. (2000). New and little-known species of the Lycosidae from Azerbaijan, the Caucasus (Araneae, Lycosidae). *Bulletin of the British arachnological Society* 11: 305–319.

## New species and records of the pseudoscorpion family Menthidae (Pseudoscorpiones)

Mark S. Harvey

Department of Terrestrial Invertebrates, Western Australian Museum,  
Locked Bag 49, Welshpool DC, Western Australia 6986, Australia

---

**Abstract** – New locality records are presented for *Menthus rossi* (Chamberlin), *M. mexicanus* Hoff, *M. californicus* Chamberlin, all from North America, and *Thenmus aigialites* Harvey from Queensland, Australia. A second species of *Thenmus*, *T. augustus* sp. nov., is described from the Kimberley region of Western Australia. The internal female genitalia of *M. californicus* are illustrated.

### INTRODUCTION

The Menthidae is one of the smallest pseudoscorpion families and has a highly disjunct distribution with completely allopatric generic ranges in arid or supra-littoral regions of the world (Harvey and Muchmore 1990). The four species of *Menthus* Chamberlin occur in the deserts of south-western U.S.A. and Mexico; the two species of *Oligomenthus* Beier reside in the deserts of Argentina and Chile; the sole species of *Paramenthus* Beier inhabits the Middle East; and the only species of *Thenmus* Harvey occurs above beaches in north-eastern Australia. Since the revision of the family by Harvey and Muchmore (1990), little has been subsequently published on the group. Harvey (1991b) recorded a species of *Thenmus* from the Kimberley region of northern Western Australia, and Harvey (1992) transferred the family, along with the Olpiidae, into a separate superfamily, the Olpioidea. Muchmore (2001) found that *Atemnus gracilis* Banks from Sonora, Mexico, tentatively placed in the chernetid genus *Lustrochernes* by Beier (1932), was a senior synonym of *M. lindahli* (Chamberlin). Most recently Ceballos (2004) presented a map showing the distribution of the family in Mexico.

The purposes of the present paper are to record additional menthid specimens recently found in museum collections, and to formally describe and name a new species from north-western Australia that was first recognised and listed by Harvey (1991b). The paper also provides distribution maps for each of the named species that were not supplied by Harvey and Muchmore (1990).

The material examined here is lodged in the American Museum of Natural History, New York (AMNH), the California Academy of Sciences, San Francisco (CAS), the University of California, Davis (UCD), and the Western Australian Museum, Perth (WAM). Terminology and mensuration mostly

follows Chamberlin (1931), with the exception of the nomenclature of the pedipalps, legs and with some minor modifications to the terminology of the trichobothria (Harvey and Muchmore 1990; Harvey 1992).

The specimens were studied using one of two techniques. Temporary slide mounts were prepared by immersion of specimens in concentrated lactic acid at room temperature for several days, and mounting them on microscope slides with 10 or 12 mm coverslips supported by small sections of 0.25, 0.35 or 0.50 mm diameter nylon fishing line. After study the specimens were returned to 75% ethanol after rinsing in water with the dissected portions placed in 12 x 3 mm glass genitalia microvials (BioQuip Products, Inc.). Permanent slide mounts were prepared by removing the pedipalps, the chelicera, left leg I and left leg IV from specimens with the use of eye-scissors or small needles and clearing the body overnight with 10% potassium hydroxide at room temperature. The specimens were then washed in several rinses of water and 5% acetic acid (to neutralise the potassium hydroxide), and dehydrated through a graded ethanol series. They were then transferred to Euparal essence overnight at room temperature, prior to mounting in Euparal on microscope slides using 10 or 12 mm coverslips supported by small sections of 0.25, 0.35 or 0.50 mm diameter nylon fishing line. All specimens were studied using an Olympus BH-2 compound microscope and illustrated with the aid of a drawing tube. Measurements were taken at the highest possible magnification using an ocular graticule.

The maps were produced with the computer program ArcView 3.2 after the relevant locality data were stored in an Access database. Coordinates were obtained from various sources, including the GeoNet Names Server (<http://earth-info.nga.mil/gns/html/>) produced by the National Geospatial-

Intelligence Agency. Recently collected specimens were usually provided with GPS coordinates taken at the collecting site.

### Family Menthidae Chamberlin, 1930

#### Genus *Menthus* Chamberlin, 1930

*Menthus* Chamberlin, 1930: 585; Harvey and Muchmore 1990: 944–945; Harvey 1991: 261 (full synonymy).

#### Type Species

*Minniza rossi* Chamberlin, 1923, by original designation.

#### Remarks

Harvey and Muchmore (1990) stated that the genus *Menthus* lacked an unequivocal synapomorphy despite the close geographical and morphological similarities between the four known species. However, it appears that the female genitalia of *Menthus* spp. differ from at least one other menthid genus, *Thenmus*. *Menthus rossi* and *M. californicus* possess a large median cribriform plate covered by widely spaced acetabular plates (Figure 1), whereas *T. aigialites* (Harvey and Muchmore 1990, figure 30) and *T. augustus* (described below) have a relatively small plate. The female genitalia of the remaining species of the family need to be examined to establish how this feature is distributed within the family.

#### *Menthus rossi* (Chamberlin, 1923)

*Minniza rossi* Chamberlin, 1923: 365, plate 1 figure 5, plate 2 figure 11, plate 3 figures 9, 17.

*Menthus rossi* (Chamberlin): Harvey and Muchmore, 1990: 945–948, figures 1–7; Harvey, 1991: 261 (full synonymy); Judson, 1997: 37; Ceballos, 2004: 428.

#### New material examined

**Mexico:** *Chihuahua*: 1 ♂, 1 ♀, 22 miles N. of Parral [27°15'N, 105°40'W], 17 July 1956, V. Roth and W. Gertsch (AMNH, S-3364.1–2, slides); 1 ♂, 1 ♀, same data (AMNH, S-3364, spirit); 1 ♀, same data except 19 July 1956 (AMNH, S-3370, slide); *Baja California*: 1 ♀, Isla Salsipuedes, Gulf of California [28°44'N, 112°59'W], 21 June 1962, R.E. Ryckman, A.E. Ryckman, C.P. Christianson (UCD, slide); 1 ♂, Bahía Concepción [26°39'N, 111°48'W], Playa El Coyote, 25 February 1987, D. Ubick (CAS).

#### Remarks

Chamberlin (1923, 1930) and Harvey and Muchmore (1990) recorded *M. rossi* from numerous localities in the Gulf of California and surrounding

regions in north-western Mexico. The new record presented here from near Parral in the state of Chihuahua represents the first record from an inland location (Figure 8) suggesting that the species may be more widely distributed than current records indicate.

#### *Menthus mexicanus* Hoff, 1945

*Menthus mexicanus* Hoff, 1945: 4–7, figures 6–7; Harvey and Muchmore, 1990: 948–950, figures 8–10; Harvey, 1991: 261; Ceballos, 2004: 428.

#### New Material Examined

**Mexico:** *Oaxaca*: 1 ♂, 5 miles W. of Tequisistlán, 16°25'N, 95°40'W, 1 September 1964, J. and W. Ivie (AMNH, spirit); 5 ♀, 1 tritonymph, 12 miles W. of Tehuantepec, 16°20'N, 95°20'W, 29 April 1963, W.J. Gertsch and W. Ivie (AMNH, spirit); 1 ♀, same data (WAM T63294, spirit); 1 ♂, 1 ♀, 8 miles W. of Tehuantepec, 16°22'N, 95°22'W, 29 August 1966, J. and W. Ivie (AMNH, spirit).

#### Remarks

The new material from Oaxaca listed above fits the previous descriptions of *M. mexicanus* (Hoff 1945; Harvey and Muchmore 1990). This species is known from the states of Guerrero and Oaxaca in southern Mexico (Figure 8; Harvey and Muchmore 1990).

#### *Menthus californicus* Chamberlin, 1930

Figure 1

*Menthus californicus* Chamberlin, 1930: 587; Harvey and Muchmore 1990: 951–953, figures 14–16; Harvey 1991: 261 (full synonymy).

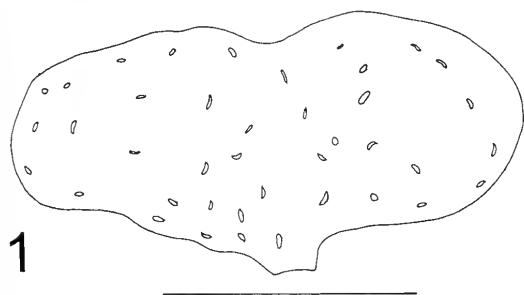
#### New material examined

**U.S.A.:** *California*: 1 ♂, Joshua Tree National Monument [ca. 34°00'N, 116°20'W], pine-creosote bush desert, 27 April 1948, E.V. Gregg (AMNH, spirit). *Nevada:* *Clark County*: 1 ♂, 1 ♀, W. of Snyder Ranch [coordinates not determined], under rocks in gravel wash, 1 April 1953, L.A. Rivers (AMNH, S-2030.1–2, slides); 3 ♂, same data (AMNH, S-2030.3–5, spirit); 3 ♀, W. of Boulder Lake Boat Dock [coordinates not determined], under surface of rocks, 4 April 1953, L.A. Rivers (AMNH, S-2031.1–3, slides); 2 ♂, 3 ♀, near Las Vegas [ca. 36°11'N, 115°08'W], Covillea area, under stone, 2 April 1934, J.C. Chamberlin, E.W. Davis (CAS, JC-1065.01001–5); 1 ♂, Corn Creek Desert Station [36°26'N, 115°22'W], 8 April 1971, S.B. Slightam (CAS).

#### Remarks

*Menthus californicus* has been previously recorded from California and Texas (Harvey and





**Figure 1** *Menthus californicus* Chamberlin, female from W. of Snyder Ranch, Nevada, U.S.A.: median cribriform plate. Scale line = 0.125 mm.

Muchmore 1990). Several newly identified specimens from Nevada slightly extend the known distribution of this species which is widespread across south-western U.S.A. making it the most widely distributed menthid species (Figure 8).

**Genus *Thenmus* Harvey**

*Thenmus* Harvey, in Harvey and Muchmore 1990: 956.

**Type Species**

*Thenmus aigialites* Harvey, in Harvey and Muchmore 1990, by original designation.

**Remarks**

The morphology of *T. augustus* challenges the generic diagnosis proposed by Harvey and Muchmore (1990) for *Thenmus* as it lacks the trichobothrial arrangement of *T. aigialites* in which trichobothrium *d* is adjacent to *ist*; in *T. augustus* trichobothrium *d* is situated adjacent to *c*. However, it possesses three features in common with *T. aigialites* that were noted in the original description of the species, but not highlighted in the generic description. The first feature is that the chelal teeth of both species are reduced to tiny, widely spaced denticles; in all other menthids the chelal teeth are well formed. The second feature is the position of trichobothrium *c*. In species of *Menthus*, *Oligomenthus* and *Paramenthus* this trichobothrium is situated antero-dorsally to trichobothrium *isb*, whereas in *T. aigialites* and *T. augustus* this trichobothrium is situated directly dorsal to *isb*. The third feature is the disposition of trichobothria *sb* and *st*; in *T. aigialites* and *T. augustus* these trichobothria are situated slightly closer to each other than to any other trichobothria, whilst in *Menthus* and *Oligomenthus* trichobothrium *st* is slightly closer to *t*, and in *Paramenthus* trichobothrium *st* is about midway between *t* and *sb*. It seems clear that *T. augustus* is correctly placed in the genus *Thenmus*, and that

further species of this rarely collected genus might be expected in other areas of tropical Australia or even Asia.

The key provided by Harvey and Muchmore (1990) must now be modified. The following generic key will assist in the identification of the four known genera:

1. Arolium twice as long as claws; flagellum of 4 blades ..... 2  
 Arolium approximately same length as claws; flagellum of 3 blades ..... *Paramenthus* Beier
2. Chelal teeth widely spaced and not numerous ..... 3  
 Chelal teeth contiguous and numerous ..... *Menthus* Chamberlin
3. Chelal teeth reduced to tiny denticles; 4 eyes present ..... *Thenmus* Harvey  
 Chelal teeth not reduced to tiny denticles; 2 eyes present ..... *Oligomenthus* Beier

***Thenmus aigialites* Harvey, 1990**

*Thenmus aigialites* Harvey, in Harvey and Muchmore 1990: 956–961, figures 22–39; Harvey 1992: figures 186–194.

**New material examined**

**Australia: Queensland:** 4 ♂, 2 tritonymphs, Shoalwater Bay, 22°19'26"S, 150°11'27"E, 7 August 2001, vine thicket inland of sand dune, Tullgren funnel extraction, J. Haines (WAM T44317).

**Remarks**

The new specimens from Shoalwater Bay were taken from a coastal vine thicket situated somewhat to the south-east of the previously known localities of this species (Harvey and Muchmore 1990).

***Thenmus augustus* sp. nov.**

Figures 2–6

*Thenmus* sp.: Harvey, 1991: 266.

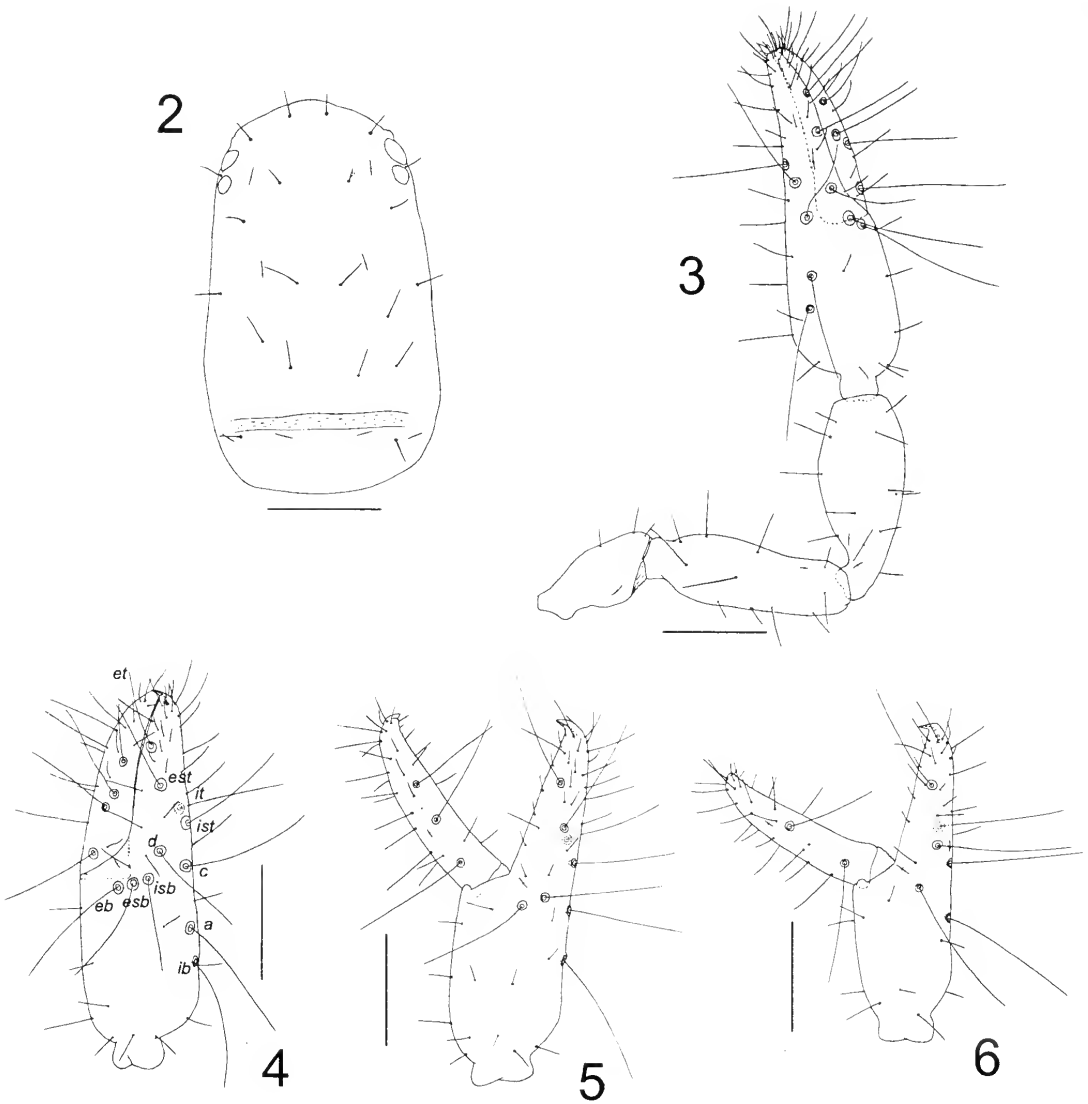
**Material examined**

**Holotype**

**Australia: Western Australia:** ♂, 2.4 km N. of Augustus Point on Augustus Island, 15°24'15"S, 124°38'55"E (CALM site 26/1), 6–11 June 1988, closed forest litter, I.D. Naumann (WAM T63295).

**Paratypes**

**Australia: Western Australia:** 1 ♀, 3.4 km SW. of Manning Creek, Prince Frederick Harbour, 15°00'15"S, 125°21'00"E (CALM site 8/4), 6–11 June 1988, closed forest litter, I.D. Naumann (WAM T63296); 2 tritonymphs, 5.6 km W. of



**Figures 2–6** *Thenmus augustus*, sp. nov.: 2, carapace, paratype female; 3, right pedipalp, dorsal, holotype male; 4, left chela, lateral, holotype male; 5, left chela, paratype tritonymph; 6, left chela, paratype deutonymph. Scale lines = 0.1 mm (Figure 3–6), 0.2 mm (Figure 2).

Evelyn Island, 14°06'55"S, 127°31'10"E (CALM site 10/2), 23–31 January 1989, rainforest litter, collected by Department of Conservation and Land Management staff (WAM T63297); 3 tritonymphs, 1 deutonymph, 25.3 km WSW. of Mt Blythe on Charnley River, 16°22'35"S, 125°12'35"E (CALM site 25/2), 25–31 Jan. 1989, rainforest litter, collected by Department of Conservation and Land Management staff (WAM T63298).

#### Diagnosis

*Thenmus augustus* is significantly smaller than *T. aigialites* [e.g., chela (with pedicel) 0.339 (♂), 0.371 (♀) in length, compared with 0.425–0.45 (♂), 0.46–0.50 (♀) in *T. aigialites*], the carapace bears only 2 setae on the posterior margin, compared with 4 in *T. aigialites*, and trichobothrium *d* is situated adjacent to *c*.

## Description

### Adults

Body long and slender, abdomen not much wider than carapace width. Colour with sclerotized portions generally very pale, pedipalps and anterior portion of carapace red-brown.

*Chelicera*: with 5 setae on hand, all setae acuminate; movable finger with 1 subdistal seta; subterminal tooth of movable finger not bifurcate and not enlarged; galea of ♂ and ♀ deeply bifurcate with 2 long rami; flagellum of 4 aspinose blades; serrula exterior with 16 (♂), 17 (♀) blades; lamina exterior present, very thin.

*Pedipalp* (Figure 3): all pedipalpal segments completely smooth; setae sparse, very long and acicular; trochanter without tubercles; trochanter 2.14 (♂), 2.16 (♀), femur 3.15 (♂), 2.92 (♀), patella 2.43 (♂), 2.34 (♀), chela (with pedicel) 3.29 (♂), 2.99 (♀), chela (without pedicel) 3.15 (♂), 2.81 (♀), hand long and cylindrical, 1.37 (♂), 1.29 (♀) times longer than broad, movable finger 1.33 (♂), 1.22 (♀) times longer than hand. Femur with 2 long tactile seta. Patella with three lyrifissures situated dorsally near pedicel. Fixed chelal finger with 11 trichobothria, movable chelal finger with 4 trichobothria (Figure 4): *eb*, *esb* and *isb* situated in straight line at base of finger; *d* situated slightly in advance of *c*; *it* and *ist* situated submedially; *est* and *et* situated subdistally; *ib* and *a* on dorsal margin of hand; ca. 4 microsetae (chemosensory setae) present on fixed finger distal to *et*; trichobothria of movable finger with *sb* and *st* situated closer to each other than to others; microsetae (chemosensory setae) not present on movable finger. Venom apparatus only present in fixed chelal finger, venom ducts very short, terminating in nodus ramosus almost immediately. Chelal teeth small, widely spaced; fixed finger with ca. 14 (♂) teeth; movable finger with ca. 10 (♂) teeth; accessory teeth absent. Exterior and interior chelal condyles small and rounded.

*Cephalothorax*: Carapace (Figure 2) 1.58 (♂), 1.71 (♀) times longer than broad; sub-rectangular; with 2 pairs of flat, corneate eyes situated near anterior margin of carapace, posterior pair slightly smaller than anterior pair; with 22 (♂), 21 (♀) setae, including 4 near anterior margin and 2 near posterior margin; ♀ with single sub-basal furrow, ♂ without furrow; with 4 pairs of lyrifissures, 1 pair near eyes, 1 pair medially and 2 pairs near posterior margin. Manducatory process with 1 long distal, 1 long sub-distal and very small internal, sub-oral seta; remainder of maxilla with 6 setae. Chaetotaxy of coxae I-IV: 6:5:4:4 (♂), 7:7:5:5 (♀). Coxal area narrow, nearly parallel-sided; junction between coxae II and III with specialised articulation joint typical of family (Chamberlin 1931; Harvey and Muchmore 1990).

*Abdomen*: Pleural membrane longitudinally

striate. Tergites and sternites without medial suture. Tergal chaetotaxy: ♂, 6:6:4:6:6:6:6:6:6:6:6:6:1T1T1T1T1: T1T1T: 2; ♀, 6:6:5:6:6:6:6:6:6:6:6:6:1T1T1T1T1: T1T1T: 2; uniseriate; all setae acicular. Sternal chaetotaxy: ♂, 7: (0)6[1+1](0): (2)4(2): 4:6:6:6:6: T1T2T1T: 1T1T1: 2; ♀, 5: (0)9(0): (2)5(2): 6:6:6:6:6:6: T2T2T2T: 1T1T1: 2; setae uniseriate and acuminate; glandular setae absent; anus not surrounded by sternite XI.

*Genitalia*: Male with no perceptible differences from *T. aigialites*: anterior apodemes small and recurved; lateral apodemes consisting of 2 separate tubes, fused distally and basally; lateral apodemes apparently with anterior arm; dorsal apodemes posteriorly placed; ejaculatory canal atrium large; dorsal anterior gland apparently absent. Female: with paired lateral cribriform plates and single small median cribriform plate; spermathecae absent.

*Legs*: junction between femora and patellae I and II not broad, and is apparently mobile; femur I longer than patella I; femur + patella of 2.72 (♀) times longer than broad; femora I and II with 1 perpendicular lyrifissure situated sub-distally; tibiae III and IV without tactile seta; metatarsi III and IV with moderately long sub-basal tactile seta; subterminal tarsal setae arcuate and acute; arolium much longer than claws, not divided.

### Dimensions (mm)

*Male holotype*: Body length 1.23. Pedipalps: trochanter 0.131/0.061, femur 0.208/0.066, patella 0.202/0.083, chela (with pedicel) 0.339/0.103, chela (without pedicel) 0.324, hand length 0.141, movable finger length 0.187. Carapace 0.320/0.203; anterior eye diameter 0.020, posterior eye diameter 0.013.

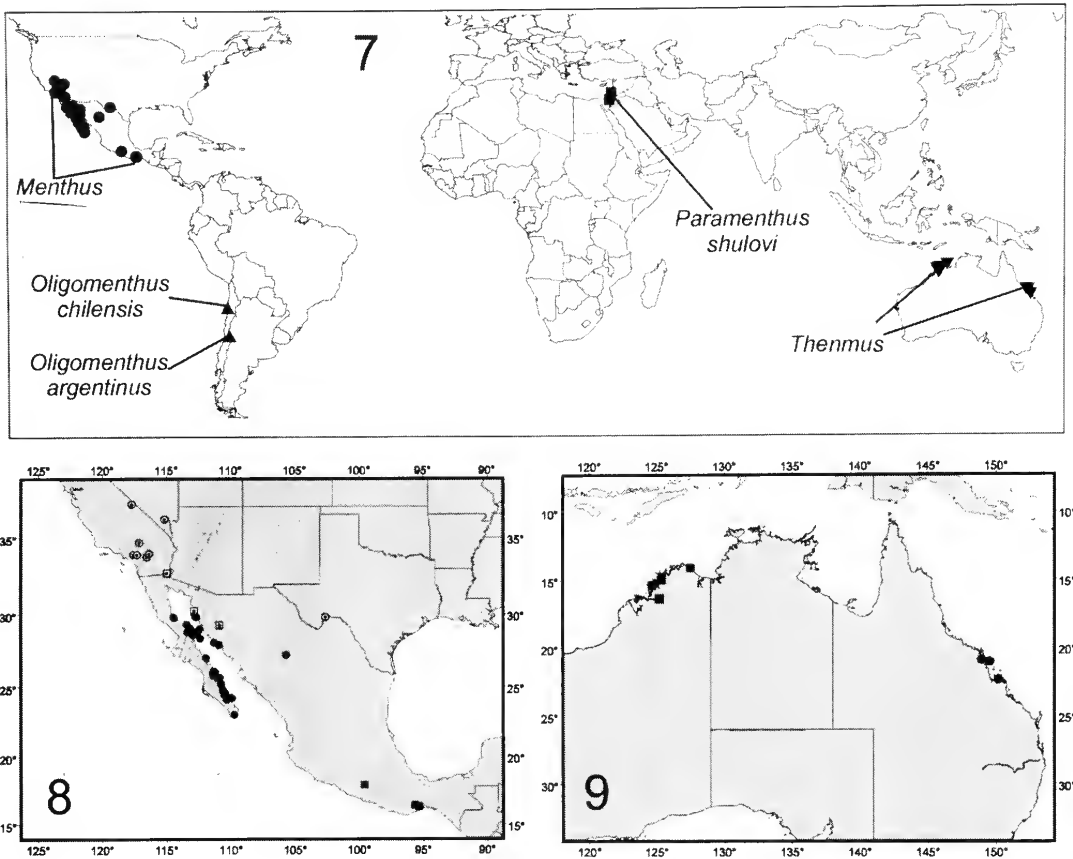
*Female paratype*: Body length 1.57. Pedipalps: trochanter 0.138/0.064, femur 0.216/0.074, patella 0.218/0.093, chela (with pedicel) 0.371/0.124, chela (without pedicel) 0.349, hand length 0.160, movable finger length 0.195. Carapace 0.339/0.198; anterior eye diameter 0.020, posterior eye diameter 0.018. Leg IV: femur + patella 0.234/0.086, tibia 0.160/0.048, metatarsus 0.056/0.029, tarsus 0.077/0.026.

