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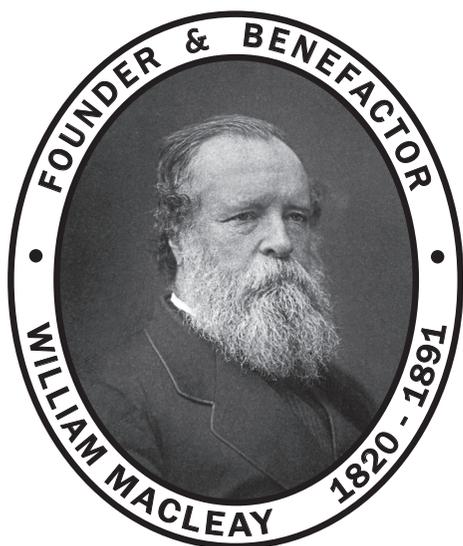
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Cover motif: *Diaphanosoma hamatum* sp. nov., parthenogenetic females, claypan No. 1 near Onslow (Western Australia) – thoracic limb of first pair.

A New Species of the Genus *Diaphanosoma* Fischer (Crustacea: Cladocera: Sididae) from Claypans in Western Australia

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Diaphanosoma hamatum sp. nov. is described from material from claypans of a restricted area near Onslow in the north-west of Western Australia. It is characterized by some peculiar features, such as presence of well developed rostrum, small reduced eye, and large hooked spine on the apical end of upper two-segmented antennal branch, which distinguish it from other known species of the genus. The new species is probably closely related to the Australian *D. unguiculatum* and may be considered as the additional member of the Australian endemic fauna. The ecological significance of morphological features of the species is discussed.

INTRODUCTION

Previous revisions of genus *Diaphanosoma* in Australia recorded five species (Korovchinsky 1981; Kořinek 1983) among which two species, *D. unguiculatum* Gurney, 1927 and *D. australiensis* Korovchinsky, 1981, appeared to be endemic. At that time only a small set of samples from the eastern part of Australia was studied. It was suggested that other species could occur in the centre, north and west of the continent (Korovchinsky 1981).

The recent collection of samples from the north-west of Western Australia has yielded three samples with the representatives of *Diaphanosoma,* one of which contained *D. excisum,* Sars, 1885 (a paperbark swamp near Onslow, clear open water) while in two others from the claypans with very turbid water the specimens of a new peculiar species were found

which is described herein. This species is common in claypans of the Ashburton River delta near Onslow (Timms, 2009).

DESCRIPTION OF LOCALITIES, MATERIAL AND METHODS

The localities are two claypans a little south of Onslow (northwest Western Australia), one 13.8 km and the other 18.6 km south. The first is 0.8 ha and the second 5.6 ha in area and both are usually less than 0.5 m deep. They fill after summer cyclones for a few to many weeks (about 10 weeks early February to late April in 2009). Water was red-brown, always very turbid (average 1725 NTU in the first and > 6000 NTU in the second), alkaline (pH = 7.6 and 7.8 respectively at time of collection and between 7.4 and

9.6 for the season) and quite fresh (conductivity 88 and 166 mS/cm respectively). Associated zooplankters include the copepod *Calamoecia halsei* Bayly 1998, the cladoceran *Moina* sp., the ciliate *Epistylis* sp. and the anostracan *Branchinella pinderi* Timms, 2008.

Zooplankton was collected with a net of mesh 35 µm on a rectangular frame 27 x 15 cm designed especially for sampling shallow waters. Samples were examined under the dissecting microscope Lomo MBS−10 and compound microscope Olympus BX51 with *camera lucida*. Body measurements were made according to Korovchinsky (2004a) mostly on specimens from the claypan No. 1. To count the number of eye ommatidia, the eye pigment was dissolved with NaOH. Molar structure of mandibles was described according to Edwards' (1980) terminology. Some specimens from both localities were prepared according to method proposed by Laforsch and Tollrian (2000), mounted on an aluminium stub, coated with gold, and examined under a scanning electron microscope (SEM) Vega-Tescan at the Institute of Ecology and Evolution.

Type material

Holotype. Female, claypan 18.6 km south of Onslow, WA, 21º48'12''S and 115º06'01''E, 15 February 2009, coll. B.V. Timms, WAM 45117. Paratypes. 10 females, same data as for holotype, WAM 45118 and 10 other females from the same sample were placed in the Zoological Museum of Moscow State University (Ml 107).

Other material

50 adult females, many deformed, from claypan 18.6km south of Onslow, WA, 21º48'12''S and 115º06'01''E, 15 February 2009, coll. B.V. Timms and 19 adult females and six juveniles from claypan 13.8 km south of Onslow, WA, 21º45'40''S and 115º 05'40''E, 12 March 2009, coll. B.V. Timms have been placed in the collection of NMK.

Abbreviations

AnL – length of swimming antennae, BL – body length, BaL – length of basipodite, D – diagonals of molar surface, DE – diameter of eye, F – fishbones of molar surface, HH – head height, HL – head length, I – large two-segmented setulated seta on distal corner of gnathobases of tl I − tl V, J − modified