### Tritonymphs

Morphology generally as in adults. Colour with all sclerotized portions generally very pale.

*Chelicera*: with 5 setae on hand, all setae acuminate; movable finger with 1 subdistal seta; galea deeply bifurcate with 2 long rami; flagellum of 4 blades; lamina exterior present, very thin.

*Pedipalp*: all pedipalpal segments completely smooth; setae sparse, very long and acicular; trochanter without tubercles; trochanter 2.16, femur 3.03, patella 2.43, chela (with pedicel) 3.30, chela (without pedicel) 3.04, hand 1.51 times longer than broad, movable finger 1.17 times longer than hand. Femur with 2 long tactile setae. Patella with three lyrifissures situated dorsally near pedicel. Fixed



Figures 7–9 Maps showing recorded distributions of Menthidae: 7, all records; 8, *Menthus rossi* (●), *M. mexicanus* (■), *M. californicus* (⊙) and *M. gracilis* (▣); 9, *Thenmus aigialites* (●) and *T. augustus* (■).

chelar finger with 8 trichobothria, movable chelar finger with 3 trichobothria (Figure 5): *isb*, *c*, *d* and *sb* absent; *eb* and *esb* situated at base of finger; *est*, *it* and *ist* situated submedially; *et* situated sub-distally; *ib* and *a* on dorsal margin of hand. Venom apparatus only present in fixed chelar finger, venom ducts very short, terminating in nodus ramosus almost immediately. Chelar teeth small, widely spaced; fixed finger with ca. 9 teeth; movable finger with 5 teeth, all situated distally.

**Cephalothorax:** carapace 1.49 times longer than broad; sub-rectangular; with 2 pairs of flat, corneate eyes situated near anterior margin of carapace; with 20 setae, including 4 near anterior margin and 4 near posterior margin. Coxal area with junction between coxae II and III with specialised articulation joint typical of family.

**Abdomen:** Pleural membrane longitudinally striate. Tergites and sternites without medial suture. Glandular setae absent; anus not surrounded by sternite XI.

**Legs:** femur I longer than patella I; tibiae III and IV without tactile seta; metatarsi III and IV with moderately long sub-basal tactile seta; metatarsi and tarsi not fused; arolium much longer than claws, not divided.

#### Dimensions (mm)

*Tritonymph paratype* (WAM T63298): Body length 1.28. Pedipalps: trochanter 0.125/0.058, femur 0.200/0.066, patella 0.192/0.079, chela (with pedicel) 0.327/0.099, chela (without pedicel) 0.301, hand length 0.149, movable finger length 0.175. Carapace 0.319/0.214.

#### Deutonymphs

Morphology generally as in adults. Colour with all sclerotized portions generally very pale.

**Chelicera:** with 5 setae on hand, all setae acuminate; movable finger with 1 subdistal seta; galea deeply bifurcate with 2 long rami; flagellum of 4 blades; lamina exterior present, very thin.

**Pedipalp:** all pedipalpal segments completely smooth; setae sparse, very long and acicular; trochanter without tubercles; trochanter 2.02, femur 2.77, patella 2.48, chela (with pedicel) 3.16, chela (without pedicel) 3.03, hand 1.72 times longer than broad, movable finger 1.31 times longer than hand. Femur with 2 long tactile setae. Patella with three lyrifissures situated dorsally near pedicel. Fixed chelal finger with 6 trichobothria, movable chelal finger with 2 trichobothria (Figure 6): *esb*, *isb*, *a*, *c*, *d*, *sb* and *st* absent; *eb* situated at base of finger; *est*, *it* and *ist* situated submedially; *et* situated subdistally; *ib* on dorsal margin of hand. Venom apparatus only present in fixed chelal finger, venom ducts very short, terminating in nodus ramosus almost immediately. Chelal teeth small, widely spaced; fixed finger with 5 teeth; movable finger with 4 teeth, all situated distally.

**Cephalothorax:** carapace 1.30 times longer than broad; sub-rectangular; with 2 pairs of flat, corneate eyes situated near anterior margin of carapace; with 18 setae, including 4 near anterior margin and 2 near posterior margin. Coxal area with junction between coxae II and III with specialised articulation joint typical of family.

**Abdomen:** Pleural membrane longitudinally striate. Tergites and sternites without medial suture. Glandular setae absent; anus not surrounded by sternite XI.

**Legs:** femur I longer than patella I; tibiae III and IV without tactile seta; metatarsi III and IV with moderately long sub-basal tactile seta; metatarsi and tarsi not fused; arolium much longer than claws, not divided.

#### Dimensions (mm)

*Deutonymph paratype* (WAM T63298): Body length 1.13. Pedipalps: trochanter 0.109/0.054, femur 0.166/0.060, patella 0.166/0.067, chela (with pedicel) 0.294/0.093, chela (without pedicel) 0.282, hand length 0.122, movable finger length 0.160. Carapace 0.291/0.224.

#### Remarks

This small species has been found in three localities in the Kimberley region of Western Australia (Figure 9) where it occurs in rainforest litter.

#### Etymology

The specific epithet is a noun in apposition taken from the type locality.

#### ACKNOWLEDGEMENTS

The specimens utilised in this study were kindly provided by Norman McKenzie (Department of

Conservation and Land Management, Perth), Norman Platnick (AMNH), Charles Griswold and Vince Lee (CAS), Steve Heydon (UCD) and Heather Proctor (formerly Griffith University). I am very grateful to two anonymous referees for their constructive comments on the manuscript.

#### REFERENCES

- Beier, M. (1932). Pseudoscorpionidea II. Subord. C. Cheliferinea. *Tierreich* 58: i–xxi, 1–294.
- Ceballos, A. (2004). Pseudoscorpionida. In J.L. Bousquets, J.J. Morrone, O.Y. Ordóñez and I.V. Fernández (eds), *Biodiversidad, taxonomía y biogeografía de Artrópodos de México: hacia una síntesis de su conocimiento*, vol. 4: 417–429. Facultad de Ciencias, UNAM, México, D.F.
- Chamberlin, J.C. (1923). New and little known pseudoscorpions, principally from the islands and adjacent shores of the Gulf of California. *Proceedings of the California Academy of Sciences* (4) 12: 353–387.
- Chamberlin, J.C. (1930). A synoptic classification of the false scorpions or chela-spinners, with a report on a cosmopolitan collection of the same. Part II. The Diplosphyronida (Arachnida-Chelonethida). *Annals and Magazine of Natural History* (10) 5: 1–48, 585–620.
- Chamberlin, J.C. (1931). The arachnid order Chelonethida. *Stanford University Publications, Biological Sciences* 7(1): 1–284.
- Harvey, M.S. (1991a). *Catalogue of the Pseudoscorpionida*. Manchester University Press, Manchester.
- Harvey, M.S. (1991b). The Pseudoscorpionida and Schizomida of the Kimberley rainforests. In N.L. McKenzie, R.B. Johnston and P.G. Kendrick (eds), *Kimberley Rainforests*, pp. 265–268. Surrey Beatty & Sons, Chipping Norton.
- Harvey, M.S. (1992). The phylogeny and systematics of the Pseudoscorpionida (Chelicerata: Arachnida). *Invertebrate Taxonomy* 6: 1373–1435.
- Harvey, M.S. and Muchmore, W.B. (1990). The systematics of the family Menthidae (Pseudoscorpionida). *Invertebrate Taxonomy* 3: 941–964.
- Hoff, C.C. (1945). New neotropical Diplosphyronida (Chelonethida). *American Museum Novitates* 1288: 1–17.
- Judson, M.L.I. (1997). Catalogue of the pseudoscorpion types (Arachnida: Chelonethi) in the Natural History Museum, London. *Occasional Papers on Systematic Entomology* 11: 1–54.
- Muchmore, W.B. (2001). On the identity of *Atemnus gracilis* Banks (Pseudoscorpiones: Menthidae). *Entomological News* 112: 230–231.



# The functional morphology of *Penicillus philippinensis* (Anomalodesmata: Clavagelloidea: Penicillidae) and the evolution of an unique muscular system in the Bivalvia

Brian Morton

Department of Zoology, The Natural History Museum, Cromwell Road, London SW7 5BD, U.K.  
e-mail: prof\_bsmorton@hotmail.com

---

**Abstract** – The Indo-West Pacific watering pot shell *Penicillus philippinensis* (Penicillidae) is essentially amyarian, that is, the posterior adductor and pedal retractor muscles are lost, their anterior equivalents vestigial. In addition to a small group of pallial retractor muscles arising from the pallial line, as is typical of other penicillids, this bivalve is connected to its adventitious tube dorso-laterally by a saddle-shaped array of papillae that prevides the more elaborate system in the southern Australian *Kendrickiana veitchi*. That species and *P. philippinensis* also differ from other penicillids in that their siphons are capable of only limited retraction into the tube. Their extension in both species is largely by hydraulic means, the complex pallial musculature acting antagonistically with extensive blood-filled haemocoels. *P. philippinensis* can also be separated from other penicillids by a number of anatomical characters. For example, some taxa such as *K. veitchi* and *Nipponoclava gigantea* (but not *Foegia novaezelandiae*) have vestigial posterior pedal retractor muscles and associated pericardial proprioceptors but *P. philippinensis* does not. Like other penicillids, however, *P. philippinensis* has a muscular pedal disc whereas *K. veitchi* does not. A trend in the Penicillidae towards even greater specialization for life inside an adventitious tube has arguably culminated in the unique muscular system of *K. veitchi*. *P. philippinensis* indicates how this may have been achieved.

## INTRODUCTION

The Anomalodesmata comprises one sixth of all bivalve families (Harper *et al.* 2000) and these, as currently defined, have been discussed by Morton (2003a) and were last reviewed by Morton (1981, 1985a). Most anomalodesmatans are ‘rare’; most are also aberrant and many are quite bizarre, compared with the generality of Bivalvia. Pojeta and Sohl (1987: 1) referred to the Late Cretaceous *Ascaulocardium armatum* (Morton, 1833) as “the ultimate variation on the bivalve paradigm”. *A. armatum* is a member of the Clavagelloidea, that is, the watering pot shells, which arguably contain the most aberrant of all bivalves and these are currently being examined in some detail by this author to reveal an adaptive radiation not hitherto wholly appreciated (Morton 2002a, b, 2003b, 2004a, b, c).

Representatives of the endobenthic tube-dwelling Clavagelloidea (Penicillidae) are characterised by the loss of the posterior adductor muscle and, sometimes, the anterior, for example, *Kendrickiana veitchi* (Smith, 1971), and either loss or great reduction of the pedal retractor muscles. *Foegia novaezelandiae* (Bruguère, 1789), for example, is amyarian (Morton 2004a). Such a loss of musculature has had powerful implications for the

mode of life of these animals. This is because, in their absence and with shell valves immovably fused horizontally into the fabric of the adventitious tube, all movements of the body with respect to siphonal extension and retraction, in particular, have to be achieved by the hydraulic pumping into and out of the mantle cavity of supernatant and interstitial water by contractions and relaxations of a muscular pedal disc. This structure acts as a pump to generate the necessary internal hydraulic pressures in the mantle cavity (Purchon 1960) that, in turn, exert equivalent pressures within the blood vascular system, that is, in the complex pallial haemocoels (Morton 1984a, 2002a).

Initially, it was thought that water was pumped out of the watering pot and into the sediment to effect either reburial following disinterment or deeper burrowing (Purchon 1960; Savazzi 1999). It is now known that the principal function of the pedal disc is to pump interstitial water *into* the mantle cavity (Morton 2002a, 2004a). There are other adaptations to a tube-dwelling mode of life, notably with regard to the development of unique, paired pericardial proprioceptors that monitor body tonus, possibly either to avoid over-filling of the capacious rectum, as may be the case in

*Brechites vaginiferus* (Lamarck, 1818) (Morton 2002a) or, more generally, to enable the body as a whole to be maintained in a state of ambient tonicity, as in *Kendrickiana veitchi* (Morton, 2004b). Strangely, however, such receptors have hitherto only been identified in epibenthic, cemented clavagelloids, for example, *Humphreyia strangei* (A. Adams, 1852) and *Dianadema multangularis* (Tate, 1887) (Morton 2002b, 2003b), and where they are associated with what are probably the surviving vestiges of posterior pedal retractor muscles. They are absent in the endobenthic *Brechites vaginiferus* and *Foegia novaezelandiae*, where such muscles are vestigial and lost, respectively (Morton, 2002a, 2004a). In *Kendrickiana veitchi* and *Nipponoclava gigantea* Sowerby, 1888, the vestigial posterior pedal retractors form a simple union with the visceral ganglia and possibly function as tonus proprioceptors (Morton 2004b, c).

The watering pot shells of the Clavagelloidea have long been of interest because of their distinctive structure and figure prominently in early malacological texts (Bruguière 1789; Chenu 1843; Reeve 1860) and were similarly objects of great scientific interest in the 19<sup>th</sup> century (Owen 1835; Gray 1847, 1858a; Lacaze-Duthiers 1870, 1883). More recently, a number of clavagelloids have been described in greater detail, for example, species of *Clavagella* (Soliman 1971; Morton 1984b), *Bryopa* (Appukuttan 1974; Savazzi 2000) and *Dianadema* (Morton 2003b) (Clavagellidae), and *Brechites* (Purchon 1956, 1960; Morton 1984a, 2002a), *Humphreyia*, *Foegia*, *Kendrickiana* and *Nipponoclava* (Morton 1984a, 2002b, 2004a, b, c) (Penicillidae). In addition, Harper and Morton (2004) have described how the penicillid adventitious tube is formed and thereby greatly clarified our understanding of how these unusual animals have been able to adopt their distinctive tube-dwelling lives. Recently, intact specimens of a species of *Penicillus* were obtained from the collections of the Museum of Comparative Zoology, The Agassiz Museum, Harvard University, and will be described below.

The anatomy of species of *Penicillus* Bruguière, 1789 have been investigated by Lacaze-Duthiers (1870, 1883), that is, *P.* (as *Aspergillum*) *javanum* Chenu, 1843 (= *P. philippinensis* Bruguière, 1789), *P.* (as *Aspergillum*) *dichotomum* Chenu, 1843 (= *P. penis* [Linnaeus, 1758]) and Purchon (1956, 1960), that is, *P.* (as *Brechites*) *penis*. Such studies were, however, undertaken with no knowledge of the anatomy of any other penicillid genus and thus of the full spectrum of clavagelloid adaptive radiation. Further, the studies were undertaken in the absence of histological information so that important anatomical details remained undescribed. As a consequence, currently published classifications, for example, Smith (1998), place all tube dwelling

anomalodesmatans in one family – the Clavagellidae Orbigny, 1844. It has been demonstrated, however, that the Clavagelloidea comprises two families – the Clavagellidae and Penicillidae Bruguière, 1789 – that show remarkable convergent adaptations to a tube-dwelling life (Morton 2004a, b, c).

This paper provides a description of a representative of one of the last genera (*Penicillus*) to be studied in the light of a better appreciation of the superfamily as a whole, building on the earlier work of Lacaze-Duthiers and Purchon (see above). This study has resulted in a more complete interpretation of the adaptive radiation of the Clavagelloidea, including an understanding of how the unique muscular system of *Kendrickiana veitchi* evolved (Morton 2004b).

## MATERIALS AND METHODS

What follows is a description of two preserved specimens of *Penicillus philippinensis* from the collections of the Agassiz Museum, Harvard University (Reg. No. MCZ 1744) and which were collected by H. Cuming from an unknown locality. One specimen was dissected; the entire second specimen was subjected to routine histological procedures and 6 µm transverse sections of the entire animal were cut. Every tenth section was stained in either Ehrlich's haematoxylin and eosin or Masson's trichrome. In addition, tubes of putative *P. philippinensis* in the collections of the Western Australian Museum were examined and are also reported on herein.

## TAXONOMY

According to Keen and Smith (1969), the type species of the genus *Penicillus* Bruguière, 1789 is *P. javanus* Bruguière, 1789 (= *Serpula penis* Linnaeus, 1758). Smith (1976), in his revision of the extant Clavagelloidea, concluded that *Penicillus* was a subgenus of *Brechites* Guettard, 1770. Keen and Smith (1969) considered this latter genus name to be a nonbinomial synonym of *Penicillus*. Morton (1984a, 2002a), however, considered *Brechites* to be sufficiently different from *Penicillus* to warrant its separation at the generic level. According to Smith (1976) *Penicillus* comprises two species, that is, the type *P. penis*, and *P. philippinensis*. Chenu (1843) and Reeve (1860) illustrated and described a large number of penicillids, many collected by H. Cuming, and which Smith (1976) and Lamprell and Healy (1998) further considered to be synonyms of either *P. philippinensis* or *P. penis*.

Morton (2004c) showed that *Nipponoclava gigantea* and other penicillids, for example, *Foegia novaezelandiae* and *Kendrickiana veitchi* (Morton, 2004a, b), differ from *Penicillus philippinensis* in



terms of adductor and pedal retractor muscle arrangements. The taxonomic arrangement followed herein, therefore, is that the name *Brechites* should be restricted to its type species, that is, *Aspergillum vaginiferum* Lamarck, 1818 and that *Penicillus* (Bruguère, 1789) should be returned to its original, full generic ranking.

#### Identity of the species herein considered

The species herein under investigation is considered to be *Penicillus philippinensis*, as noted above. The two studied specimens were part of a larger lot of 12 preserved individuals held in the collections of the Museum of Comparative Zoology, Harvard University (MCZ). The label of the lot reads only 'Coll. H. Cuming. Ex. J. G. Anthony, 15 Dec. 1863'. It seems possible that the specimens of *P. philippinensis* in MCZ were collected by Cuming and eventually either sold to or exchanged with American shells in the collections of J. G. Anthony.

Cuming made extensive collections in Southeast Asia including the Philippines, Indonesia and Singapore. The holotype of *Penicillus philippinensis* is a specimen collected by Cuming with the type locality as 'Saint Nicolas, Zebu Island, Philippines'. Smith (1976) provides a map of the distribution of *P. philippinensis* and shows it to range throughout the Philippines, the eastern islands of Indonesia and the eastern half of the South China Sea and from southern Western Australia (Rottnest Island) across northern Australia to central Queensland. Smith (1976) also provides a map of the distribution of *P. penis*. It is described therein as ranging from the Arabian Gulf, the east coast of Africa, across the Indian Ocean to the Andaman Sea, West Malaysia, Thailand, the western islands of Indonesia and East Malaysia, and the western half of the South China Sea and Singapore (Purchon 1956, 1960). *Penicillus penis* is not known to occur in Australia and it appears therefore that the distributions of the two species are mainly contiguous except for some overlap only in waters of central Southeast Asia. Moreover, only specimens of *P. penis* have been recorded from Singapore and, therefore, the specimens herein under consideration very probably would have come from either the Philippines or Java, Indonesia (from where they are illustrated, as *P. javanum*, by Dharma [1992, plate 26, fig 19]) and, hence, confirming their identity as *P. philippinensis*.

#### HABITAT NOTES

Apart from the above description of the distribution of *Penicillus philippinensis*, there is little other information on it hitherto available except for details of the Australian and other material reported upon by Smith (1971). He cites specimens from off Pratas Island in the South China

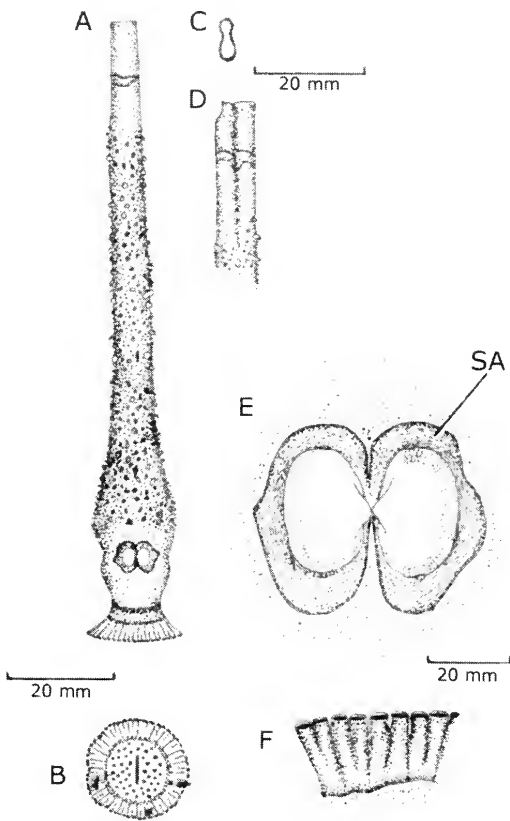
Sea in 88 fathoms (160 m), the southeast coast of Tawi Tawi in 18 fathoms (33 m) and one in the United States National Museum from an unknown location and a depth of 100 fathoms (183 m). In the collections of the Western Australian Museum, Perth (WAM), there are a number of specimens of *P. philippinensis* (as *P. strangulatus* [Chenu, 1843]). These were collected from Onslow/Broome (WAM Reg. No. 194-71), Gunn Point, east of Darwin (WAM Reg. No. S10849), Torres Strait, Queensland (WAM Reg. No. S15949) and Cape York, Queensland (WAM Reg. No. 600-69) and thus fit into the distribution described by Smith (1976). I have collected one empty tube of *P. philippinensis* from an intertidal sand flat at Dampier, northwestern Western Australia (own collection).

## RESULTS

### Anatomy

#### *The adventitious tube*

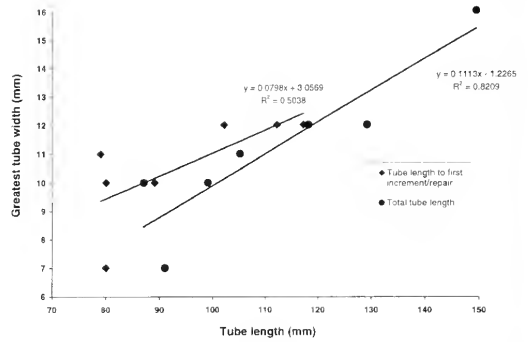
The adventitious tubes of specimens of *Penicillus philippinensis* in the collections of the MCZ, range in length from 66–96 mm and in greatest width from 7–12 mm. Those in the collections of the WAM range in total length from 80–150 mm and in greatest width from 7–16 mm. One such adventitious tube is illustrated in Figure 1. The tube is chalky white with only a light covering of sand and other particles along the central part of its shaft. From the watering pot, the tube tapers posteriorly, except that it bulges anterior to and more strongly posterior from the true shell valves (Figure 1A). This is unlike the situation in the congeneric *P. penis*, that tapers smoothly from anterior to posterior (Smith 1971, 1976, figs 21–25). The posterior bulge in *P. philippinensis* houses the main body of the animal, the anterior one the pedal disc. Anteriorly, there is a circular "watering pot". This is seen from the posterior aspect in Figure 1B. Its rim comprises a continuous radiating flange of fused tubules, some of which branch dichotomously (Figure 1F). The central convex element of the watering pot also possesses tubules and there is a central dorso-ventrally aligned pedal gape. Few sand grains and other debris attach to the anterior region of the tube and watering pot. The shaft of the tube containing the siphons accounts for approximately three-quarters of its total length and it ends posteriorly at an 8-shaped siphonal opening (Figure 1C). The adventitious tube is not covered with sand grains posteriorly, suggesting that it projects above the sediment, and shows signs of either growth or repair. In the illustrated specimen, there are two growth/repair increments located close together in the posteriorly naked element of the tube (Figure 1D). Antero-ventrally, as in *Brechites vaginiferus* (Morton 2002a), there is a



**Figure 1** *Penicillus philippinensis*. The adventitious tube as seen from A, the dorsal; B, the anterior and C, the posterior aspects. D is a more detailed view of the posterior siphonal end showing growth/repair increments. E shows the true shell valves and surrounding saddle (SA) in more detail and F, the tubules of the watering pot rim.

"line" separating tube from watering pot, although Harper and Morton (2004) do not believe this to have any significance in terms of tube manufacture and its provenance remains obscure. Where the covering of sand and other particles is eroded from it (Figure 1A), the chalky nature of the tube is more obvious and is covered in a delicate, light-brown periostracum.

Some of the tubes of *Penicillus philippinensis* in the collections of the WAM have a series of either growth or repair increments, as illustrated in Figures 1A and D. Two of these had breaks and repairs just above the watering pot, but in most individuals these were located posteriorly and ranged in number from one to eight and in such cases it is unclear whether these are repairs or growth increments (or both). It seems likely, however, that the posterior extensions represent



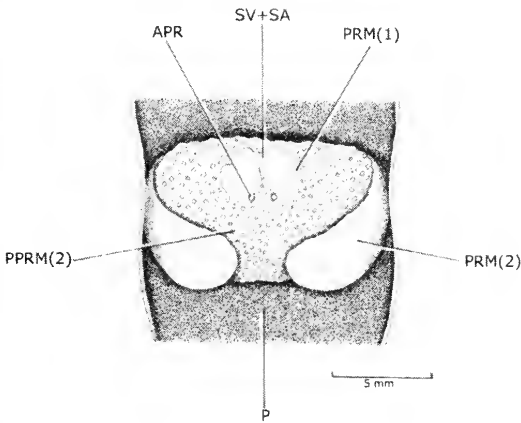
**Figure 2** *Penicillus philippinensis*. The relationships between adventitious tube width and total length (●) and length to the first growth (or repair) increment (◆).

damage and repair events but which, in the longer term, also keep the siphonal apertures above the habitat of accretive sand.

The greatest adventitious tube width plotted against (i), total tube length and (ii), tube length to the first break and repair are illustrated in Figure 2. Both are, albeit weak, straight-line relationships that parallel each other approximately. Thus, (i), there is a positive correlation between tube length and width, (ii), tube repairs (or a growth increment) occur at approximately half the maximum tube length and (iii), there is no positive correlation between break length (or increment addition) and tube width. This suggests, as has been proposed and similarly illustrated for other endobenthic penicillids, for example, *Brechites vaginiferus*, *Foegia novaezelandiae* and *Kendrickiana veitchi* (Morton 2002a, 2004a, b), that the main structure of the tube is probably produced only once, as argued by Harper and Morton (2004), but can be added to posteriorly as either repair or growth increments.

#### The shell valves

Harper and Morton (2004, fig. 3) describe and illustrate the true shell valves of a specimen of *Penicillus pulchrum* (Reeve, 1860, species 13) (= *P. penis*) (Smith 1976). The shell valves of *P. philippinensis* are illustrated in Figure 1A in relation to the adventitious tube and in greater detail in Figure 1E. As in all clavagelloids, except *Nipponoclava gigantea* (Morton 2004c), the valves are about 3.5 mm long and 3.0 mm high and are equivalve and inequilateral, that is, anteriorly foreshortened and posteriorly elongate. There is a light pattern of radial striae and periostracal spinules as first described for *Lyonsia hyalina* Conrad, 1848 by Prezant (1979a, 1981). Similar spicules have been reported upon for some representatives of the Laternulidae (Aller 1974; Carter and Aller 1975), Pholadomyidae,



**Figure 3** *Penicillus philippinensis*. An internal view of the adventitious tube showing the 'saddle' of calcareous material secreted beneath the periostracum and its various muscle impressions. For abbreviations see the Appendix.

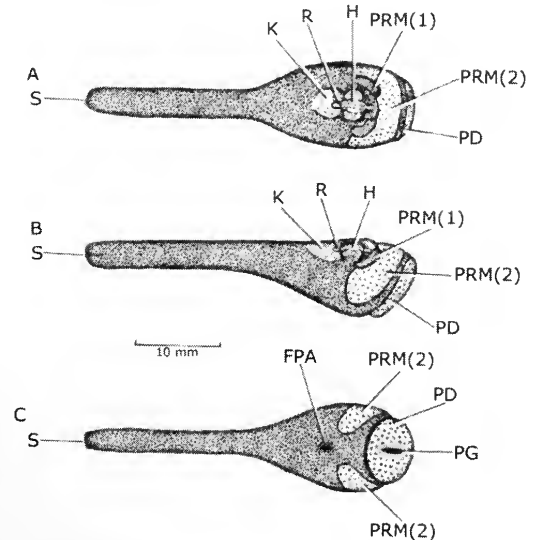
Parilimyidae, Poromyidae, Thraciidae, Verticordiidae and Lyonsiellidae (Morton 1985, 2003a). The shell valves of *P. philippinensis*, indeed of all clavagelloids, however, resemble those of representatives of the Lyonsiidae which Dreyer, Steiner and Harper (2003) have shown genetically to be a sister taxon. Where the outer aragonitic layer has been eroded away, the true shell of *P. philippinensis* is seen to be nacreous, as in all other penicillids so far described (Taylor *et al.* 1973). The two valves are aligned horizontally and surrounded by and united with a "saddle" of shell material that has been secreted subsequently and is characterized by a weak sculpture of irregular concentric growth lines.

As in other penicillids, the shell and saddle of *Penicillus philippinensis* are hidden internally within the fabric of the adventitious tube by a similarly saddle-shaped coating of aragonite secreted by the dorsal surface of the mantle. In *P. philippinensis*, the shell valve and saddle impressions are indistinct (Figure 3) in this internal sheet of secondarily secreted tube material. Similarly, the impressions of the two bean-shaped pallial lines, identifying pallial retractor muscle attachments, and anterior pedal retractor scars are difficult to identify. The internally secreted saddle is, however, distinctly isolated from the remainder of the adventitious tube by the surrounding sheet of periostracum that defines its circumference. Thus, the internal saddle (Figure 1E, SA) is secreted beneath the periostracum and serves the principal function of similar concretions in other penicillids, for example *Brechites vaginiferus* (Morton 2002a), of binding the shell, external saddle and tube

elements into a structurally stronger whole. Unlike these other penicillids, however, dorsally and laterally, just anterior to the position of the true shell and pallial line with pallial retractor muscles, the saddle concretion is lightly dimpled. As will be discussed, this is reminiscent of the internal tube structure of *Kendrickiana veitchi* (Morton 2004b). As noted above, the periostracal sheet that covers the body of the animal, including the siphons and the pedal disc, arises from the circumference of the internal saddle-shaped concretion. Because of the concretion, however, the correspondingly saddle-shaped area of mantle beneath it is not covered in periostracum and, as will be described, is dotted with small papillae.

#### Internal anatomy

The anatomy of an individual of *Penicillus philippinensis* that has been removed from its tube is illustrated in Figure 4. In dorsal view (Figure 4A), the pericardium and its contained organs is the most obvious structure. There is a single ventricle that has paired lateral auricles. The rectum is enclosed by the ventricle of the heart and passes posteriorly over the paired kidneys. Anterior to the pericardium, there is a pair of tiny anterior pedal retractor muscles located on the antero-dorsal edges of the left and right blocks of pallial retractor muscles. Purchon (1956, 1960) did not identify anterior pedal retractor muscles in *P.* (as *Brechites*) *penis*. As in *Brechites vaginiferus*, *Foegia novaezelandiae* (Morton 2002a, 2004a) and *P. penis*



**Figure 4** *Penicillus philippinensis*. Views of an intact individual, as seen from A, the dorsal; B, right lateral and C, ventral aspects. For abbreviations see the Appendix.

(Purchon 1956), however, there are no posterior pedal retractor muscles.

The pericardium of *Penicillus philippinensis* is surrounded, except posteriorly, by the saddle-shaped array of papillae, the tip of each of which is located in the dimples or slight impressions in the surface of the internal calcareous concretion of the adventitious tube above it. These will be described in detail but are also illustrated in right lateral view in Figure 4B, and wherein the pedal disc is also seen to be positioned anterior to the saddle of papillae. The circular pedal disc with its dorso-ventrally aligned pedal gape is seen from the ventral view in Figure 4C. As in *Kendrickiana veitchi* and *Nipponoclava gigantea*, but unlike *B. vaginiferus* and *F. novaezelandiae*, *P. philippinensis* has a fourth pallial aperture located just posterior to the ends of the saddle of papillae. Lacaze-Duthiers (1883) also described *P.* (as *Aspergillum*) *dichotomum* Chenu, 1843 (= *P. philippinensis*) as possessing a fourth pallial aperture, whereas *P.* (as *Brechites*) *penis* does not (Purchon 1956, 1960). The entire body of *P. philippinensis* is covered in periostracum, except for the saddle-shaped area of papillate mantle beneath the overlying calcareous concretion. In Figure 4 also the periostracum has been removed from the pedal disc to show the papillae on its outer surface.

#### The organs of the mantle cavity

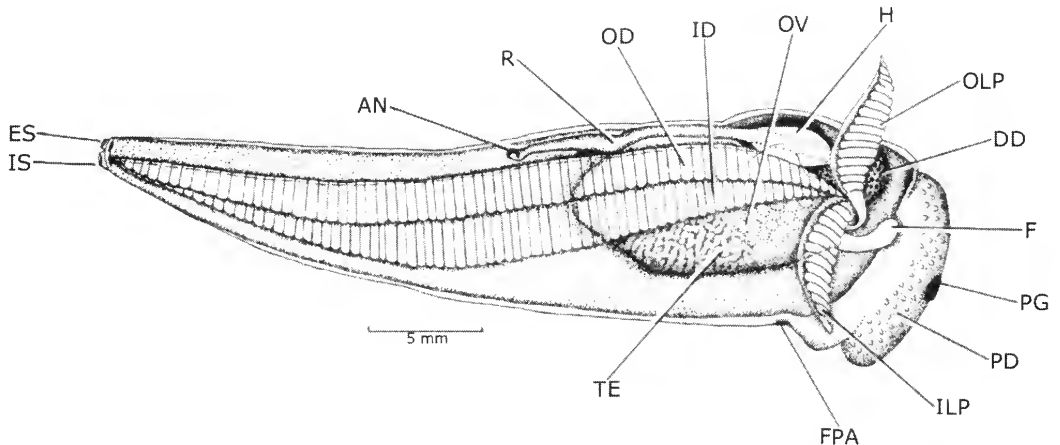
The organs of the mantle cavity of *Penicillus philippinensis* are shown from the right lateral aspect in Figure 5. From the antero-ventral surface of the visceral mass arises a small round-ended foot that is aligned approximately with the gape of the pedal disc. The visceral mass is also pointed posteriorly and contains paired dorsal ovaries and ventral testes. The ctenidia are long, as in *P. penis*

(Purchon 1956), and extend into the apices of the siphons as in *Foegia novaezelandiae* (Morton 2004a). Each ctenidium comprises a complete inner demibranch and the ascending limb only of the outer demibranch. This is typical of all known, non-septibranch anomalodesmatans (Morton 1981, 1985) and is of the Type E of Atkins (1936, 1937a). There are thus ciliary acceptance tracts in the ctenidial axes and in the ventral marginal food grooves of the inner demibranchs. The ctenidia are, however, very short dorso-ventrally and link up anteriorly with relatively large labial palps in a junction described by Stasek (1963) as Category III. All labial palps possess transverse ridges on their inner faces and thus effect sorting of any particles collected and transported to them by the ctenidia. The proximal oral grooves are long and the outer lip of the mouth overarches the inner.

#### The siphons

The siphons of *Penicillus philippinensis* are illustrated from the posterior aspect in Figure 6. The exhalant siphon comprises a simple unornamented cone while the aperture of the inhalant siphon is fringed by eight small papillae. Surrounding the two siphons is a ring of fourteen papillae, eight around the exhalant and six around the inhalant. The periostracum extends up to the apices of the siphonal openings but does not cover them. As in *Nipponoclava gigantea* (Morton 2004c), but unlike other penicillids, including *P. penis* (Purchon 1956, 1960), the siphonal periostracum is not camouflaged by adhering sand grains and other debris.

The siphons are illustrated in transverse section in Figure 7A. The 14 siphonal nerves that connect up with the encircling siphonal papillae are shown, as is the general distribution of the siphon glands that characterise the siphonal apices of most



**Figure 5** *Penicillus philippinensis*. The organs of the mantle cavity, as seen from the right side. For abbreviations see the Appendix.

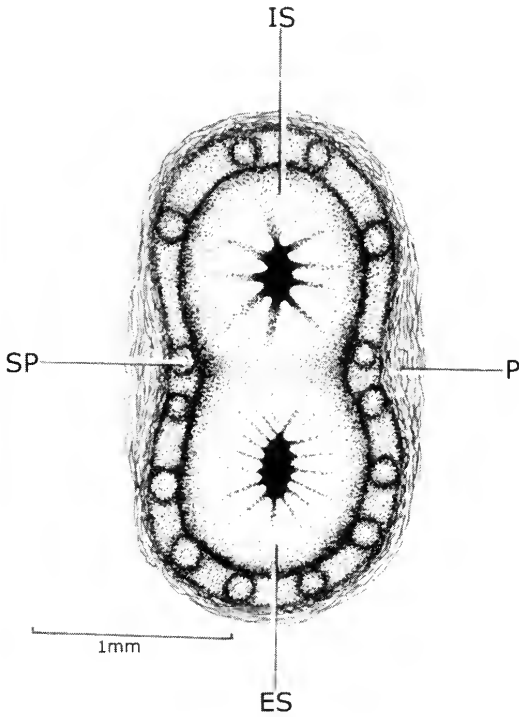


Figure 6 *Penicillus philippinensis*. The siphons as seen from the posterior aspect. For abbreviations see the Appendix.

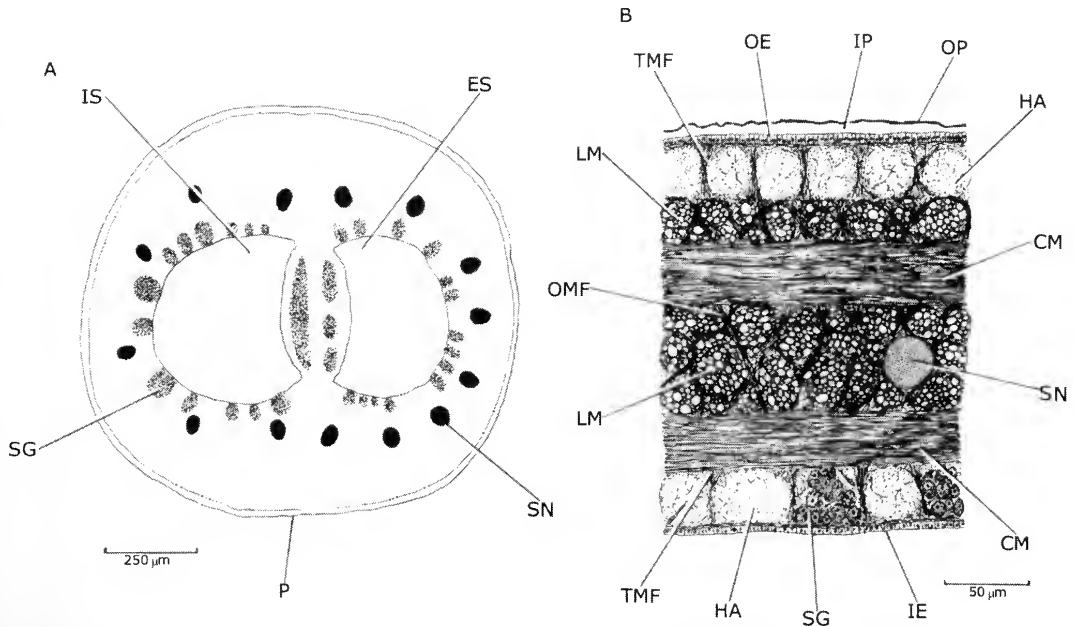
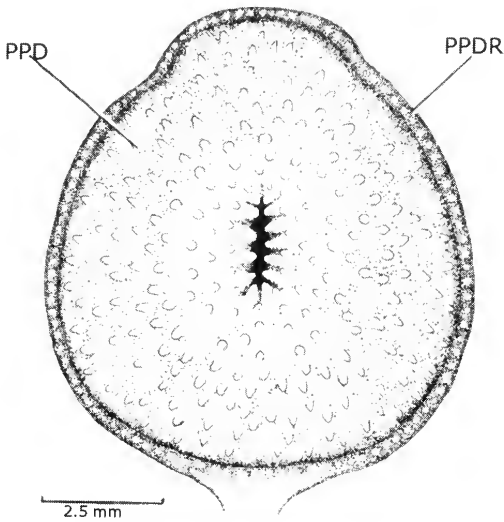


Figure 7 *Penicillus philippinensis*. A, A diagrammatic illustration of a transverse section through the siphons at their tips and B, a detail of a transverse section through the siphonal wall. For abbreviations see the Appendix.

penicillids. Unlike other penicillids, but as in *Nipponoclava gigantea* (Morton 2004c), there are no radial mantle glands in the apices of the siphons. Such glands were first described by Prezant (1979b) for *Lyonsia hyalina* and were believed to produce a sticky secretion binding sand grains and other debris to the siphons and shell to camouflage them. The absence of such glands in both *P. philippinensis* and *Nipponoclava gigantea* (Morton 2004c) probably explains the absence of debris attached to the siphonal periostracum of these species. The siphonal wall is shown in greater detail in Figure 7B. Internal to the inner epithelium is a haemocoelomic area that also contains the red staining (in Masson's trichrome) siphonal glands, illustrated in greater detail for *N. gigantea* (Morton 2004c). The outer epithelium is connected to the body of the siphonal wall by bundles of transverse muscle fibres. Internal to this are twice repeated layers of circular and longitudinal muscles. Beneath the outer epithelium is another haemocoelomic area cross-connected to the internal muscle layers by bundles of transverse fibres. The two layers of longitudinal muscles in the siphonal walls are cross-connected by bundles of oblique muscles. The outer epithelium is covered by periostracum comprising two layers, that is, a thick inner layer which stains blue in Masson's trichrome and is therefore probably mucoid and a thinner (~ 2 μm) outer layer which stains red and is therefore proteinaceous.



**Figure 8** *Penicillus philippinensis*. The pedal disc as seen from the anterior aspect. For abbreviations see the Appendix.

#### The pedal disc

The highly muscular pedal disc of *Penicillus philippinensis* is illustrated from the posterior aspect in Figure 8. The periostracum covering it has been removed to show the epithelium of the disc dotted with small papillae. Similarly, the circumference of the disc is defined by a papillate, raised rim. In the centre of the disc is a dorso-ventrally aligned pedal gape. In *Foegia*

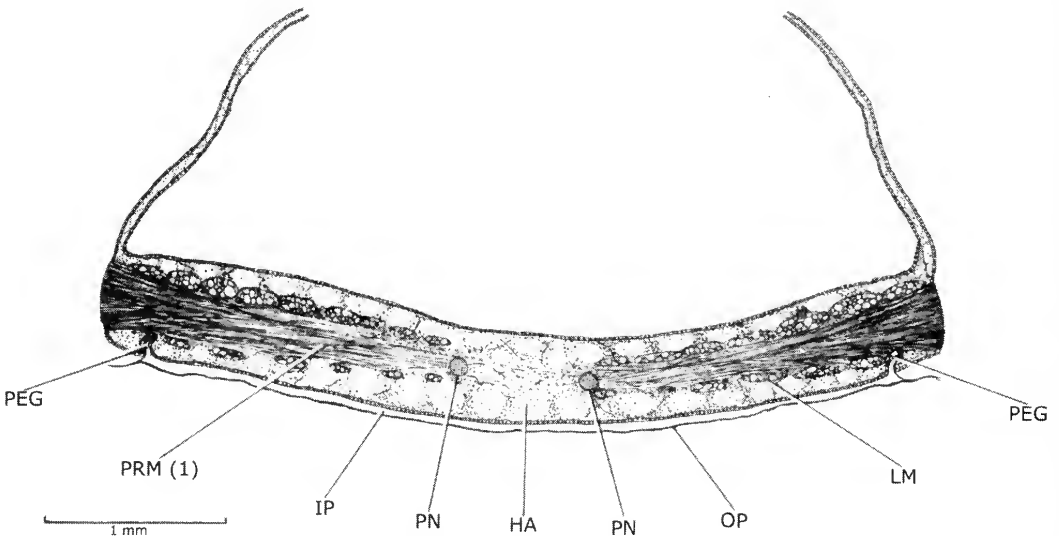
*novaezelandiae*, the periostracum covering the pedal disc is covered in an agglomeration of inorganic and organic debris and rod-shaped bacteria (Morton 2004a): this has not been observed in *P. philippinensis*.

#### The ventral mantle margin

The mid-ventral mantle margin of *Penicillus philippinensis* is illustrated in transverse section in Figure 9. Mantle fusion is extensive and involves inner and middle mantle folds and the inner surfaces only of the outer mantle folds, Type C of Yonge (1982). Virtually the entire surface of the mantle is therefore covered in periostracum. The periostracum arises from left and right periostracal grooves, located just below the point of attachment of the pallial retractor muscles onto the tube. The ventral mantle margin largely comprises a haemocoel but there are additional bundles of longitudinal muscles that will assist in siphonal retraction.

#### The papillate pallial saddle and musculature

The structure of the pallial saddle in *Penicillus philippinensis* is illustrated in dorsal view in Figure 10. It abuts the pallial line and hence its pallial retractor muscles and the dorsal visceral mass posteriorly and the rim of the pedal disc anteriorly. It extends laterally, to the left and right, around the mantle (Figure 4). It is not covered in periostracum and, although covered in small papillae, is transparent enough to identify the fine strands of the vestigial anterior adductor muscle, also identified in *P. penis* (Purchon 1956, 1960). Two



**Figure 9** *Penicillus philippinensis*. A transverse section through the mid-ventral mantle margin. For abbreviations see the Appendix.

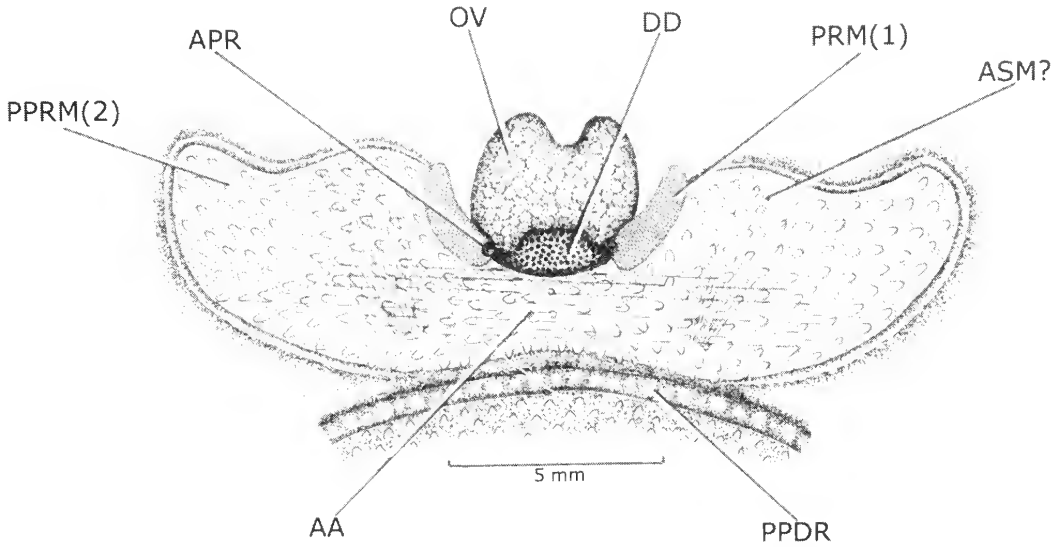


Figure 10 *Penicillus philippinensis*. The true pallial retractor muscles and saddle-shaped array of pallial papillae as seen from the dorsal aspect and somewhat spread out. For abbreviations see the Appendix.

small muscles, herein termed accessory suspensory muscles as they function like those of greater definability seen in *Kendrickiana veitchi* (Morton 2004b), serve to attach the antero-dorsal region of the visceral mass to the adventitious tube. Purchon (1956, 1960) did not identify such muscles in *P. penis*.

The mantle margin of *Penicillus philippinensis* at the pallial saddle is illustrated in transverse section

in Figure 11. As with the mantle margin further posteriorly (Figure 9), mid ventrally there are large haemocoelomic spaces, (fewer) longitudinal muscle fibres and both left and right pallial retractor muscles. However, here, the lateral areas of the mantle are thickened and are traversed from the inner mantle epithelium to the outer by discrete muscle blocks interspersed by haemocoelomic spaces. These must be responsible for contraction of

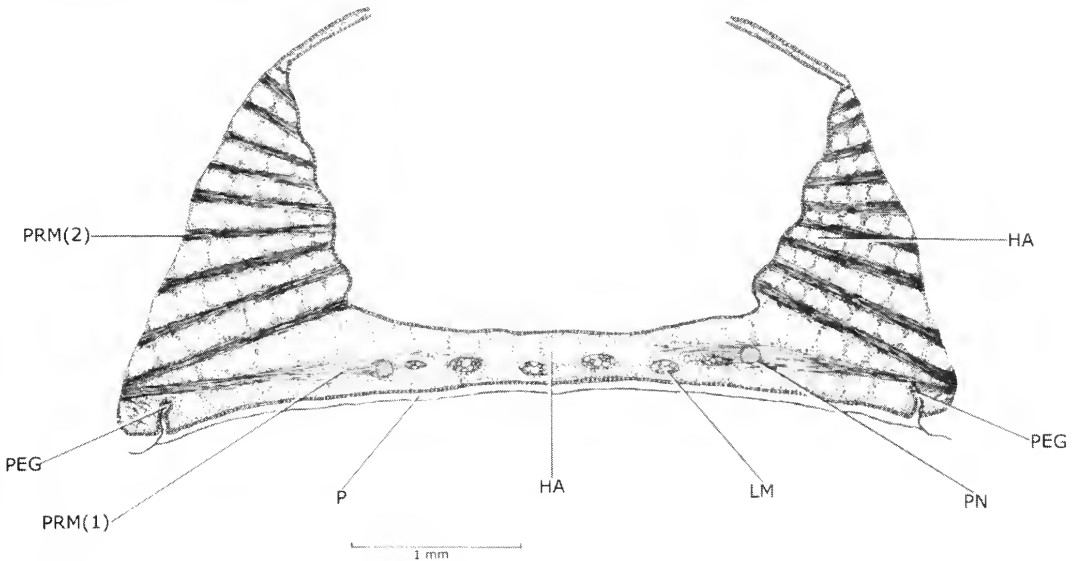
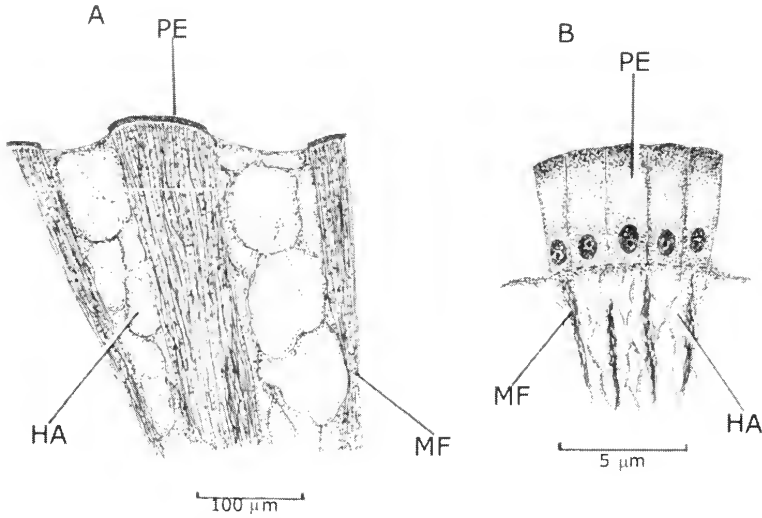


Figure 11 *Penicillus philippinensis*. A transverse section through the antero-ventral mantle margin showing the true pallial retractor muscles and the muscles of the saddle-shaped array of pallial papillae. For abbreviations see the Appendix.



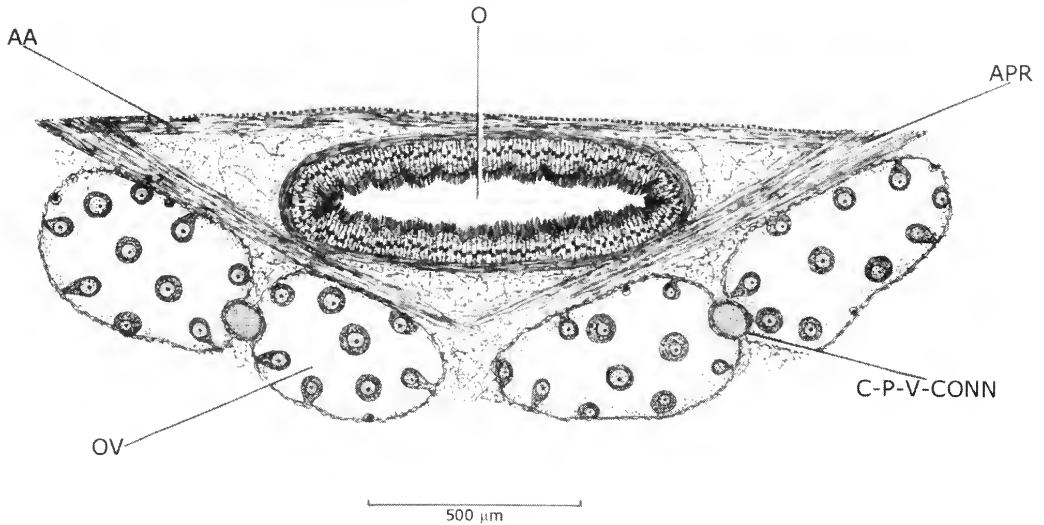
**Figure 12** *Penicillus philippinensis*. Transverse sections through the points of attachment of the papillae of the saddle-shaped array of pallial retractor muscles to the adventitious tube at two different levels of magnification. For abbreviations see the Appendix.

the mantle inwards and upwards, as in *Kendrickiana veitchi* (Morton 2004b).

Points of attachment of the pallial saddle papillae to the calcareous area of the adventitious tube of *Penicillus philippinensis* are shown in greater detail in Figure 12A. Each muscle unit, separated from its neighbours by haemocoelomic spaces, ends in a small swelling, identified as a small papillae, on the outer surface of the saddle. Closer inspection of the attachment point shows that the muscles are not attached directly to the tube but form a union with the basement membrane of a group of epithelial

cells some 5 µm tall (Figure 12B). This is unlike the situation seen in *Kendrickiana veitchi* where the much larger equivalent papillae are attached directly to the tube by papilla muscles (Morton 2004b).

The remnants of the true musculature of *Penicillus philippinensis* are illustrated in Figure 13 in a transverse section through the dorsal visceral mass. Above it is the delicate, vestigial anterior adductor muscle and flanking it are the paired remnants of the anterior pedal retractor muscles. Also seen in Figure 13 are antero-dorsally located



**Figure 13** *Penicillus philippinensis*. A transverse section through the oesophagus also showing the vestigial anterior adductor and pedal retractor muscles. For abbreviations see the Appendix.



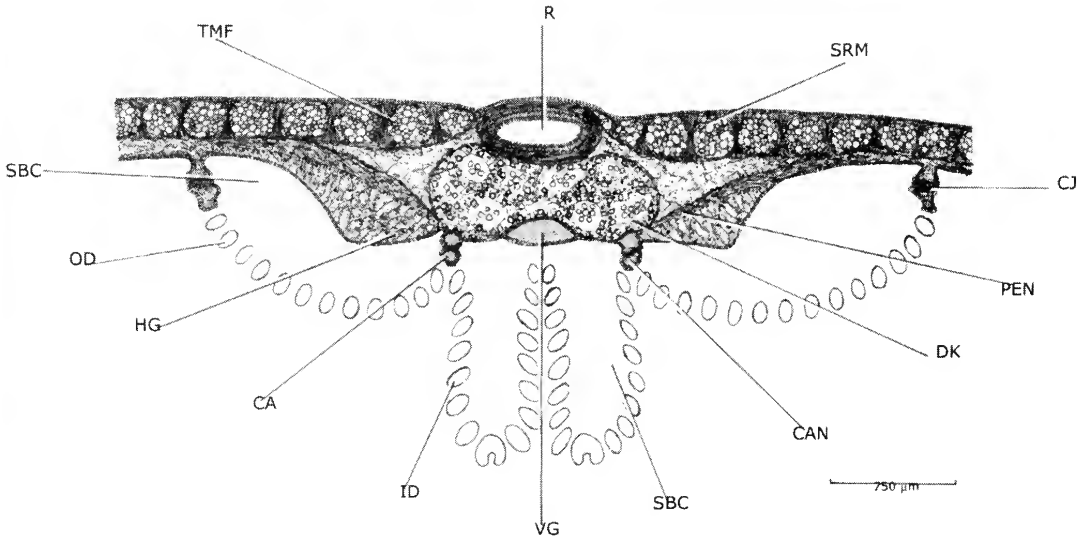


Figure 14 *Penicillus philippinensis*. A transverse section through the rectum, kidneys, hypobranchial glands and visceral ganglia. For abbreviations see the Appendix.

ovaries. The paired testes are located postero-ventrally in the visceral mass.

*The pericardium and kidneys*

The pericardium of *Penicillus philippinensis* is illustrated in right lateral view in Figure 5. The ventricle of the contained heart surrounds the rectum. The auricles lie above the supra-branchial chamber of the outer demibranch. In transverse section (Figure 14), the rectum comprises a simple tube that possesses a thick muscular coat. In the dorsal mantle, to the left and right of the rectum, are the dorsal elements of the longitudinal muscles of the siphonal retractors. Beneath the pericardium are the posterior elements of the kidneys. In this section, only the tubules of the distal limbs are present. The paired kidneys do, however, comprise paired ciliated proximal limbs that open into the supra-branchial chamber at renal apertures. The surrounding distal limbs comprise tubules made up of epithelial cells some 8 μm tall and which are mostly vacuolated. Within some cells and densely occupying the tubule lumina are spherical kidney concretions approximately 10 μm in diameter and which stain blue in Masson's trichrome but have a lighter core.

The supra-branchial chamber of the outer demibranch is lined dorsally by a hypobranchial gland typical of all penicillids and illustrated in detail for *Nipponoclava gigantea* by Morton (2004c). Beneath the posterior edges of the kidneys lie the visceral ganglia with nerves extending into the mantle and tentacular axes. The outer demibranch attaches to the mantle at a cuticular junction like that described by Atkins (1937b).

*The visceral ganglia*

The visceral ganglia of *Penicillus philippinensis* are illustrated from beneath in Figure 15. They lie

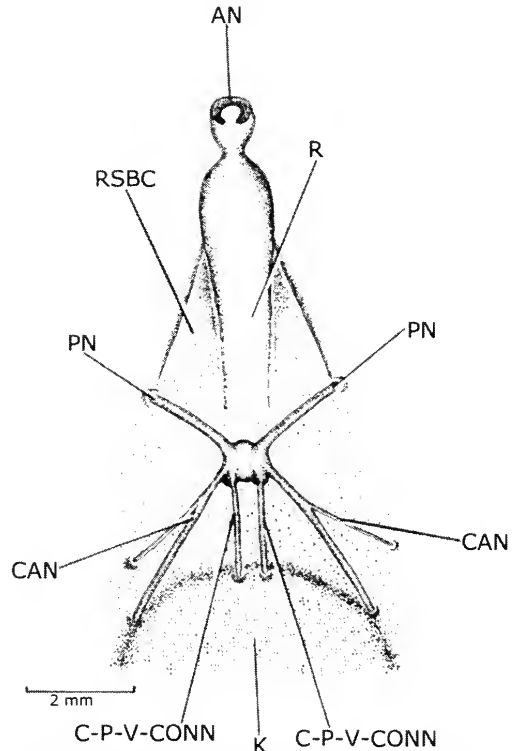


Figure 15 *Penicillus philippinensis*. A ventral view of the visceral ganglia and associated nerves. For abbreviations see the Appendix.

between the kidneys anteriorly and rectum, the latter extending into the supra-branchial chamber posteriorly. The paired ganglia are connected to the cerebro-pleural ganglia anteriorly by cerebro-pleural visceral connectives that pass anteriorly into the kidneys. From the posterior ends of the ganglia arise the posterior pallial nerves that posteriorly divide and extend into the siphons. From the anterior lateral edges of the ganglia arise nerves that divide into two components and make connection with the ctenidia at the ctenidial axes.

*The statocysts*

The statocysts of *Penicillus philippinensis* are located in close proximity to the dorso-lateral edges of the pedal ganglia (Figure 16). But one is

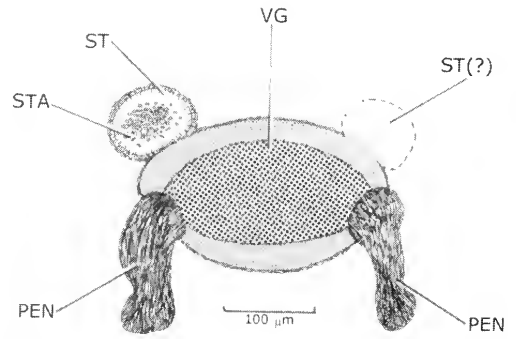


Figure 16 *Penicillus philippinensis*. A transverse section through the right statocyst and pedal ganglia. For abbreviations see the Appendix.

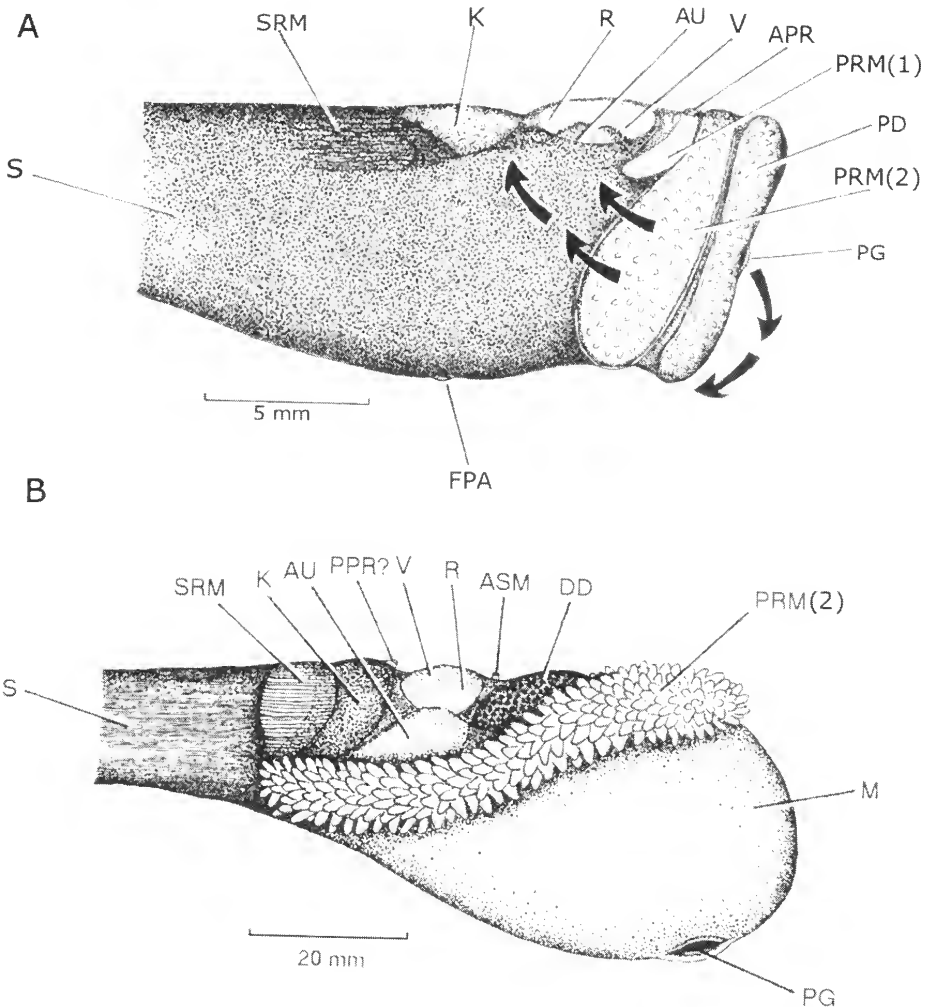


Figure 17 *Penicillus philippinensis*. A, The anterior end of an individual showing how the postero-dorsal movement of the papillate pallial retractor muscles and pedal disc would essentially recreate the situation seen in B, *Kendrickiana veitchi* (redrawn after Morton 2004a). For abbreviations see the Appendix.

illustrated because only one in ten sections of the specimen was saved thus losing the second statocyst. The statocysts are Type B<sub>3</sub> of Morton (1985b) as are those of all other penicillids described to date. Each statocyst thus possesses a large number of small crystalline statocytia of about equal size and there is not one dominant statolith as in other statocyst types (Morton 1985b).

## DISCUSSION

*Penicillus philippinensis* can be separated from *P. penis* on the basis of the form of the adventitious tube which is curved in the former and straight in the latter, and by the presence of anterior pedal retractor muscles and a fourth pallial aperture (Purchon 1956, 1960; this study). Of all known penicillids, however, *P. philippinensis* (Figure 17A) is structurally most similar to *Kendrickiana veitchi* (Morton 2004b) (Figure 17B). This similarity relates to the occurrence in both, respectively, of a saddle- or horseshoe-shaped array of muscular papillae, that connects each animal to its adventitious tube dorso-laterally. No other clavagelloid possesses such an array of muscular pallial papillae. The situation in *K. veitchi* seems to have evolved from an ancestral condition similar to that in *P. philippinensis* by the rotation dorsally of the papillate area of mantle and the movement of the pedal gape to a more antero-ventral, as opposed to a more anterior, position (Figure 17). This scenario may also account for the radial symmetry of the watering pot of *P. philippinensis* and the asymmetrical one of *K. veitchi*. There are, moreover, other differences between the two. In many ways the simple, tiny papillae of *P. philippinensis* foreshadow the situation seen in *K. veitchi*. That is, the papillae of the latter are large and have a deep muscular attachment within pits in the adventitious tube, whereas in the former they are slightly attached, via the intermediary of an epithelium, to the calcareous concretion covering the interior surface of the tube beneath and anterior to the positions of the true shell valves. *Kendrickiana veitchi* also possesses a distinct pair of accessory suspensory muscles, attaching the visceral mass dorsally to the adventitious tube. There is a similar but much smaller, less distinct, pair of such muscles in *P. philippinensis*. Conversely, *P. philippinensis* possesses an, albeit small, pallial line on the tube (with pallial retractor muscles), whereas *K. veitchi* does not. Purchon (1956, 1960) described neither dorsal saddle papillae nor suspensory muscles for *P. penis*.

This study of *Penicillus philippinensis* completes a personal series of papers on the structure of the adventitious tubes and anatomical characteristics of representatives of the known genera of the Penicillidae, that is, *Brechites vaginiferus*,

*Humphreyia strangei*, *Foegia novaezelandiae*, *Kendrickiana veitchi* and *Nipponoclava gigantea* (Morton 1984a, 2002a, b, 2004a, b, c). Such characteristics are compared and summarized in Table 1. Morton (2006) has published a similar table for representatives of the extant genera of the Clavagellidae, that is, *Dacosta australis* (Sowerby, 1829), *Bryopa aligamenta* (Morton, 2005), *Dianadema multangularis* and *Stirpulina ramosa* Dunker, 1882. All representatives of the Penicillidae are characterized by having both shell valves incorporated into the structure of the adventitious tube, unlike representatives of the Clavagellidae where only the left valve is – the right being free within the crypt (*Dacosta*, *Bryopa*) or tube (*Dianadema*, *Stirpulina*). *Humphreyia strangei* is easily distinguished from all other penicillids by being cemented epibenthically. Representatives of all other genera are endobenthic and occupy vertically oriented adventitious tubes. Representatives of the five endobenthic genera are separable in terms of the details of the tube structure, for example whether the shell valves are clearly visible (*Brechites*, *Penicillus*, *Nipponoclava*) or covered by concretions (*Foegia*, *Kendrickiana*). They are also separable in terms of anatomical details. For example, although all have lost their posterior adductor muscles, a vestigial anterior muscle is present in both *Penicillus* and *Nipponoclava*. Similarly, remnant anterior pedal retractor muscles are present only in *Brechites*, *Penicillus* and *Nipponoclava* whereas remnant posterior pedal retractor muscles are present only in *Humphreyia*, *Kendrickiana* and *Nipponoclava* facilitating the development in these genera only of pericardial proprioceptors. Similarly a fourth pallial aperture is present only in the juvenile of *Humphreyia* and in *Nipponoclava*, while only *Penicillus* and *Nipponoclava* do not possess radial mantle glands at the siphonal tips.

Notwithstanding such differences of detail, all penicillids are united in the possession of Type C pallial fusions (Yonge 1982), Type E ctenidia (Atkins 1936, 1937a), a Type 3 ctenidial labial palp junction (Stasek 1963) and statocysts of Type B<sub>3</sub> (Morton 1985b). Such characters are also common to representatives of the Clavagellidae (Morton 2006) suggesting a common ancestry, albeit with radiation of the two families in the Mesozoic (Clavagellidae) and Cenozoic (Penicillidae) (Morton 2006).

Gray (1858b), Lamy 1923, Smith (1978) and Morton (1984a, 2002a), among others, have speculated upon the formation of the clavagelloid adventitious tube. All authors agree that the structure is produced but once although it may be added to posteriorly to effect growth and repair. Harper and Morton (2004) described how in *Brechites vaginiferus* the sequential secretion of

**Table 1** A comparison of shell, adventitious tube and internal anatomical characters of *Brechites* and its allies (Penicilloidea: Penicillidae)

Character	<i>Brechites</i>	<i>Humphreyia</i>	<i>Penicillus</i>	<i>Foegia</i>	<i>Kendrickiana</i>	<i>Nipponoclava</i>
<b>Shell</b>	Juvenile + saddle	Juvenile + saddle	Juvenile + saddle	Juvenile + saddle	Juvenile + saddle	Post-juvenile + saddle
Shell	Both valves united with adventitious tube	Both valves united with adventitious tube	Both valves united with adventitious tube	Both valves united with adventitious tube	Both valves united with adventitious tube	Both valves united with adventitious tube
Ligament	External	External	External	External	External	External
Lithodesma	Unknown	Present	Unknown	Unknown	Unknown	Unknown
Periostracum	Two layers	Two layers	Two layers	Two layers	Two layers	Two layers
Shell microstructure	Prismatic outer layer Inner sheet nacre	Prismatic outer layer Inner sheet nacre	Prismatic outer layer Inner sheet nacre	Prismatic outer layer Inner sheet nacre	Prismatic outer layer Inner sheet nacre	Prismatic outer layer Inner sheet nacre
<b>Adventitious tube</b>	Present	Present	Present	Present	Present	Present
Adventitious tube	Free / cemented	Cemented	Free	Free	Free	Free
Watering pot	Present	Present	Present	Present	Present	Present
Anterior tubules	Present	Present but occluded	Present	Present	Present	Present
<b>Juvenile</b>	Juvenile metamorphosis	Juvenile metamorphosis	Juvenile metamorphosis	Juvenile metamorphosis	Juvenile metamorphosis	Juvenile metamorphosis
Anterior adductor muscles	Unknown	Present	Unknown	Unknown	Unknown	Present
Posterior adductor muscle	Unknown	Present	Unknown	Unknown	Unknown	Present
Anterior pedal retractor muscles	Unknown	Absent	Unknown	Unknown	Unknown	Present
Posterior pedal retractor muscles	Unknown	Absent	Unknown	Unknown	Unknown	Present
Pallial sinus	Unknown	Absent		Unknown		Present
<b>Adult</b>						
Anterior adductor muscle	Absent	Absent	Present	Absent	Absent	Present
Posterior adductor muscle	Absent	Absent	Absent	Absent	Absent	Absent
Anterior pedal retractor muscles	Present	Absent	Present	Absent	Absent	Present
Posterior pedal retractor muscles	Absent	Present	Absent	Absent	Present	Present
Pedal disc	Present	Present	Present	Present	Absent	Present
Pericardial proprioceptors	Absent	Present	Absent	Absent	Present	Present
Rectum	Passes above kidneys	Passes above kidneys	Passes above kidneys	Passes above kidneys	Passes above kidneys	Passes above kidneys
Suspensory muscles	Absent	Absent	Present	Absent	Present	Absent
U-shaped papillae	Absent	Absent	Present	Absent	Present	Absent
Ctenidial ciliation	Type E	Type E	Type E	Type E	Type E	Type E
Ctenidial/labial palp junction	Category 3	Category 3	Category 3	Category 3	Category 3	Category C
Pallial fusion	Type C	Type C	Type C	Type C	Type C	Type C
Fourth pallial aperture	Present	Present (only in the juvenile)	Present	Present	Absent	Present
Pedal gape	Present	Partially occluded	Present	Present	Present	Present
Pedal disc glands	Present	Absent	Absent	Absent	Absent	Present
Radial mantle glands	Present	Present	Absent	Present	Present	Absent
Siphonal sense organs	Present	Present	Absent	Absent	Absent	Present
Statocysts	Type B <sub>3</sub>	Type B <sub>3</sub>	Type B <sub>3</sub>	Unknown	Type B <sub>3</sub>	Type B <sub>3</sub>

periostracum, calcium carbonate and another layer of periostracum form the adventitious tube against the template of the burrow wall. The tube of *Penicillus philippinensis* is probably secreted in the same manner and, like all other penicillids, is probably produced but once.

Savazzi (1982) has described the general adaptations to life in a clavagelloid adventitious tube. The function of the tube has also been speculated upon. Purchon (1956, 1960) thought that water was pumped out of the watering pot into the sediment to liquefy the sediments and thereby effect reburial following disinterment. Savazzi (1999) inferred an ability to rebury on the basis of a reconstruction of the growth process of anomalous individuals of *Brechites*. Notwithstanding, Morton (2002a) showed that *B. vaginiferus* could not rebury and that interstitial water was pumped into the mantle cavity via the watering pot. Such an activity may have a number of functions, as described for *Foegia novaezelandiae* by Morton (2004a). One is to effect siphonal extension, following their withdrawal, by the hydraulic forces generated inside the mantle cavity and via pallial haemocoels pumping blood into the siphonal walls. Morton (2004a) further suggested for *F. novaezelandiae* that the tube also fulfils other functions of the true shell. That is, it functions as an exoskeleton which acts antagonistically to the hydraulically-generated forces in the mantle and body to effect the movement into and out of the mantle cavity of water from both the sea above and the interstitial spaces at the end of the burrow. The same structures and the forces they collectively engender essentially act to maintain the body in a state of optimal tonus.

*Penicillus philippinensis* and *Kendrickiana veitchi* are different from all other known penicillids, for example, *Brechites vaginiferus*, *Foegia novaezelandiae*, *Nipponoclava gigantea* (Morton 2002a, 2004a, b) and *P. penis* (Purchon 1956, 1960) in the possession by the former two species of the saddle- or horseshoe-shaped array of muscular mantle papillae. This can be considered to represent a neomorph, that is, a secondarily derived structure replacing the pumping function of either the lost (*K. veitchi*) or vestigial (*P. philippinensis*) adductor and pallial retractor muscles but further serving to attach the animal to its tube and no longer the shell valves. As such, the papillae do not serve to close the shell valves, since these structures are tiny and immovably fused into the fabric of the adventitious tube, but re-create another function, that is, to generate the forces which effect the exchange of mantle fluids with the water column above and interstitial waters in the burrow below. How this is achieved has been illustrated and described for *K. veitchi* by Morton (2004b). It is suggested here that the same forces are generated

by the saddle-shaped array of pallial papillae seen in *P. philippinensis*.

The siphons of *Kendrickiana veitchi* are poorly muscularised and cannot be contracted deeply into the adventitious tube (Morton 2004b) unlike in *Brechites vaginiferus*, *Foegia novaezelandiae* and *Nipponoclava gigantea* (Morton 2002a; 2004a, c). Strangely, the siphons of *Penicillus philippinensis* are well muscularised but the two specimens studied were not retracted deeply into their tubes. This species may be anatomically and functionally intermediate between *B. vaginiferus* and *F. novaezelandiae*, both of which exchange fluids in the mantle cavity using a pedal disc (a structure which *P. philippinensis* also possesses), and the muscularised mantle papillae of *K. veitchi* with no pedal disc. In these two groups of species, therefore, there are two quite different 'pumps' that create the hydraulic forces in the mantle cavity necessary to effect siphonal extension, the exchange of fluids between the supernatant water above and that of the burrow, respiration, the collection of particulate food and the discharge of pseudofaeces and faeces.

The pressures generated in the mantle cavity by contraction of the muscular mantle papillae (or pedal disc) must act, in turn, on the haemocoelomic blood vascular system to achieve movements of, for example, the foot but, especially, the siphons. In the case of *Penicillus philippinensis* and *Kendrickiana veitchi*, the blood vessels and pallial haemocoels are huge in comparison with those of other penicillids, for example, *Brechites vaginiferus*, *Foegia novaezelandiae* and *Nipponoclava gigantea* (Morton 2002a, 2004a, b).

In many other respects *Penicillus philippinensis* is a typical penicillid, for example, with regard to the presence of a distinct pair of pallial retractor muscles attached to a pallial line on the tube, as in *Brechites vaginiferus*, *Foegia novaezelandiae*, *Kendrickiana veitchi* and *Nipponoclava gigantea* (Morton 2002a, 2004a, b, c) and to the structures of the mantle cavity, that is, the siphons, ctenidia and labial palps. Commensurate upon the earliest loss of the adductor and pedal retractor muscles with the adoption of a tube-dwelling mode of life, however, natural selection has resulted in the evolution of a new 'adductor muscle' system, that is, a heavily muscularised pedal disc pump. This structure characterizes many representatives of the endobenthic Penicillidae, for example, *B. vaginiferus* and *F. novaezelandiae*, and even the epibenthic cemented *Humphreyia strangei* (Morton 2002b). Possibly because of some inherent inefficiency in this system, however, natural selection has acted further to, essentially, re-create a yet more elaborate replacement for the lost adductor muscle system, that is, the horseshoe-shaped array of muscular mantle papillae in *K. veitchi*. *P. philippinensis* seems, in the possession

of a pallial line and functional pallial retractor muscles, a pedal disc but also a saddle-shaped array of muscular mantle papillae, to be representative of an intermediate state between these two kinds of pumps, thereby giving us an invaluable insight into how the unique muscular system of *K. veitchi* may have evolved.

#### ACKNOWLEDGEMENTS

This research was undertaken during the tenure of a Research Associateship awarded by the Western Australian Museum, Perth, Western Australia. I am grateful to the Director and staff of the Western Australian Museum for the provision of facilities. Ms S. M. Slack-Smith is also thanked for assistance in accessing the collections of modern Mollusca at the museum. I am particularly grateful to Dr A. Baldinger of the Museum of Comparative Zoology, The Agassiz Museum, Harvard University, for sending and allowing me to dissect and section the two specimens of *Penicillus philippinensis* herein reported upon. Finally, I would like to thank Dr J. D. Taylor (The Natural History Museum, London) for reading and critically commenting on the first draft of the manuscript of this paper.

#### REFERENCES

- Aller, R.C. (1974). Prefabrication of shell ornamentation in the bivalve *Laternula. Lethaia* 7: 43–56
- Appukuttan, K.K. (1974). Rediscovery of *Clavagella (Bryopa) lata* Bivalvia) from the Gulf of Mannar, Southeast coast of India. *Journal of the Malacological Society of Australia* 3: 19–24.
- Atkins, D. (1936). On the ciliary mechanisms and interrelationships of lamellibranchs. *Quarterly Journal of Microscopical Science* 79: 181–308.
- Atkins, D. (1937a). On the ciliary mechanisms and interrelationships of lamellibranchs. Part III. Types of lamellibranch gills and their food currents. *Quarterly Journal of Microscopical Science* 79: 375–421.
- Atkins, D. (1937b). On the ciliary mechanisms and interrelationships of lamellibranchs. Part IV. Cuticular fusion with special reference to the fourth pallial aperture in certain lamellibranchs. *Quarterly Journal of Microscopical Science* 79: 423–445.
- Bruguère, M. (1789). *Encyclopedie Méthodique: Histoire Naturelle des Vers*, Vol.1 (XV): genus 33, 126–130. Pankouche, Paris.
- Carter, J.G. and Aller, R.C. (1975). Calcification of the bivalve periostracum. *Lethaia* 8: 315–320.
- Chenu, M. (1843). *Aspergillum*. Arrosior. *Illustrations de Conchyliologie* 1: 1–4, pl. 1–4.
- Dharma, B. (1992). *Indonesian Shells*. Vol. 2. Hemmen, Wiesbaden.
- Dreyer, H., Steiner, G. and Harper, E.M. (2003). Molecular phylogeny of Anomalodesmata (Mollusca: Bivalvia) inferred from 18S rRNA sequences. *Zoological Journal of the Linnean Society* 139: 229–246
- Gray, J.E. (1847). A list of the genera of Recent Mollusca, their synonyms and types. *Proceedings of the Zoological Society of London* 15: 129–219.
- Gray, J.E. (1858a). On the families of Aspergillidae, Gastrochaenidae and Humphreyiadae. *Proceedings of the Zoological Society of London* 26: 307–318.
- Gray, J.E. (1858b). On the development of the shell and tube in *Aspergillum*. *Annals and Magazine of Natural History* 1: 423–426.
- Harper, E.M. and Morton, B. (2004). Tube construction in the watering pot shell *Brechites vaginiferus* (Bivalvia: Anomalodesmata: Clavagelloidea). *Acta Zoologica* 85: 149–161.
- Harper, E.M., Hide, E.A. and Morton, B. (2000). Relationships between the extant Anomalodesmata: a cladistic test. In E.M. Harper, J.A. Crame and J.D. Taylor (eds), Geological Society, London, Special Publications 177: 129–143.
- Keen, M. and Smith, L.A. (1969). Superfamily Clavagellacea d'Orbigny, 1844. In R.C. Moore, (ed), *Treatise on Invertebrate Paleontology*, Part N, Vol. 2: Mollusca 6, Bivalvia. Lawrence, Kansas: Geological Society of America and University of Kansas Press, Lawrence, Kansas.
- Lacaze-Duthiers, H. de (1870). Sur l'organisation de l'arrosior *Aspergillum javanicum*. *Compte Rendu, Academie des Sciences, Paris* 70: 268–271.
- Lacaze-Duthiers, H. de (1883). Anatomie de l'arrosior (*Aspergillum dichotomum*, L. Reeve). *Archives de Zoologie Expérimentale et Générale* 2: 1–68.
- Lamprell, K. and Healy, J. (1998). *Bivalves of Australia*, Vol. 2. Backhuys, Leiden.
- Lamy, E. (1923). Les Clavagelles et arrosiors de la Mer Rouge (d'après les matériaux recueillis par de la Dr. Josseume). *Bulletin du Muséum National d'Histoire Naturelle, Paris* 29: 104–107
- Morton, B. (1981). The Anomalodesmata. *Malacologia* 21: 35–60.
- Morton, B. (1984a). Adventitious tube construction in *Brechites vaginiferus* (Bivalvia: Anomalodesmata: Clavagellacea) with an investigation of the juvenile of "*Humphreyia strangei*". *Journal of Zoology, London* 203: 461–484.
- Morton, B. (1984b). The biology and functional morphology of *Clavagella australis* (Bivalvia: Anomalodesmata). *Journal of Zoology, London* 202: 489–511.
- Morton, B. (1985a). Adaptive radiation in the Anomalodesmata. In: E.R. Trueman and M.R. Clark (eds.), *The Mollusca*, Vol. 10, Evolution: 405–459. Academic Press, Sydney.
- Morton, B. (1985b). Statocyst structure in the Anomalodesmata (Bivalvia). *Journal of Zoology, London* 206: 23–34.
- Morton, B. (2002a). Biology and functional morphology of the watering pot shell *Brechites vaginiferus* (Bivalvia: Anomalodesmata: Clavagelloidea). *Journal of Zoology, London* 257: 545–562.
- Morton, B. (2002b). The biology and functional morphology of *Humphreyia strangei* (Bivalvia:

- Anomalodesmata: Clavagellidae): an Australian cemented 'watering pot' shell. *Journal of Zoology, London* **258**: 11–25.
- Morton, B. (2003a). The biology and functional morphology of *Bentholyonsia teramachii* (Bivalvia: Lyonsiellidae): clues to the origin of predation in the deep-water Anomalodesmata. *Journal of Zoology, London* **261**: 363–380.
- Morton, B. (2003b). The biology and functional morphology of *Dianadema* gen. nov. *multangularis* (Tate, 1887) (Bivalvia: Anomalodesmata: Clavagelloidea). *Journal of Zoology, London* **259**: 389–401.
- Morton, B. (2004a). The biology and functional morphology of *Foegia novaezelandiae* (Bivalvia: Anomalodesmata: Clavagelloidea) from Western Australia. *Malacologia* **46**: 37–55.
- Morton, B. (2004b). The biology and functional morphology of *Kendrickiana* gen. nov. *veitchi* (Bivalvia: Anomalodesmata: Clavagelloidea). *Invertebrate Biology* **123**: 244–259.
- Morton, B. (2004c). The biology and functional morphology of *Nipponoclava gigantea* (Bivalvia: Anomalodesmata): clues to the origin of tube dwelling in the Penicillidae. *Journal of Zoology, London* **264**: 1–15.
- Morton, B. (2006). The structure and formation of the adventitious tube of the Japanese watering pot shell *Stirpulina ramosa* (Bivalvia: Anomalodesmata: Clavagellidae) and a comparison with that of the Penicillidae. *Invertebrate Biology* [In press].
- Owen, R. (1835). On the anatomy of *Clavagella* Lam. *Transactions of the Zoological Society of London* **1**: 269–274.
- Pojeta, J. and Sohl, N.F. (1987). *Ascaulocardium armatum* (Morton, 1833), new genus (Late Cretaceous): the ultimate variation on the bivalve paradigm. *Paleontological Society Memoirs* **24**: 1–77.
- Prezant, R.S. (1979a). Shell spinules of the bivalve *Lyonsia hyalina* (Bivalvia: Anomalodesmata). *Nautilus* **93**: 93–95.
- Prezant, R.S. (1979b). The structure and function of the radial mantle glands of *Lyonsia hyalina* (Bivalvia: Anomalodesmata). *Journal of Zoology, London* **187**: 505–516.
- Prezant, R.S. (1981). Comparative shell ultrastructure of lyonsiid bivalves. *The Veliger* **23**: 289–299.
- Purchon, R.D. (1956). A note on the biology of *Brechites penis* (L.). Lamellibranchia. *Zoological Journal of the Linnean Society* **43**: 43–54.
- Purchon, R.D. (1960). A further note on the biology of *Brechites penis* (L.). Lamellibranchia. *Proceedings of the Malacological Society of London* **34**: 19–23.
- Reeve, L. (1860). *Conchologica Iconica*, 12 *Aspergillum*, London.
- Savazzi, E. (1982). Adaptations to tube dwelling in the Bivalvia. *Lethaia* **15**: 275–297.
- Savazzi E. (1999). Boring, nestling and tube-dwelling bivalves. In E. Savazzi (ed), *Functional Morphology of the Invertebrate Skeleton*, 205–237. Wiley & Sons, Chichester.
- Savazzi, E. (2000). Morphodynamics of *Bryopa* and the evolution of clavagellids. In E.M. Harper, J.D. Taylor and J.A. Crame (eds), *The Evolutionary Biology of the Bivalvia*. Geological Society, London, Special Publications **177**: 313–327.
- Smith, B.J. (1971). A revision of the family Clavagellidae (Pelecypoda: Mollusca) from Australia with descriptions of two new species. *Journal of the Malacological Society of Australia* **2**: 135–161.
- Smith, B.J. (1976). Revision of the recent species of the family Clavagellidae (Mollusca: Bivalvia). *Journal of the Malacological Society of Australia* **3**: 187–209.
- Smith, B.J. (1978). Further notes on the Clavagellidae, with speculation on the process of tube growth. *Journal of the Malacological Society of Australia* **4**: 77–79.
- Smith, B.J. (1998). Family Clavagellidae. In P.L. Beesley, G.J.B. Ross and A. Wells (eds), *Mollusca: The Southern Synthesis. Fauna of Australia*. Vol. 5. Part A, 413–415. CSIRO Publishing, Melbourne.
- Soliman, G.N. (1971). On a new clavagellid bivalve from the Red Sea. *Proceedings of the Malacological Society of London* **39**: 389–397.
- Stasek, C.R. (1963). Synopsis and discussion of the association of ctenidia and labial palps in the bivalved molluscs. *The Veliger* **6**: 91–97.
- Taylor, J.D., Kennedy, W.J. and Hall, A. (1973). The shell structure and mineralogy of the Bivalvia II. Lucinacea – Clavagellacea. Conclusions. *Bulletin of the British Museum (Natural History), Zoology* **22**: 235–294.
- Yonge, C.M. (1982). Mantle margins with a revision of siphonal types in the Bivalvia. *Journal of Molluscan Studies* **48**: 102–103.

## APPENDIX

AA	Anterior adductor muscle	OP	Outer layer of periostracum
AN	Anus	OV	Ovary
APR	Anterior pedal retractor muscle (or impression)	P	Periostracum
ASM?	Anterior suspensory muscle?	PD	Pedal disc
AU	Auricle	PE	Papilla epithelium
CA	Ctenidial axis	PEG	Periostracal groove
CAN	Ctenidial axis nerve	PEN	Pedal nerve
CJ	Cuticular junction	PG	Pedal gape
CM	Circular muscle layer	PN	Pallial nerve
C-P-V-CONN	Cerebro-pleural visceral connective	PPD	Papilla of pedal disc
DD	Digestive diverticula	PPDR	Papilla of pedal disc rim
DK	Distal limb of the kidney	PPR	Posterior pedal retractor muscle
ES	Exhalant siphon	PRM(1)	Pallial retractor muscle (or impression)
F	Foot	PRM(2)	Papillate pallial retractor muscle (or impression)
FPA	Fourth pallial aperture	PPRM(2)	Papilla of pallial retractor muscle (or impression)
H	Heart	R	Rectum
HA	Haemocoel	RSBC	Roof of the supra-branchial chamber
HG	Hypobranchial gland	S	Siphons
ID	Inner demibranch	SA	Shell saddle (or impression)
IE	Inner epithelium	SBC	Supra-branchial chamber
ILP	Inner labial palp	SG	Siphonal gland
IP	Inner layer of periostracum	SN	Siphonal nerve
IS	Inhalant siphon	SP	Siphonal papilla
K	Kidney	SRM	Siphonal retractor muscles
LM	Longitudinal muscle	ST	Statocyst
M	Mantle	STA	Statoconia
MF	Muscle fibres	SV	Shell valve (or impression)
O	Oesophagus	TE	Testes
OD	Outer demibranch	TMF	Transverse muscle fibres
OE	Outer epithelium	V	Ventricle
OLP	Outer labial palp	VG	Visceral ganglia
OMF	Oblique muscle fibres		



## A troglobitic cryptopid centipede (Chilopoda: Scolopendromorpha) from western Queensland

Gregory D. Edgecombe

Australian Museum, 6 College Street, Sydney, NSW 2010, Australia

**Abstract** – *Cryptops* (*Trigonocryptops*) *camoowealensis* sp. nov. from Five O’Clock cave in the Camooweal district of Queensland, is the second troglobitic species of the subgenus *Trigonocryptops* to be described from Australia. The new species is less troglomorphic than is a recently described congener from caves in the Nullarbor Region of Western Australia.

### INTRODUCTION

The scolopendromorph *Cryptops* Leach, 1815, is one of the most diverse centipede genera, with 153 named species (Lewis 2002). Among these, troglomorphic species include members of the subgenera *Cryptops* Leach, 1815, and *Trigonocryptops* Verhoeff, 1906 (see Edgecombe 2005 and Lewis 2005 for discussion of subgenera of *Cryptops* and diagnostic characters of *Trigonocryptops*). Troglomorphic species of *Cryptops* have been described from caves in Europe, the Canary Islands, Cuba, and Western Australia. The latter record is based on the highly troglomorphic *C.* (*Trigonocryptops*) *roeplainsensis* Edgecombe, 2005, which occurs in caves in the Nullarbor Region. This troglomorph was the first Australian species to be referred to *C.* (*Trigonocryptops*), which is otherwise known from Spain, North Africa, tropical West, Central and East Africa, Peru, Brazil, Cuba, India, Indonesia, and New Caledonia. Additional records of *C.* (*Trigonocryptops*) in Australia, as well as occurrence in New Zealand, Fiji and the Solomon Islands, were provided by the reassignment of *C. spinipes* Pocock, 1891, to that subgenus (Edgecombe 2005).

A new troglobitic species of *Cryptops* (*Trigonocryptops*) is described herein from the Camooweal area of western Queensland (Figure 1). *Cryptops* (*Trigonocryptops*) *camoowealensis* sp. nov. occurs in the deep zone of the Five O’Clock cave, Camooweal Caves National Park, 24 km south of the town of Camooweal. The Camooweal caves are part of the extensive Barkley Karst Region, developed in the Cambrian Camooweal Dolomite. Five O’Clock cave (C-36 of Matthews 1985) has a length of 800 m +/- 10 m, and is dry with connections to intermittent standing water.

Drawings were prepared with a camera lucida attachment to a Leica MZ12. Morphological terminology follows recommendations by Lewis *et al.* (2005).

### SYSTEMATICS

Family Cryptopidae Kohlrausch, 1881

Subfamily Cryptopinae Kohlrausch, 1881

Genus *Cryptops* Leach, 1815

Type species

*Scolopendra hortensis* Donovan, 1810, by monotypy.

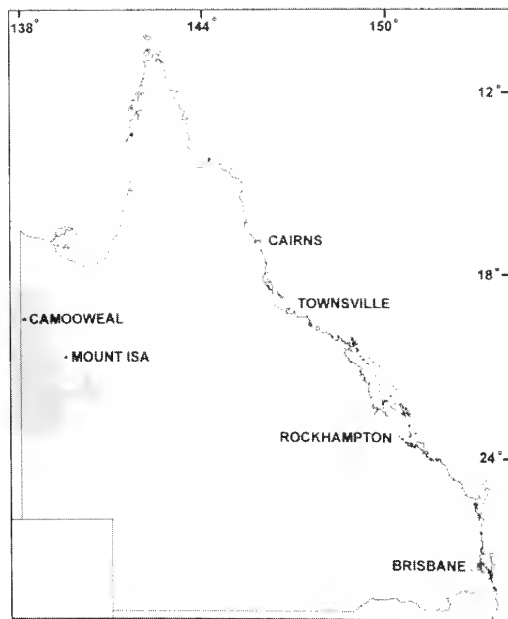


Figure 1 Location of Camooweal, northwestern Queensland. Barkley Karst Region indicated by shading.

Subgenus *Trigonocryptops* Verhoeff, 1906

Type species

*Cryptops gigas* Kraepelin, 1903, by subsequent designation of Attems (1930).

*Cryptops (Trigonocryptops) camoowealensis*

sp. nov.

Figures 2–4

Material examined

*Holotype*

**Australia: Queensland:** Camooweal area, c. 20°05'S 138°10'E, Five O'Clock Cave, WAM survey BES:6807, 1995, deep zone of cave (WAM T60508, male; Figures 2–4).

Diagnosis

A *Trigonocryptops* species with antenna extending back to tergite 6; complete paramedian sutures on head plate and tergites 1–20; complete oblique sutures on tergites 2–7; sternites 2–4 with anterior transverse suture that curves forwards near lateral margin, anterior longitudinal median suture running to anterior transverse suture; ultimate leg with distal spinose process on anterior side of femur and tibia; 10/10 saw teeth on tibia, 5/3 on tarsus.

Description

Length (anterior margin of head plate to posterior margin of telson) 37.7 mm. Head plate 1.6 mm long, antenna 9 mm long.

Head and tergite 1 pale orange; tergites and sternites 2 and 3 grading to yellow, remainder of trunk (including legs) yellow.

Head plate overlaps tergite 1; length and width of head plate nearly equal, posterior corners rounded, sides weakly convex outwards for much of their length, anterior apex indented; paramedian sutures diverging anteriorly on head plate (Figure 2), strongly directed outwards near their anterior termination; head punctate, with relatively sparse, scattered setae.

Antenna composed of 17 articles; basal article stout, articles then gradually increasing in length to a maximum along articles 5–10, then gradually shortening along articles 11–15; last three articles each about equally long; longest articles 3–3.5 times longer than their maximum width. Article 1 bearing strong, lanceolate setae of varied length (Figure 3E), these strong setae progressively less abundant on articles 2–5; short setae moderately abundant on articles 2–5; from article 6 or 7, short, fine setae form a fur-like covering, with long setae confined to an irregular whorl around proximal end of each article.

Anterior setose area on clypeus diamond shaped, widest at about ¼ of its length (Figure 3E), bearing

two longer setae and a minute posteromedian seta, flanked by a long seta just outside its widest point. Pair of posteriorly diverging sutures arises from posterior apex of the setose area, terminating at about half distance to labrum, three short setae between these sutures. Band of 11 slender, moderately long prelabral setae. Labrum with shallow incision against rounded sclerotised bulge in sidepiece, not strongly tridentate.

Maxillipede with anterior edge of coxosternum convex on each side, bearing a row of six marginal setae (Figure 3C). Coxosternum bearing only a few pairs of moderately long setae, concentrated anteriorly, sparse short setae. Trochanteroprefemur scattered with long to short, fine setae (Figure 3B); band of seven mostly longer setae along inner margin. Single band of setae of varied length on each of femur and tibia. Tarsungulum articulated with trochanteroprefemur along wide hinge.

Apical claw of second maxilla with slender hook distally, lacking a flange along its inner edge. Dorsal brush dense, running along distal three-quarters of article 3.

Tergite 1 with complete anterior transverse suture; parallel paramedian sutures; posterolateral sutures gently curved forwards, intersecting posterior margin at their union with paramedian sutures (Figure 2). Lateral longitudinal sutures on tergites 1–19, becoming submarginal by about

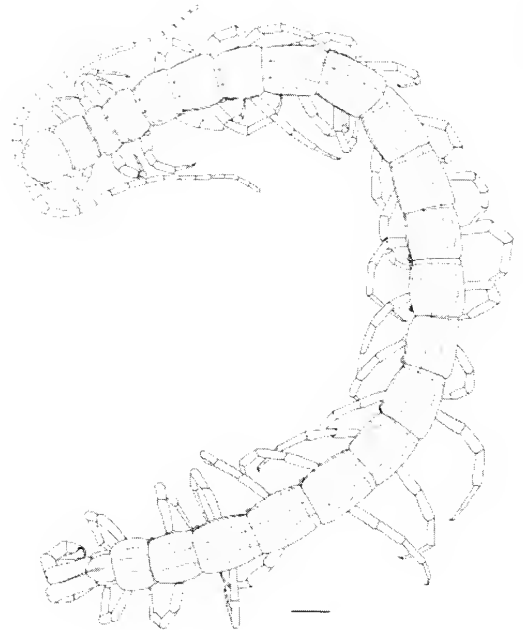


Figure 2 *Cryptops (Trigonocryptops) camoowealensis* sp. nov. Holotype, WAM T60508. Habitus, scale 1 mm.

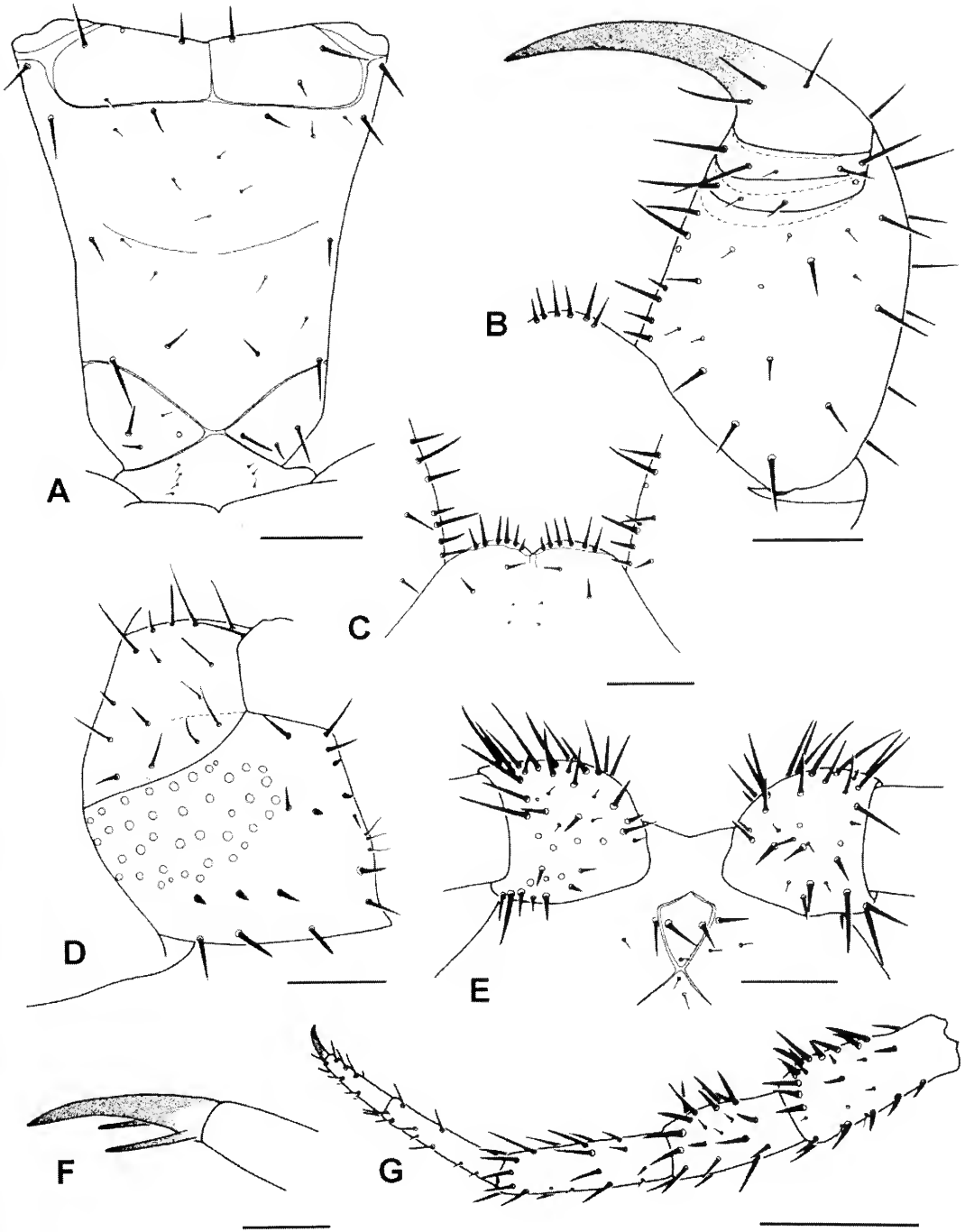


Figure 3 *Cryptops (Trigonocryptops) camoowealensis* sp. nov. Holotype, WAM T60508. A, sternite 4. B, forcipule. C, margin of maxillipede coxosternum. D, ventrolateral view of sternite and coxopleuron of segment 21. E, both basal antennal segments and anterior setose area on clypeus. F, anterior view of pretarsus of leg 9. G, leg 1, posterior side. Scale bars 0.25 mm except F, 0.1 mm, and G, 0.5 mm.

tergite 6. Complete oblique sutures on tergites 2–7; incomplete oblique sutures on tergite 8. Lateral region delimited by lateral longitudinal sutures cut by two sutures, one representing the distal part of the oblique sutures on tergites 2–7 but maintaining the same position even when oblique sutures are incomplete or absent (tergites 8–19). Paramedian sutures converging anteriorly on tergite 2, parallel along much of their length on tergites 3–20 but with weak divergence in their anterior part and more marked divergence in their posterior part; paramedian sutures weakly convergent on pretergite 1, parallel on pretergites 2–4, divergent on pretergites 5–20. Shallow crescentic sulci on tergites 4–20. Anterior trunk tergites with just a few pairs of short and moderately long setae; mostly symmetrically-paired setae more numerous on posterior tergites. Tergite 21 slightly longer than wide, posterior margin with rounded apex; shallow longitudinal median depression along posterior two-thirds of tergite.

Sternites 2–4 with anterior region bounded by transverse suture that curves forwards near lateral margin of sternum (Figure 3A) and is bisected medially by a longitudinal suture; small transversely elongate sclerite isolated at anterolateral corner of sternite; longitudinal median suture and curved lateral part of transverse suture distinct on sternites 5–7. Sternites 2–19 with curved transverse sulcus; shallow longitudinal sulcus on sternites 4–19, their intersection forming a large depression. Sternites sparsely scattered with moderately long, symmetrically-paired setae, mostly concentrated near margins; inner part of sternites with numerous short, fine setae; setae coarsest on sternite 1. Anterior branch of trigonal sutures complete on sternites 3–6. Endosternite with two subparallel rows of short setae (Figure 3A).

Spiracles elongate elliptical.

Legs relatively long and thin, e.g., leg 10 with prefemur 0.9 mm long, femur 0.8 mm, tibia 1.0 mm, tarsus 1 0.9 mm, tarsus 2 0.35 mm compared to tergal width of 1.55 mm. All tarsi strongly bipartite. Leg 1 (Figure 3G) with robust lanceolate to subspiniiform setae on all surfaces of prefemur and femur, slightly more slender on tibia, considerably more slender on tarsus; from leg 2, lanceolate setae on prefemur to tibia more slender and of more even thickness on each podomere; tarsal setae shorter, slender. Leg 20 prefemur and femur about equally long; tarsus 2 0.54 times as long as tarsus 1 (Figure 4F); lacking dense tufts of setae ventrally. Ultimate leg: prefemur 2.1 mm long, femur 1.8 mm, tibia 1.3 mm, tarsus 1 0.9 mm, tarsus 2 1.4 mm; prefemur and femur 4.5 and 4.7 times longer, respectively, than their maximal widths at distal ends (Figure 4E); distal spinose process on anterior side of femur and tibia, lacking on posterior side; robust lanceolate setae on anterior, posterior and ventral

sides of prefemur, mostly slender setae on dorsal side; robust lanceolate setae confined to posterior and ventral sides of femur, anterior and dorsal sides with slender setae; tibial and tarsal setae exclusively slender; 10/10 saw teeth on tibia (Figure 4A), 5/3 on tarsus 1 (Figure 4B); inner margin of tarsus 2 a ridge. Pair of gently divergent accessory spurs half length of pretarsus on legs 1–20 (Figure 3F); anterior accessory spur slightly longer than posterior spur; accessory spurs lacking on ultimate leg.

Sternite 21 with sides weakly convex and converging posteriorly; posterior corners rounded, hind edge approximately transverse. Coxopleural pore field elliptical, terminating at a distance from posterior margin of coxopleuron about half the height of the pore field, with up to 40 pores (Figure 3D), no setae amidst the pores. Row of three or four robust lanceolate setae above pore field, two lanceolate setae behind pore field. Posterior margin of coxopleuron bearing seven strong setae and a few fine setae.

## DISCUSSION

Membership in *Cryptops* (*Trigonocryptops*) is indicated by the trigonal sutures on several anterior sternites and a projection at the anterolateral corner of the endosternite (Figure 3A), an anterior setose area on the clypeus delimited by sutures (Figure 3E), the head overlying tergite 1 and a transverse suture on tergite 1 (Figure 2), distal spinose projections on the femur and tibia of the ultimate leg (Figures 4C, D), and bipartite tarsi on all legs (Figure 3C).

The new species does not exhibit the extreme troglomorphic characters of *Cryptops* (*Trigonocryptops*) *roepainsensis* Edgecombe, 2005, or *C. (T.) troglobius* Matic *et al.*, 1977, having only moderate elongation of the antennal articles, legs and tergites compared to epigeal species of *C. (Trigonocryptops)*. In addition to its lesser degree of troglomorphy (i.e., shorter antennae and legs, fewer saw teeth on the ultimate leg), the new species is distinguished from *C. (T.) roepainsensis* by its continuous paramedian sutures on tergites 1–3, lateral longitudinal sutures on tergite 1; much sparser setation on the trunk sternites, maxillipede coxosternum, and forcipule; fewer fine setae on the proximal parts of legs 20 and 21; single (versus paired) distal spinose processes on the femur and tibia of leg 21; and far fewer coxopleural pores on leg 21.

*Cryptops (Trigonocryptops) camoowealensis* and *C. (T.) spinipes* Pocock, 1891, the latter known from New South Wales (Sydney and the Blue Mountains: Chamberlin 1920), Queensland (Blackall Ranges and Atherton Tablelands: Kraeplin 1916), Fiji, the Solomon Islands (Chamberlin 1920) and New Zealand (Archey 1924), share continuous

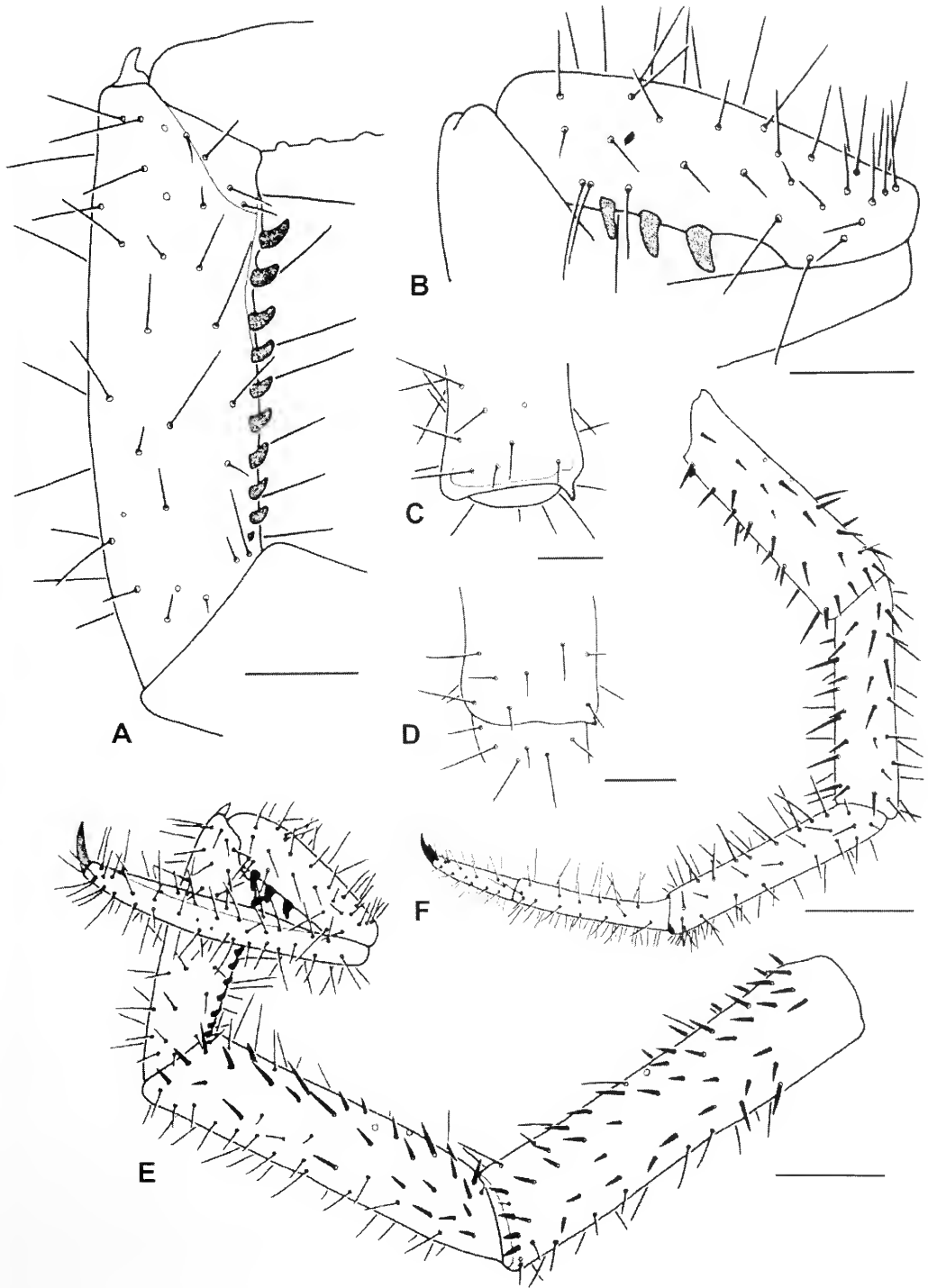


Figure 4 *Cryptops (Trigonocryptops) camoowealensis* sp. nov. Holotype, WAM T60508. A-E, leg 21. A, tibia. B, tarsus I. C, D, distal end of tibia and femur, dorsal views. E, posterior view of leg. F, leg 20, posterior view. Scale bars 0.25 mm except E, F, 0.5 mm.

paramedian sutures on the head plate and robust lanceolate and subspiniform setae on the legs. The new species is most readily distinguished from *C. (T.) spinipes* by its tendency towards troglomorphy (longer legs, e.g., the ultimate leg having a markedly longer prefemur, femur and tibia; longer antennal articles), as well as by its predominantly yellow rather than orange pigment, and having complete, parallel paramedian sutures on tergite 1 and oblique sutures on tergite 2.

Among non-Australian species, *C. (T.) loveridgei* Lawrence, 1953 [= *C. (T.) bokumensis* Kraus, 1958, *vide* Lewis, 2005] from Tanzania and the Democratic Republic of Congo, is similar to *C. (T.) camoowealensis* in most respects, e.g., the segmental distribution of paramedian sutures, setation of the maxillipede coxopleural margin, presence of posteriorly-diverging sutures behind the anterior setose area on the clypeus, and comparable proportions and dentition of the ultimate leg. The specific distinction of *C. (T.) camoowealensis* is indicated by having curved posterolateral sutures on tergite 1, complete oblique sutures on tergites 2–7 (versus 2 to 4 or 5), a less extensive series of trigonal sutures on the sternum, presence of anterior transverse and longitudinal median sutures on sternites 2–4, and less developed distal spinose processes on the ultimate leg (lacking a process on the prefemur, single rather than paired processes on the tibia).

#### ACKNOWLEDGEMENTS

I thank Suzanne Bullock for illustrations. The holotype was made available courtesy of Mark Harvey and Julianne Waldock (Western Australian Museum). John Lewis and Alessandro Minelli made useful suggestions for improving the manuscript.

#### REFERENCES

- Archey, G. (1924). The genus *Cryptops* (Chilopoda) in New Zealand. *Record of the Canterbury Museum* 2: 203–220.
- Attems, C. (1930). Myriapoda 2. Scolopendromorpha. In F.E. Schulze and W. Kükenthal (eds), *Das Tierreich* 54. Walter de Gruyter and Co., Berlin and Leipzig.
- Edgecombe, G.D. (2005). A troglomorphic species of the centipede *Cryptops* (*Trigonocryptops*) (Chilopoda: Scolopendromorpha) from Western Australia. *Records of the Western Australian Museum* 22: 315–323.
- Kraepelin, K. (1916). Results of Dr E. Mjöberg's Swedish Scientific Expeditions to Australia 1910–1913. 4. Scolopendriden und Skorpione. *Arkiv för Zoologi* 10: 1–43.
- Kraus, O. (1958). Myriapoda (Chilopoda, Diplopoda). *Parc National de l'Upemba, I. Mission G. F. de Witte en collaboration avec W. Adam, A. Janssens, L. van Meel et R. Verheyen (1946–1949)* 54: 4–67.
- Lawrence, R.F. (1953). Zoological results of a fifth expedition to East Africa V Chilopoda (Myriopoda). *Bulletin of the Museum of Comparative Zoology at Harvard College* 110: 409–423.
- Leach, W.E. (1815). A tabular view of the external characters of four classes of animals which Linné arranged under Insecta; with the distribution of the genera composing three of these classes into orders, etc. and descriptions of several new genera and species. *Transactions of the Linnean Society of London, Series 1*, 11: 306–400.
- Lewis, J.G.E. (2002). The scolopendromorph centipedes of Mauritius and Rodrigues and their adjacent islets (Chilopoda: Scolopendromorpha). *Journal of Natural History* 36: 79–106.
- Lewis, J.G.E. (2005). A reassessment of *Cryptops loveridgei* Lawrence, with observations on the subgenus *Trigonocryptops* Verhoeff and *Paratrigonocryptops* Demange (Chilopoda, Scolopendromorpha). *African Invertebrates* 46: 115–124.
- Lewis, J.G.E., Edgecombe, G.D. and Shelley, R.M. (2005). A proposed standardised terminology for the external taxonomic characters of the Scolopendromorpha (Chilopoda). *Fragmenta Faunistica* 48: 1–8.
- Matic, Z., Negrea, S. and Fundora Martinez, C. (1977). Recherches sur les Chilopodes hypogés de Cuba (II). *Résultats des expéditions biospéologiques cubano-roumaines à Cuba* 2: 277–301.
- Matthews, P.G. (ed.) (1985). *Australian Karst Index 1985*. Australian Speleological Federation Inc.
- Pocock, R.I. (1891). Descriptions of some new species of Chilopoda. *Annals and Magazine of Natural History, Series 6*, 8: 152–164.
- Verhoeff, K.W. (1906). Vergleichendmorphologische Studie über die coxopleuralen Körperteile der Chilopoden, mit besonderer Berücksichtigung der Scolopendromorpha, ein Beitrag zur Anatomie und Systematik derselben nebst physiologischen Mitteilungen und Ausblicken auf die Insekten. *Nova Acta Academiae Caesareae Leopoldino-Carolinae Germanicum Naturae Curiosorum* 86: 349–501.

## The distribution of *Eukoenia mirabilis* (Palpigradi: Eukoeniidae): a widespread tramp

Mark S. Harvey<sup>1</sup>, Frantisek Štáhlavský<sup>2</sup> and Pieter D. Theron<sup>3</sup>

<sup>1</sup>Department of Terrestrial Invertebrates, Western Australian Museum, Locked Bag 49,  
Welshpool DC, Western Australia 6986, Australia.

<sup>2</sup>Department of Zoology, Charles University, Viničná 7, CZ-128 44 Prague 2, Czech Republic.

<sup>3</sup>School of Environmental Sciences and Development, North-West University, Potchefstroom Campus,  
Potchefstroom, P. Bag X6001, Potchefstroom 2520, South Africa.

---

**Abstract** – We report on the discovery of populations of the palpigrade *Eukoenia mirabilis* (Grassi and Calandruccio, 1885) in South Africa and Western Australia, and compile known distributional records for the species. It is found to be widespread throughout the Mediterranean region, with additional populations occurring in Madagascar, South Africa, Chile and southern Australia. Accidental synanthropic introductions are the most likely cause of these additional records.

### INTRODUCTION

Members of the arachnid order Palpigradi represent one of the more obscure and poorly-known arachnid orders with only 79 species named in six genera and two families (Harvey 2003; Mayor and Barranco 2002). Their phylogenetic affinities are poorly known and several competing hypotheses exist regarding their systematic placement. For example, Hammen (1977, 1989) treated palpigrades as members of the Epimerata along with the mite taxon Actinotrichida. Weygoldt and Paulus (1979) and Weygoldt (1998) regarded them as sister to Solifugae, Chelonethi (Pseudoscorpiones), Opiliones, Ricnulei and Acari. Shultz (1990) and Wheeler and Hayashi (1998) treated them as sister to the Tetrapulmonata (Araneae, Amblypygi, Schizomida and Uropygi).

The most abundant palpigrade genus, *Eukoenia* Börner, is found in many parts of the world and is represented by over 60 species (Harvey 2003). Two species of this genus, *E. mirabilis* (Grassi and Calandruccio, 1885) and *E. florenciae* (Rucker, 1903), are widely distributed and appear to consist of largely parthenogenetic populations that have probably been inadvertently dispersed through human agency (Walter and Condé 1997). *Eukoenia mirabilis* is widely distributed in north Africa and southern Europe, and has also been recorded from other parts of the world, including Madagascar (Rémy 1950, 1960), Chile (Condé 1974) and South Australia (Savory 1935). The Malagasy and Chilean records were made by experienced palpigrade taxonomists but there has long been suspicion regarding the identity of the Australian populations. We have examined and confirmed the

identity of the South Australian palpigrade populations and here report on the recent discovery of *E. mirabilis* in South Africa and Western Australia. We also discuss the known distribution of this species and present a distribution map depicting the known populations.

The specimens examined for this study are lodged in the South Australian Museum, Adelaide (SAM) and the Western Australian Museum, Perth (WAM). Specimens were examined with an Olympus BH-2 compound microscope by temporarily mounting the specimens on microscope slides in glycerol after clearing in very dilute lactic acid. After study they were returned to 75% ethyl alcohol in microvials.

### *Eukoenia mirabilis* (Grassi and Calandruccio, 1885)

Figures 1–4

*Koenenia mirabilis* Grassi and Calandruccio, 1885: 165.

*Eukoenia mirabilis* (Grassi and Calandruccio): Harvey 2003: 156–157 (full synonymy).

### Material examined

**Australia: South Australia:** 1 ♀, 1 ♀ (stage B), Adelaide (SAM 1991693-4; B. Condé det.); 4 ♀, Glen Osmond [34°57'S, 138°38'E], March 1933, August 1933, 11 May 1934, H. Womersley (SAM); 4 ♀, Glen Osmond [34°57'S, 138°38'E], 27 July 1935, 4 August 1935, 3 September 1950, 9 October 1950, R.V. Southcott (SAM); 7 specimens (including 3 ♀), Glen Osmond, Birksgate [34°57'S, 138°38'E], under stones, 31 August 1975, 13 September 1975, R.V.

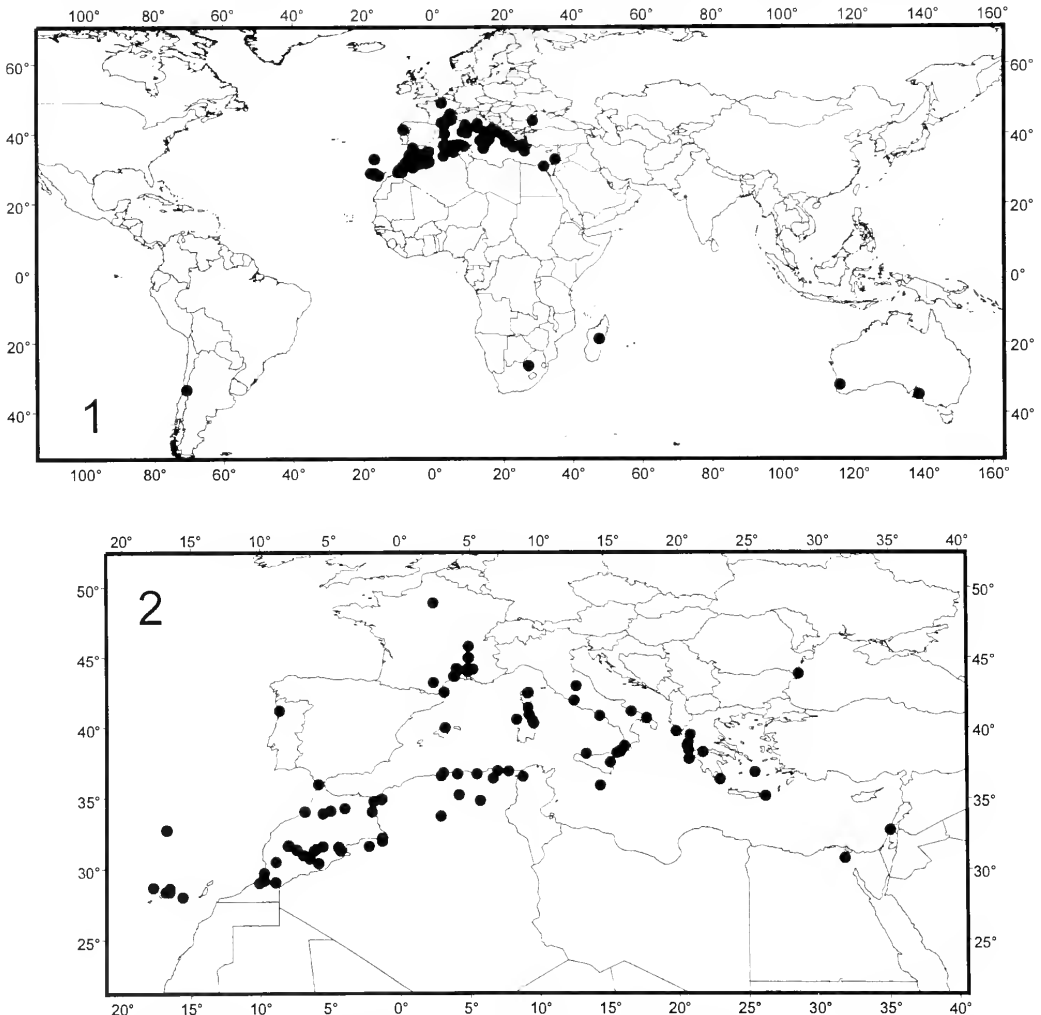
Southcott and A.M.S. (SAM); 1 ♀, Glen Osmond, Woodley Vineyard [34°57'S, 138°38'E], 16 November 1952, R.V. Southcott (SAM); 2 specimens (chelicerae only), Mt Osmond [34°57'S, 138°39'E], 16 April 1933, H. Womersley (SAM); 7 ♀, Mt Osmond [34°57'S, 138°39'E], 30 August 1953, R.V. Southcott (SAM); 7 specimens, Waterfall Gully [34°57'S, 138°40'E], north-eastern bank, pond, ex moss and soil, 1968, D.C. Lee (SAM N1991686-94); **Western Australia:** 13 ♀, Wungong Dam [32°11'41"S, 116°03'33"E], on underside of rocks embedded in soil, 26 August 2003, M.S. Harvey, F. Štáhlavský (WAM T55860-55861); 2 ♀, Wungong Dam, hillside above carpark, 32°11'38"S, 116°03'36"E, under rocks, 12 July 2004, M.S. Harvey, J. Waldoock, R. Engel, T. Moulds (WAM T62256); 2 ♀, Wungong Dam, above trail to dam [32°11'40"S, 116°03'37"E], under rocks, 12 July 2004, J.M. Waldoock (WAM T62259). **South**

**Africa: North-West Province:** 6 ♀, Botanical Garden, North-West University, Potchefstroom Campus [26°40'S, 27°05'E], from underside of stones, and from leaf litter, P.D. Theron (WAM 99/1082-1087).

**Remarks**

Identification of female specimens is confirmed by the presence of 5–6 stout glandular setae on sternites V and VI, and by the presence of a single blade in the lateral organ. This combination of features conforms to that described for *E. mirabilis* by previous authors such as Silvestri (1905) and Condé (1991), who noted very slight differences between different populations of *E. mirabilis*.

The anterolateral margin of the prosoma bears a single pair of ovoid lateral organs in specimens from all collections. These blades provide an



Figures 1–2 Maps showing known distribution records of *Eukoenia mirabilis*. 1, total records. 2, detail depicting records in Mediterranean region.



important feature for the identification of palpigrades. Multiple blades, ranging from 2 to 13 blades, in the lateral organ can be found in adults of most species of *Eukoenenia*, some species of *Koeleniodes* (*K. deharvengi*, *K. leclerci*, *K. notabilis* and *K. spiniger*) and all species of *Leptokoenenia*, *Prokoenenia* and *Triadokoenenia*. The number of blades is fairly consistent within a single species, but minor variations in blade number have been recorded, both within populations and on either side of an individual specimen. The presence of only a single blade is a feature shared by only a few species, including *E. mirabilis*, *E. angusta hindua* Condé, 1989, *E. berleseii* (Silvestri, 1903), *E. gadorensis* Mayoral and Barranco, 2002, *E. hesperia* (Rémy, 1953), *E. madeirae* Strinati and Condé, 1995, *E. necessaria* Rémy, 1960, *Allokoenenia afra* Silvestri, 1913, *Koeleniodes berndi* Condé, 1988, *K. frondiger* Rémy, 1950 (Condé 1994, Rémy 1958), *K. madecassus* Rémy 1950 (Condé 1990; Rémy 1961) and *K. malagassorum* Rémy 1960. The adults and, where known, the immatures of all known species of other palpigrade genera (*Leptokoenenia*, *Prokoenenia* and *Triadokoenenia*) bear more than one blade.

The subadult stages of two of these species (*E. mirabilis* and *Koeleniodes frondiger*) are known and, like the adults, bear a single blade in the lateral organ (Rémy 1952, 1958). Other immatures, such as *Allokoenenia?* sp. (Condé 1992), also bear a single blade only. The immature stages of some other *Eukoenenia* species bear just a single blade, but the adults bear multiple blades: *E. condei* Orghidan, Georgesco and Sârbu, 1982, *E. florentiae* (Rucker, 1903) (the "youngest known" stage), *E. lienhardi* Condé, 1989 (stage "immature A"), and various unidentified *Eukoenenia* species (Condé 1994; Rémy 1959, 1960). It may be possible that the presence of a single blade is a pedomorphic trait amongst palpigrades.

#### Distribution

*Eukoenenia mirabilis* was first recorded from Sicily (Grassi 1886, Grassi and Calandruccio 1885) and has been subsequently reported from many other localities in the Mediterranean region ranging from the Canary Islands and Madeira in the west to Israel in the east (Figures 1, 2). The most northerly records are from France but these are based upon specimens collected from artificial environments



Figures 3–4 *Eukoenenia mirabilis*, female (WAM T55860): 3, dorsal aspect. 4, lateral aspect. Note that some of the flagellum has been lost.

such as greenhouses. Outside of the Mediterranean region, *E. mirabilis* has been previously found in Chile, Madagascar and South Australia. The only Chilean record is from San Bernardo (Cekalovic 1984; Condé 1974), whilst in Madagascar, *E. mirabilis* has only been found in the vicinity of Antananarivo (Legendre 1972; Rémy 1950, 1960). *Eukoenia mirabilis* was first recorded from Australia by Savory (1935), who later (Savory 1964) stated that "...in 1933 *Koeneia mirabilis* was found on the lower slopes of Mount Osmond, Adelaide, whither it had most probably been imported." Lee and Southcott (1979) also recorded its presence in the Lofty Ranges on the outskirts of Adelaide, where it can be locally common (the late D.C. Lee, pers. comm.). MSH found many specimens of *E. mirabilis* in the collections of the South Australian Museum collected by H. Womersley, an avid and accomplished collector of minute invertebrates in the Adelaide region (Southcott 1964), the earliest of which was taken in March 1933 at Glen Osmond. These specimens appear to represent the source of Savory's record of *E. mirabilis* which were presumably conveyed to him by Womersley. Since that time many specimens have been collected by Womersley, R. Southcott and D.C. Lee in the eastern suburbs of Adelaide (see list of specimens examined above) suggesting that the species is firmly established in the area.

To these records we now add single localities from Western Australia and South Africa. The Western Australian locality is a natural eucalypt woodland situated on the outskirts of Perth dominated by Marri (*Corymbia calophylla*) with a heath understorey. The palpigrades were found on the underside of stones and rocks that were deeply embedded in the surrounding soil, and the palpigrades moved quickly when disturbed. The South African specimens were collected from the Potchefstroom Campus of the North-West University. The first specimens were recovered from the upper soil in an undisturbed *Acacia karroo* biotope outside of the Botanical Garden. Subsequent sampling revealed fair members of palpigrades running freely on the undersides of stones. Large numbers of isotomid collembolans were noted and they are probably preyed on by the palpigrades.

The discovery of *E. mirabilis* in Western Australia and South Africa, and the confirmation of the identity of the South Australian specimens demonstrates that *E. mirabilis* is more widely distributed in the southern hemisphere than previously suspected. It also suggests that it may eventually be found in other localities. For example, Forster and Forster (1999) noted the presence of at least two species of palpigrades in New Zealand, but at present the specimens cannot be located (P. Sirvid, pers. comm.). Therefore, their identification remains a mystery.

All of the records from the southern continents are situated in Mediterranean climates between 18°S and 35°S, and appear to represent accidental introductions through human agency. The earliest recorded occurrence of *E. mirabilis* from outside the Mediterranean region is from Glen Osmond in 1933. The natural distribution of *E. mirabilis* in the Mediterranean region is impossible to ascertain as centuries of sea-faring trading commerce in the region have probably dispersed these small soil-dwelling animals far beyond their original natural range.

#### ACKNOWLEDGEMENTS

We wish to gratefully acknowledge the assistance of David Hirst for his assistance in allowing access to the collections of the South Australian Museum, Adelaide, and Volker Framenau (Western Australian Museum, Perth) and an anonymous referee for their comments on a draft of the manuscript.

#### REFERENCES

- Cekalovic K., T. (1984). Catalogo de los Pseudoscorpiones y Palpigradi de Chile (Chelicerata). *Boletín de la Sociedad de Biología de Concepción* 55: 7-35.
- Condé, B. (1974). Palpigrades du Chile. *Revue d'Ecologie et de Biologie du Sol* 11: 449-455.
- Condé, B. (1988). Nouveaux Palpigrades de Trieste, de Slovénie, de Malte, du Paraguay, de Thaïlande et de Bornéo. *Revue Suisse de Zoologie* 95: 723-750.
- Condé, B. (1989). Palpigrades (Arachnida) endogés de l'Inde et de Sumatra. *Revue Suisse de Zoologie* 96: 411-424.
- Condé, B. (1990). Palpigrades endogés de Singapour et de l'Indonésie. *Revue Suisse de Zoologie* 97: 681-697.
- Condé, B. (1991). Le Palpigrade *Eukoenia mirabilis* dans les Archipels macaronésiens. *Revue d'Ecologie et de Biologie du Sol* 28: 119-124.
- Condé, B. (1992). Un Palpigrade énigmatique de Thaïlande avec une brève revue des grandes divisions de l'ordre. *Revue Suisse de Zoologie* 99: 741-746.
- Condé, B. (1994). Palpigrades cavernicoles et endogés de Thaïlande et des Célèbes (2<sup>e</sup> note). *Revue Suisse de Zoologie* 101: 233-263.
- Forster, R.R. and Forster, L.M. (1999). *Spiders of New Zealand and their Worldwide Kin*. University of Otago Press and Otago Museum: Dunedin.
- Grassi, B. (1886). I progenitori dei Miriapodi e degli Insetti Memoria V. Intorno ad un nuovo Aracnide artrogastro (*Koeneia mirabilis*) rappresentante di un nuovo ordine (Microthelyphonida). *Bollettino della Società Entomologica Italiana* 18: 153-172.
- Grassi, B. and Calandruccio, S. (1885). Intorno ad un nuovo Aracnide Artrogastro (*Koeneia mirabilis* [sic]) che crediamo rappresentante d'un nuovo ordine (Microteliphonida). *Naturalista Siciliano* 4: 127-133, 162-168.

- Hammen, L. van der (1977). A new classification of Chelicerata. *Zoologische Mededelingen* 51: 307–319.
- Hammen, L. van der (1989). *An Introduction to Comparative Arachnology*. SPB Academic Publishing: The Hague.
- Harvey, M.S. (2003). *Catalogue of the Smaller Arachnid Orders of the World: Amblypygi, Uropygi, Schizomida, Palpigradi, Ricinulei and Solifugae*. CSIRO Publishing: Melbourne.
- Lee, D.C. and Southcott, R.V. (1979). Spiders and other arachnids of South Australia. In B.E. Leonard (ed.), *South Australian Year Book*, pp. 29–43. Australian Bureau of Statistics: Adelaide.
- Legendre, R. (1972). Les Arachnides de Madagascar. In R. Battistini and G. Richard-Vindard (eds), *Biogeography and Ecology in Madagascar*, pp. 427–457. Junk: The Hague.
- Mayoral, J.G. and Barranco, P. (2002). Descripción de una nueva *Eukoenia* Börner, 1901 del Sureste Ibérico (Arachnida, Palpigradi, Microthelyphonida). *Revista Ibérica de Arachnología* 6: 129–134.
- Rémy, P.A. (1950). Palpigrades de Madagascar. *Mémoires de l'Institut Scientifique de Madagascar, Série A* 4: 135–164.
- Rémy, P.A. (1952). Palpigrades de l'île de la Réunion. *Mémoires de l'Institut Scientifique de Madagascar, Série A* 7: 69–79.
- Rémy, P.A. (1953). Description d'un nouveau palpigrade d'Afrique occidentale française. *Bulletin du Muséum National d'Histoire Naturelle, Paris* (2) 25: 86–89.
- Rémy, P.A. (1958). Palpigrades de l'île Maurice. *Mauritius Institute Bulletin* 5: 94–102.
- Rémy, P.A. (1959). Palpigrades et Paupropodes du Natal (nouvelles récoltes du Dr R.F. Lawrence). *Bulletin du Muséum National d'Histoire Naturelle, Paris* (2) 31: 256–260.
- Rémy, P.A. (1960). Palpigrades de Madagascar. II. *Mémoires de l'Institut Scientifique de Madagascar, Série A* 13: 33–66.
- Rémy, P.A. (1961). Les Palpigrades de Ceylan et leur écologie. *Revue Française d'Entomologie* 28: 112–119.
- Rucker, A. (1903). A new *Koenea* from Texas. *Quarterly Journal of Microscopical Science (n. s.)* 47: 215–231.
- Savory, T.H. (1935). *The Arachnida*. Edward Arnold and Co.: London.
- Savory, T.H. (1964). *Arachnida*. Academic Press: London.
- Shultz, J.W. (1990). Evolutionary morphology and phylogeny of Arachnida. *Cladistics* 6: 1–38.
- Silvestri, F. (1903). Fauna Napoletana. Descrizione preliminare di due nuove specie di *Koenea* trovate in Italia. *Annuario del Museo Zoologico della R. Università di Napoli* 1(11): 1–2.
- Silvestri, F. (1905). Note arachnologiche I. Specie Italiane del genere *Koenea* con descrizione delle femmine giovani e del maschio della *K. mirabilis*. *Redia* 2: 239–253.
- Silvestri, F. (1913). Novi generi e specie de Koeneiidae (Arachnida, Palpigradi). *Bollettino di Laboratorio di Entomologia Agraria Portici* 7: 211–217.
- Southcott, R.V. (1964). Obituary and bibliography of Herbert Womersley. *Records of the South Australian Museum* 14: 603–632.
- Strinati, P. and Condé, B. (1995). Grottes et Palpigrades de Madère. *Mémoires de Biospéologie* 22: 161–168.
- Walter, D.E. and Condé, B. (1997). *Eukoenia florenciae* Rucker, 1903 (Arachnida: Palpigradi: Eukoeneiidae), Australia's second record of a cosmopolitan all-female species of palpigrade. *Australian Entomologist* 24: 164.
- Weygoldt, P. (1998). Evolution and systematics of the Chelicerata. *Experimental and Applied Acarology* 22: 63–79.
- Weygoldt, P. and Paulus, H.F. (1979). Untersuchungen zur Morphologie, Taxonomie und Phylogenie der Chelicerata. II. Cladogramme und die Entfaltung der Chelicerata. *Zeitschrift für Zoologische Systematik und Evolutionsforschung* 17: 177–200.
- Wheeler, W.C. and Hayashi, C.Y. (1998). The phylogeny of the extant chelicerate orders. *Cladistics* 14: 173–192.



## A new troglomorphic species of *Austrochthonius* (Pseudoscorpiones: Chthoniidae) from Australia, with remarks on *Chthonius caecus*

Mark S. Harvey<sup>1</sup> and Lee G. Mould<sup>2</sup>

<sup>1</sup>Department of Terrestrial Invertebrates, Western Australian Museum,  
Locked Bag 49, Welshpool DC, Western Australia 6986, Australia.

E-mail: mark.harvey@museum.wa.gov.au

<sup>2</sup>Biota Environmental Sciences Pty Ltd, PO Box 176,  
North Perth, Western Australia 6906, Australia.

E-mail: lee@biota.net.au

---

**Abstract** – A new species of the chthoniid genus *Austrochthonius* Chamberlin is described and named from the Ludlow region of southern Western Australia. *Austrochthonius strigosus* sp. nov. exhibits some strong troglomorphic adaptations such as eye loss, elongate pedipalps and pallid colouration. *Chthonius caecus* Tullgren, 1909, a junior homonym, and its replacement name *Sathrochthonius tullgreni* Chamberlin, 1962, are transferred to *Austrochthonius*. A new replacement name, *Austrochthonius muchmorei*, is provided, as *A. tullgreni* is a junior secondary homonym of *A. tullgreni* (Beier, 1931).

### INTRODUCTION

The chthoniid genus *Austrochthonius* possesses a typical Gondwanan distribution with eight species recorded from southern South America, three species from New Zealand, three species from Australia, one species from the Îles Crozet, and one species from South Africa (Harvey 1991a, 1991c; Judson 2001). The Australian fauna consist of *Austrochthonius australis* Hoff from southern Australia and two troglobitic species from caves in the Naracoorte region, South Australia (*A. cavicola* Beier) and Cape Range peninsula, Western Australia (*A. easti* Harvey). Kennedy (1990) presented a redescription of *A. australis* based upon large quantities of material from south-eastern Australia and noted that the Western Australian specimens attributed to *A. australis* by Beier (1966a) were sufficiently different from *A. australis* that they represented a distinct species. An additional species from the Kimberley region of Western Australia was reported by Harvey (1991b) but it currently remains undescribed.

Epigeal members of *Austrochthonius* in Australia can be quite common in leaf litter and soil, but the troglobitic species are relatively uncommon with just a few specimens collected. Whilst considerable work is needed to unravel the systematic relationships of the genus within Australia, we are here describing a new troglomorphic species of the genus that has been recovered from subterranean sampling undertaken in the Ludlow area near Busselton, south-western Australia. Although only a single male has been collected, it is sufficiently

distinct from all other species of the genus that we have prepared a systematic description to formally record this unusual species in the scientific literature. We also comment on the species first named as *Chthonius caecus* Tullgren from south-western Australia (Tullgren 1909) which has since been transferred to the genus *Sathrochthonius* Chamberlin and renamed *S. tullgreni* (Chamberlin, 1962). We suggest that this species is in fact a species of the genus *Austrochthonius*.

### MATERIAL AND METHODS

The material utilized in the present study is lodged in the Western Australian Museum, Perth (WAM). Terminology and mensuration mostly follows Chamberlin (1931), with the exception of the nomenclature of the pedipalps, legs and with some minor modifications to the terminology of the trichobothria (Harvey 1992). In particular, it should be noted that the terminology for the trichobothria used by Harvey (1992) differs slightly from that used by other workers.

The specimen was examined by preparing a temporary slide mounts by immersing the specimen in 75% lactic acid at room temperature for several days, and mounting it on a microscope slide with 10 mm coverslips supported by small sections of 0.25 mm or 0.50 mm diameter nylon fishing line. It was examined with an Olympus BH-2 compound microscope and illustrated with the aid of a drawing tube. Measurements were taken at the highest possible magnification using an ocular

graticule. After study the specimen was returned to 75% ethanol with the dissected portions placed in 12 x 3 mm glass genitalia microvials (BioQuip Products, Inc.).

## SYSTEMATICS

### Family Chthoniidae Daday

#### Subfamily Chthoniinae Daday

#### Genus *Austrochthonius* Chamberlin

*Austrochthonius* Chamberlin, 1929: 68. Type species: *Chthonius chilensis* Chamberlin, 1923, by original designation.

*Paraustrochthonius* Beier, 1931: 52 (synonymised by Beier, 1976: 203). Type species: *Paraustrochthonius tullgreni* Beier, 1931, by original designation.

*Cecoditha* Mello-Leitão, 1939: 115–116 (synonymised by Judson, 2001: 142). Type species: *Cecoditha parva* Mello-Leitão, 1939, by original designation.

#### Remarks

*Austrochthonius* belongs to a group of genera characterised by the presence of coxal spines only on coxa II and that lack one or more enlarged spine-like setae on the interno-basal margin of the chelal hand. Defined in this way, this group currently includes nine genera: *Austrochthonius*, *Chiliochthonius* Vitali-di Castri, *Drepanochthonius* Beier, *Francochthonius* Vitali-di Castri, *Maorichthonius* Chamberlin, *Malcolmochthonius* Benedict, *Mexichthonius* Muchmore, *Mundochthonius* Chamberlin and *Tyrannochthoniella* Beier. The African genus *Congochthonius* Beier was also attributed by Muchmore (2001) to a group containing some of these genera but the affinities of this unusual genus appear to lie with *Sathrochthonius* Chamberlin and *Sathrochthoniella* Beier due to a small suite of morphological features of which the most prominent is the sub-basal position of trichobothria *ib* and *isb*.

Six genera of the *Austrochthonius* group occur in the southern hemisphere, whereas three genera occur in the northern hemisphere. *Austrochthonius* species are found on all of the southern continents (Harvey 1996), as well as the Îles Crozet (Vitali-di Castri 1968); species of *Chiliochthonius*, *Drepanochthonius* and *Francochthonius* are restricted to Chile (Beier 1964a; Vitali-di Castri 1976); and the genera *Maorichthonius* and *Tyrannochthoniella* are endemic to New Zealand (Beier 1976). The three Laurasian genera, *Mundochthonius*, *Malcolmochthonius* and *Mexichthonius*, occur in North America, whilst species of

*Mundochthonius* have also been recorded from Europe and East Asia (summarized by Harvey 1991a), with subsequent species recently named by Kim and Hong (1994), Muchmore (1996), Sakayori (2002), Dashadamirov (2005) and Zaragoza and Harvey (2006). The relationships and status of some of these genera is doubtful and some rationalisation may be expected in the future.

#### *Austrochthonius strigosus* sp. nov.

Figures 1–5

#### Material Examined

##### *Holotype*

♂, Ludlow region (site LDMB2, 33.58921503°S, 115.4904651°E), 33°35'21"S, 115°29'26"E, Western Australia, Australia, 18 November 2004, from borehole at approximately 5 m depth, L. Mould and D. Kamien (WAM T65550).

#### Diagnosis

*Austrochthonius strigosus* differs from all previously named species of the genus by the elongate pedipalpal chela which is 6.35 times longer than broad in the holotype male, but less than 5.4 times longer than broad in other species (Table 1).

#### Description

*Adult male (holotype, WAM T65550)*: Colour generally pale yellow-brown, legs slightly paler than body.

*Chelicera*: with 5 setae on hand and 1 medial seta on movable finger (Figure 3); fixed finger with 5 small teeth, of approximately same size; movable finger slightly shorter than hand, with 4 small teeth and 2 extremely small teeth; blades of the flagellum not clearly visible; galea a short rounded nubbin.

*Pedipalp*: trochanter 1.73, femur 4.95, patella 1.89, chela 6.35, chelal hand 2.17 times longer than broad; movable chelal finger 1.90 times longer than hand; fixed chelal finger with 69 teeth, moveable chelal finger with 55 teeth, all teeth closely spaced and either gently rounded or slightly truncate (Figure 1); fixed chelal finger and hand with 8 trichobothria, movable chelal finger with 4 trichobothria (Figures 1, 2); *ib* and *isb* situated sub-medially on dorsum of chelal hand; *eb* and *esb* situated sub-laterally at base of chelal fingers; *xs* situated slightly distal to *et* near tip of fixed finger, each hair shorter than those of other trichobothria; *b* situated slightly closer to *t* than to *sb*; *sb* closer to *b* than to *st*; venom apparatus absent.

*Carapace*: 1.05 times longer than broad; without eyes; anterior margin finely denticulate with very distinct and strongly toothed epistome (Figure 5); with 18 setae arranged 6: 4: 4: 2: 2; the pre-ocular seta about 50% length of other setae in anterior row;

Table 1 Species of *Austrochthonius*, with distributions and pedipalpal chela ratios.

Species	Distribution	Ratio of pedipalpal chela length/width	Reference
<i>A. argentinae</i> Hoff	South America	4.81 (female)	(Hoff, 1950)
<i>A. australis</i> Hoff	Australia	4.07 (female)	(Hoff, 1951)
		4.1 (adult)	(Beier, 1966a)
<i>A. bolivianus</i> Beier	South America	4.2 (adult)	(Beier, 1932)
<i>A. cavicola</i> Beier	Australia	5.2 (male)	(Beier, 1967a)
<i>A. chilensis chilensis</i> (Chamberlin)	South America	4.30 (female)	(Chamberlin, 1923)
<i>A. chilensis magalhanicus</i> Beier	South America	not stated	(Beier, 1964a)
<i>A. chilensis transversus</i> Beier	South America	5.4 (male)	(Beier, 1964b)
		4.8 (female)	
<i>A. easti</i> Harvey	Australia	4.17 (male)	(Harvey, 1991c)
<i>A. iguazuensis</i> Vitali-di Castri	South America	2.82 (female)	(Vitali-di Castri, 1975)
<i>A. insularis</i> Vitali-di Castri	Îles Crozet	4.4 (female)	(Vitali-di Castri, 1968)
<i>A. mordax</i> Beier	New Zealand	5.2-5.3 (male)	(Beier, 1967b)
		4.5 (female)	
<i>A. paraguayensis</i> Vitali-di Castri	South America	3.54 (male)	(Vitali-di Castri, 1975)
<i>A. parvus</i> (Mello-Leitão)	South America	5.3 (male)	(Judson, 2001)
<i>A. persimilis</i> Beier	South America	4.0 (female)	(Beier, 1964a)
<i>A. rapax</i> Beier	New Zealand	4.2	(Beier, 1976)
<i>A. semiserratus</i> Beier	South America	4.64 (female)	(calculated from Beier, 1930, fig. 11a)
<i>A. strigosus</i> sp. nov.	Australia	6.35 (male)	this paper
<i>A. tullgreni</i> (Beier)	South Africa	4.6 (adult)	(Beier, 1931)
<i>A. zealandicus zealandicus</i> Beier	New Zealand	4.9-5.2 (male)	(Beier, 1967b)
		4.1-4.4 (female)	(Beier, 1966b)
<i>A. zealandicus obscurus</i> Beier	New Zealand	4.0 (adult)	(Beier, 1966b)

with 3 pairs of lyrifissures, one pair situated antero-medially, the second pair situated interno-lateral to the "ocular" region, and the third pair situated exterior to the sole pair of setae of the posterior row.

**Coxal region:** coxal chaetotaxy: 2+3: 3 + 2m: 4: 5: 5 (Figure 4); manducatory process with 2 acuminate distal setae, about equal in length to each other; pedipalpal coxa without dorsal setae; intercoxal tubercle absent; coxa I without apical projection, but with 2 small microsetae (m) situated on distal margin; other setae on coxa I situated near trochanteral foramen (Figure 4); coxal spines present only on coxa II, 6 (left coxa) or 7 (right coxa) bipinnate spines present, bases not contiguous (Figure 4).

**Legs:** femur+patella IV 2.84 times longer than deep; heterotarsate; arolium slightly shorter than claws, claws simple.

**Abdomen:** tergites and sternites undivided; tergal chaetotaxy, 4: 4: 4: 5: 6: 6: 6: 6: 6: 0; sternal chaetotaxy, 10: (1) 26 (1): (2) 7 [4+4] (2): 9: 8: 8: 8: 8: 8: -: 2. All setae bordering sternite III acuminate. Genitalia of male not studied in detail (due to poor preservation), but 4 pairs of stout glandular setae present within genital atrium. Pleural membrane evenly plicate.

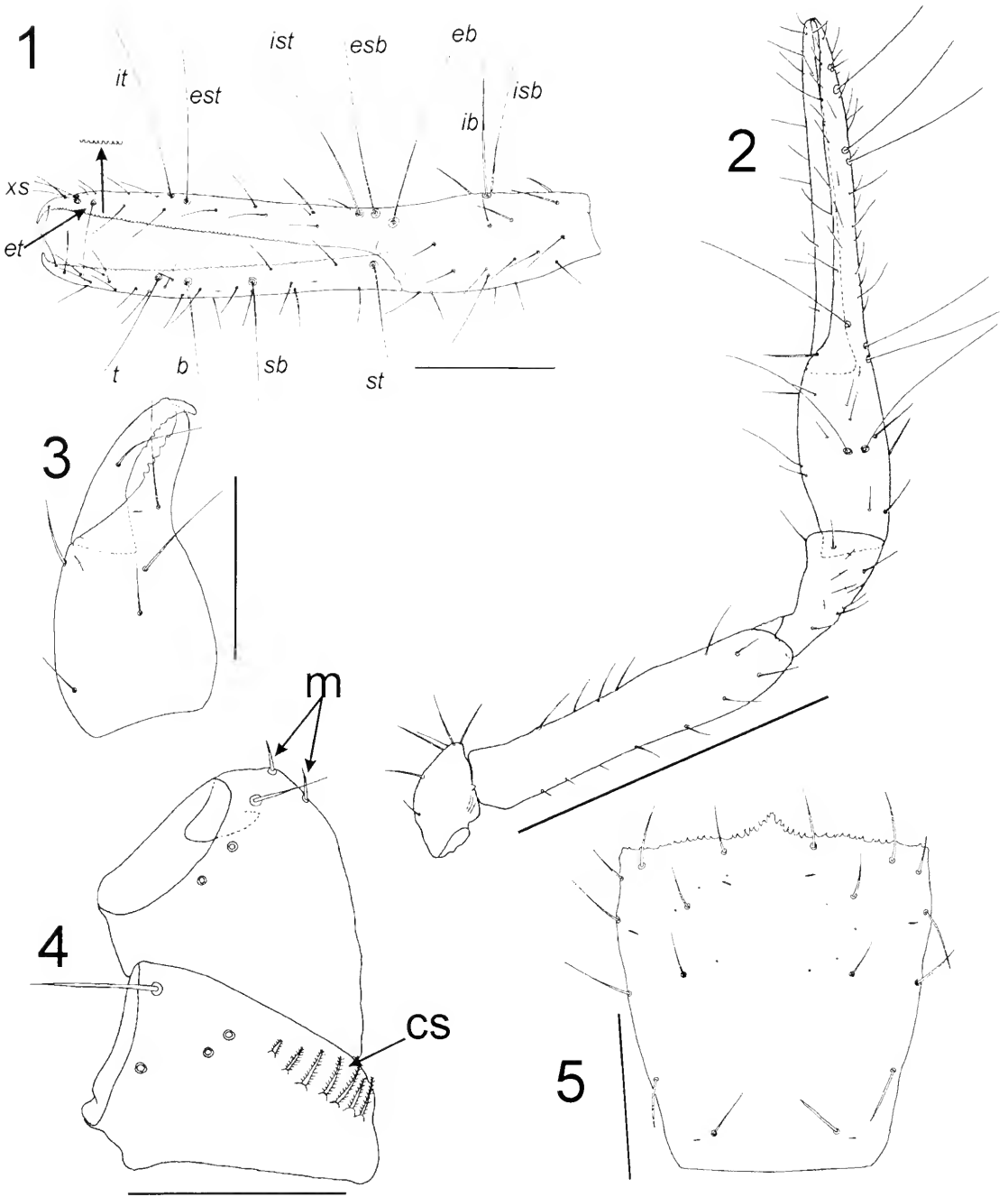
#### Dimensions (mm)

**Holotype male** (WAM T65550): Body length 1.184. Pedipalps: trochanter 0.176/0.102, femur

0.505/0.102, patella 0.217/0.115, chela 0.768/0.121, hand length 0.262, movable finger length 0.499. Chelicera 0.352/0.169, movable finger length 0.195. Carapace 0.403/0.384. Leg I: femur 0.280/0.054, patella 0.131/0.051, tibia 0.150/0.041, tarsus 0.438/0.141. Leg IV: femur + patella 0.417/0.147, tibia 0.301/0.069, metatarsus 0.146/0.052, tarsus missing.

#### Remarks

The single specimen was taken from a bore at a depth of approximately 5 m during sampling targeting stygofauna in the region. The pseudoscorpion was collected in a sample raised to the surface using a modified plankton net and collection jar, lowered into a borehole through a 50 mm diameter piezometer (a non-pumping well, generally of small diameter, for measuring the elevation of a water table or for other groundwater monitoring) within limestone sediments in the Ludlow region. Additional wells were sampled in the area by the junior author and, despite several sampling attempts in the region, no further specimens were obtained. Thus, at present, *A. strigosus* is known only from a single karst location situated in south-western Australia. The type locality comprises open woodland composed of Tuart (*Eucalyptus gomphocephala*, Myrtaceae) and Peppermint (*Agonis flexuosa*, Myrtaceae) with an understorey dominated by weeds including Arum Lily (*Zantedeschia aethiopica*, Araceae) and introduced grasses on a floor of dense leaf litter and sandy soil.



Figures 1–4 *Austrochthonius strigosus* sp. nov., holotype male. 1, left chela, lateral view. 2, right pedipalp, dorsal view. 3, left chelicera, dorsal view. 4, right coxae I and II (abbreviations: ca = coxal spines; m = microsetae). 5, carapace, dorsal view. Scale lines = 0.10 mm (Figure 4), 0.20 mm (Figures 1, 3, 5), 0.50 mm (Figure 2).



The holotype is slightly macerated and covered in a fine sediment which is consistent with the specimen spending some time after death in the water within the bore, or at least on the surface of the water column. It is lacking several legs and the distal segments are missing on others.

On the basis of the total lack of eyes (Figure 5) and the strongly elongated pedipalpal segments (Figures 1, 2), *A. strigosus* is clearly the most troglomorphic species thus far recognized in the genus. The only other cave-dwelling species, *A. cavicola* from the Naracoorte Caves, South Australia and *A. easti* from the Cape Range Caves, Western Australia, possess less elongate pedipalpal segments. Although both *A. strigosus* and *A. cavicola* completely lack eyes (Beier, 1968), *A. easti* has a single pair of small anterior eyes (Harvey, 1991c). All epigeal species of the genus, with the exception of the blind *A. iguazuensis*, either possess two pairs of eyes or a single pair of eyes.

*Austrochthonius strigosus* satisfies the criteria discussed by Harvey (2002) to be considered as a short-range endemic species. It has an exceedingly small distribution and occurs in such a specialised habitat – karst within the Ludlow region – that the total area of occupancy is likely to be minimal.

### Etymology

The specific epithet denotes the slender pedipalpal chela (*strigosus*, Latin, lean, thin).

### *Austrochthonius muchmorei* nom. nov.

*Chthonius caecus* Tullgren, 1909: 414–415, figure 3 [junior primary homonym of *Chthonius coecus* Packard, 1884 and *Chthonius caecus* Simon, 1885].

*Mundochthonius* (?) *caecus* (Tullgren): Beier 1932: 38; Roewer 1937: 238.

*Mundochthonius caecus* (Tullgren): Nicholls 1933: 111; Chamberlin, 1934: 3; Weidner 1959: 115.

*Sathrochthonius tullgreni* Chamberlin, 1962: 306–307 [replacement name for *Chthonius caecus* Tullgren; junior secondary homonym of *Austrochthonius tullgreni* (Beier, 1931)]; Harvey 1981: 241; Harvey 1985: 140–141; Harvey 1991a: 202.

*Sathrochthonius* (?) *tullgreni* Chamberlin: Beier, 1966a: 276; Muchmore 1982: 158.

### Remarks

Tullgren (1909) described *Chthonius caecus* based upon a single male collected from Brunswick (a small town to the south of Perth that is now called Brunswick Junction, 33°15'S, 115°50'E) during the Michaelsen and Hartmeyer Expedition on 7 October

1905. The specimen was doubtfully transferred to the genus *Mundochthonius* by Beier (1932: 38) who reported that the specimen was lost ("Type verloren gegangen"). Weidner (1959) reported that the specimen was lost in July 1930 from the Zoologisches Institut und Zoologisches Museum, Universität Hamburg Germany, which has been recently confirmed for us by Dr Hieronymus Dastyh (in litt., 17 May 2006). Chamberlin (1962) speculated on the identity of *C. caecus* and tentatively transferred it to his newly formed genus *Sathrochthonius*, also noting that it was a junior primary homonym of both *C. coecus* Packard, 1884 and *C. caecus* Simon, 1885 (International Commission on Zoological Nomenclature, 1999, Article 58). To resolve the homonymy, Chamberlin (1962) provided the replacement name *S. tullgreni*. Beier (1966a) and Muchmore (1982) doubted that Chamberlin's generic placement of this species was correct, the former by including a question mark after the generic name [*Sathrochthonius* (?) *tullgreni*], and the latter by stating that "there is no way to determine the identity of this species until topotypic material ... is studied."

The speculation that Tullgren's specimen was a member of the genus *Sathrochthonius* is here believed to be erroneous, and we suggest that it is better placed in the genus *Austrochthonius*. The original description by Tullgren (1909) clearly illustrates a specimen with straight chelal fingers (when viewed dorsally). The chelal fingers of *Sathrochthonius* species are gently but unquestionably curved (e.g., Chamberlin 1962, fig. 1b; Muchmore 1982, fig. 2), whereas species of *Austrochthonius*, as well as many other chthoniids, possess straight or nearly straight chelal fingers. Furthermore, whilst members of *Austrochthonius* are quite common throughout south-western Australia, species of *Sathrochthonius* are very rare. Indeed, the only records of *Sathrochthonius* from the region are of an unnamed species from Quininup (34°28'S, 116°15'E) (WAM 80/1373), West Cape Howe (35°08'S, 117°36'E) (WAM 89/363-364) and Warren National Park near Pemberton (34°27'S, 116°02'E) (WAM 80/1151-1153). The only other chthonioids in the region are *Lagynochthonius australicus* (Beier) which occurs in high rainfall regions along the south coast of Western Australia, and several species of *Pseudotyranochthonius* which are found in a variety of disjunct locations in the area (Harvey, unpublished data). The description of *C. caecus* by Tullgren (1909) clearly demonstrates that it does not belong to either of these genera.

Based upon this reasoning, we here transfer *Chthonius caecus* Tullgren and the replacement name *Sathrochthonius tullgreni* Chamberlin to *Austrochthonius*. Unfortunately this species then becomes a junior secondary homonym of *Austro-*

*chthonius tullgreni* (Beier, 1931) from South Africa. Therefore a replacement name, *A. muchmorei*, is here proposed.

It is beyond the scope of this paper to provide a complete description of *A. muchmorei* as there is more than one species of *Austrochthonius* occurring in leaf litter and soil within south-western Australia (Harvey, unpublished data) and there are considerable difficulties in determining suitable species level boundaries amongst this assemblage.

### Etymology

This species is named for William B. Muchmore, in recognition of his outstanding contribution to pseudoscorpion systematics over a 40-year period. He also suggested that *S. tullgreni* may be misplaced in *Sathrochthonius*.

### ACKNOWLEDGEMENTS

We wish to thank Cable Sands (WA) Pty Ltd for access to the study site and Biota Environmental Sciences Pty Ltd for their resources and support. Dr H. Dastych (Zoologisches Museum und Zoologisches Museum, Universität Hamburg) kindly provided information on the holotype of *Chthonius caecus*, and two anonymous referees made valuable comments on a draft of the manuscript.

### REFERENCES

- Beier, M. (1930). Alcuni Pseudoscorpioni esotici raccolti dal Prof. F. Silvestri. *Bollettino del Laboratorio di Zoologia Generale e Agraria del R. Istituto Superiore Agrario in Portici* 23: 197–209.
- Beier, M. (1931). Zur Kenntnis der Chthoniiden (Pseudoscorpione). *Zoologischer Anzeiger* 93: 49–56.
- Beier, M. (1932). Pseudoscorpionidea I. Subord. Chthoninea et Neobisiinea. *Tierreich* 57: i–xx, 1–258.
- Beier, M. (1964a). Die Pseudoscorpioniden-Fauna Chiles. *Annalen des Naturhistorischen Museums in Wien* 67: 307–375.
- Beier, M. (1964b). The zoological results of Gy. Topál's collectings in South Argentina. 15. Pseudoscorpionidea. *Annales Historico-Naturales Musei Nationalis Hungarici* 56: 487–500.
- Beier, M. (1966a). On the Pseudoscorpionidea of Australia. *Australian Journal of Zoology* 14: 275–303.
- Beier, M. (1966b). Zur Kenntnis der Pseudoscorpioniden-Fauna Neu-Seelands. *Pacific Insects* 8: 363–379.
- Beier, M. (1967a). Some Pseudoscorpionidea from Australia, chiefly from caves. *Australian Zoologist* 14: 199–205.
- Beier, M. (1967b). Contributions to the knowledge of the Pseudoscorpionidea from New Zealand. *Records of the Dominion Museum* 5: 277–303.
- Beier, M. (1968). Some cave-dwelling Pseudoscorpionidea from Australia and New Caledonia. *Records of the South Australian Museum* 15: 757–765.
- Beier, M. (1976). The pseudoscorpions of New Zealand, Norfolk and Lord Howe. *New Zealand Journal of Zoology* 3: 199–246.
- Chamberlin, J.C. (1923). On two species of pseudoscorpion from Chile with a note in [sic] one from Sumatra. *Revista Chilena de Historia Natural* 27: 185–192.
- Chamberlin, J.C. (1929). A synoptic classification of the false scorpions or chela-spinners, with a report on a cosmopolitan collection of the same. Part 1. The Heterosphyronida (Chthoniidae) (Arachnida-Chelonethida). *Annals and Magazine of Natural History* (10) 4: 50–80.
- Chamberlin, J.C. (1931). The arachnid order Chelonethida. *Stanford University Publications, Biological Sciences* 7(1): 1–284.
- Chamberlin, J.C. (1934). Check list of the false scorpions of Oceania. *Occasional Papers of the Bernice P. Bishop Museum* 10(22): 1–14.
- Chamberlin, J.C. (1962). New and little-known false scorpions, principally from caves, belonging to the families Chthoniidae and Neobisiidae (Arachnida, Chelonethida). *Bulletin of the American Museum of Natural History* 123: 303–352.
- Dashdamirov, S. (2005). Pseudoscorpions from the mountains of northern Pakistan (Arachnida: Pseudoscorpiones). *Arthropoda Selecta* 13: 225–261.
- Harvey, M.S. (1981). A checklist of the Australian Pseudoscorpionida. *Bulletin of the British Arachnological Society* 5: 237–252.
- Harvey, M.S. (1985). Pseudoscorpionida. In D.W. Walton (ed.), *Zoological Catalogue of Australia*, vol. 3: 126–155. Australian Government Publishing Service: Canberra.
- Harvey, M.S. (1991a). *Catalogue of the Pseudoscorpionida*. Manchester University Press: Manchester.
- Harvey, M.S. (1991b). The Pseudoscorpionida and Schizomida of the Kimberley Rainforests. In N.L. McKenzie, R.B. Johnston and P.G. Kendrick (eds), *Kimberley Rainforests*, pp: 265–268. Surrey Beatty & Sons: Chipping Norton.
- Harvey, M.S. (1991c). The cavernicolous pseudoscorpions (Chelicerata: Pseudoscorpionida) of Cape Range, Western Australia. *Records of the Western Australian Museum* 15: 487–502.
- Harvey, M.S. (1992). The phylogeny and classification of the Pseudoscorpionida (Chelicerata: Arachnida). *Invertebrate Taxonomy* 6: 1373–1435.
- Harvey, M.S. (1996). The biogeography of Gondwanan pseudoscorpions (Arachnida). *Revue Suisse de Zoologie, hors série* 1: 255–264.
- Harvey, M.S. (2002). Short-range endemism in the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* 16: 555–570.
- Hoff, C.C. (1950). Pseudoscorpionidos nuevos o poco conocidos de la Argentina (Arachnida, Pseudoscorpionida). *Arthropoda, Buenos Aires* 1: 225–237.
- Hoff, C.C. (1951). New species and records of chthoniid pseudoscorpions. *American Museum Novitates* 1483: 1–13.
- International Commission on Zoological Nomenclature

- (1999). *International Code of Zoological Nomenclature*, fourth edition. International Trust for Zoological Nomenclature: London.
- Judson, M.L.I. (2001). Synonymy of *Cecoditha* (Cecodithinae) with *Austrochthonius* (Chthoniinae) (Chelonethi, Chthoniidae). *Journal of Arachnology* **29**: 141–145.
- Kennedy, C.M.A. (1990). Redescription of *Austrochthonius australis* Hoff (Chthoniidae: Pseudoscorpionida). *Proceedings of the Linnean Society of New South Wales* **111**: 233–240.
- Kim, T.H. and Hong, Y. (1994). Two new species of Chthoniidae (Arachnida: Pseudoscorpiones) from Korea. *Korean Journal of Systematic Zoology* **10**: 47–53.
- Mello-Leitão, C. (1939). Pseudoscorpionidos de Argentina. *Notas del Museo de La Plata* **4**: 115–122.
- Muchmore, W.B. (1982). A new cavernicolous *Sathrochthonius* from Australia (Pseudoscorpionida: Chthoniidae). *Pacific Insects* **24**: 156–158.
- Muchmore, W.B. (1996). A new *Mundochthonius* from the Dominican Republic (Pseudoscorpionida: Chthoniidae). *Insecta Mundi* **10**: 104.
- Muchmore, W.B. (2001). An unusual new species of *Mundochthonius* from a cave in Colorado, with comments on *Mundochthonius montanus* (Pseudoscorpiones, Chthoniidae). *Journal of Arachnology* **29**: 135–140.
- Nicholls, G.E. (1933). The composition and biogeographical relations of the fauna of Western Australia. In A.B. Walkom, (ed.), *Report of the Twenty-First Meeting of the Australian and New Zealand Association for the Advancement of Science, Sydney Meeting, August, 1932*, pp: 93–138. Australian and New Zealand Association for the Advancement of Science: Sydney.
- Packard, A.S. (1884). New cave arachnids. *American Naturalist* **18**: 202–204.
- Roewer, C.F. (1936, 1937, 1940). Chelonethi oder Pseudoskorpione. In H.G. Bronns (ed.), *Klassen und Ordnungen des Tierreichs*, vol. **5(IV)(6)(1)**: 1–534. Akademische Verlagsgesellschaft M.B.H.: Leipzig.
- Sakayori, H. (2002). Two new species of the family Chthoniidae from Kyushu, in western Japan (Arachnida: Pseudoscorpionida). *Edaphologia* **69**: 1–8.
- Simon, E. (1885). Arachnides recueillies dans la vallée de Tempé et sur le mont Ossa (Thessalie) par M. de Dr J. Stussiner (de Laibach). *Annales de la Société Entomologique de France* (6) **5**: 209–217.
- Tullgren, A. (1909). Chelonethi. In Michaelsen, W. and Hartmeyer, R. (eds), *Fauna Südwest-Australiens*, vol. **2**: 411–415. Gustav Fischer: Jena.
- Vitali-di Castri, V. (1968). *Austrochthonius insularis*, nouvelle espèce de pseudoscorpions de l'Archipel de Crozet (Heterosphyronida, Chthoniidae). *Bulletin du Muséum National d'Histoire Naturelle, Paris* (2) **40**: 141–148.
- Vitali-di Castri, V. (1975). Nuevos *Austrochthonius* sudamericanos (Pseudoscorpionida, Chthoniidae). *Physis, Buenos Aires* **34**: 117–127.
- Vitali-di Castri, V. (1976). Deux nouveaux genres de Chthoniidae du Chili: *Chiliochthonius* et *Francochthonius* (Arachnida, Pseudoscorpionida). *Bulletin du Muséum National d'Histoire Naturelle, Paris* (3) **334**: 1277–1291.
- Weidner, H. (1959). Die Entomologischen Sammlungen des Zoologischen Staatsinstituts und Zoologischen Museums Hamburg. I. Teil. Pararthropoda und Chelicerata I. *Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institute* **57**: 89–142.
- Zaragoza, J.A. and Harvey, M.S. (2006). The first record of the genus *Mundochthonius* Chamberlin (Pseudoscorpiones: Chthoniidae) from Spain: *Mundochthonius gallaecicus* sp. nov. *Revista Ibérica de Aracnología* **12**: 17–23.







S 1088-

# Guide to Authors

## Subject Matter:

Reviews, observations and results of research into all branches of natural science and human studies will be considered for publication. However, emphasis is placed on studies pertaining to Western Australia. Longer papers will be considered for publication as a Supplement to the *Records of the Western Australian Museum*. Short communications should not normally exceed three typed pages and this category of paper is intended to accommodate observations, results or new records of *significance*, that otherwise might not get into the literature, or for which there is a particular urgency for publication. All material must be original and not have been published elsewhere.

## Presentation:

Authors are advised to follow the layout and style in the most recent issue of the *Records of the Western Australian Museum* including headings, tables, illustrations and references.

The title should be concise, informative and contain key words necessary for retrieval by modern searching techniques. An abridged title (not exceeding 50 letter spaces) should be included for use as a running head.

An abstract must be given in full length papers but not short communications, summarizing the scope of the work and principal findings. It should normally not exceed 2% of the paper and should be suitable for reprinting in reference periodicals.

The International System of units should be used.

Numbers should be spelled out from one to nine in descriptive text; figures used for 10 or more. For associated groups, figures should be used consistently, e.g., 5 to 10, not five to 10.

Spelling should follow the *Concise Oxford Dictionary*.

Systematic papers must conform with the International Codes of Botanical and Zoological Nomenclature and, as far as possible, with their recommendations.

Synonymies should be given in the short form (taxon, author, date, page) and the full reference cited at the end of the paper. All citations, including those associated with scientific names, must be included in the references.

## Manuscripts:

The original and two copies of manuscripts and figures should be submitted to the Editor, c/- Publications Department, Western Australian Museum, Locked Bag 49, Welshpool DC, Western Australia 6986. They must be in double-spaced typescript on A4 sheets. All margins should be at least 30 mm wide. Tables plus heading and legends to illustrations should be typed on separate pages. The desired position for insertion of tables and illustrations in the text should be indicated in pencil. Tables should be numbered consecutively, have headings which make them understandable without reference to the text, and be referred to in the text.

High quality illustrations are required to size (16.8 cm x 25.2 cm) or no larger than 32 cm x 40 cm with sans serif lettering suitable for reduction to size. Photographs must be good quality black and white prints, not exceeding 16.8 cm x 25.2 cm. Scale must be indicated on illustrations. All maps, line drawings, photographs and graphs, should be numbered in sequence and referred to as Figure/s in the text and captions. Each must have a brief, fully explanatory caption. On acceptance a computer disk containing all corrections should be sent with amended manuscript. The disk should be marked with program (e.g. Word, WordPerfect, etc).

In papers dealing with historical subjects references may be cited as footnotes. In all other papers references must be cited in the text by author and date and all must be listed alphabetically at the end of the paper. The names of journals are to be given in full.

## Processing:

Papers and short communications are reviewed by at least two referees and acceptance or rejection is then decided by the editor.

The senior author is sent one set of page proofs which must be returned promptly.

The senior author will receive fifty free offprints of the paper. Additional offprints can be ordered at page proof stage.

*Records of the Western Australian Museum*  
*Volume 23 Part 2 2006*

CONTENTS

- R.E. Johnstone**  
The birds of Gag Island, Western Papuan islands, Indonesia 115
- David L. Morgan and Howard S. Gill**  
Osteology of the first dorsal fin in two terapontid fishes,  
*Leiopotherapon unicolor* (Günther, 1859) and *Amniataba caudavittata*  
(Richardson, 1845), from Western Australia: evidence for hybridisation? 133
- Volker W. Framenau**  
The wolf spider genus *Venatrix* Roewer: new species, synonymies and  
generic transfers (Araneae, Lycosidae) 145
- Mark S. Harvey**  
New species and records of the pseudoscorpion family Menthidae  
(Pseudoscorpiones) 167
- Brian Morton**  
The functional morphology of *Penicillus philippinensis*  
(Anomalodesmata: Clavagelloidea: Penicillidae) and the evolution of  
an unique muscular system in the Bivalvia 175
- Gregory D. Edgecombe**  
A troglobitic cryptopid centipede (Chilopoda: Scolopendromorpha)  
from western Queensland 193
- Mark S. Harvey, František Štáhlavský and Pieter D. Theron**  
The distribution of *Eukoenenia mirabilis* (Palpigradi: Eukoeneniidae):  
a widespread tramp 199
- Mark S. Harvey and Lee G. Mould**  
A new troglomorphic species of *Austrochthonius* (Pseudoscorpiones:  
Chthoniidae) from Australia, with remarks on *Chthonius caecus* 205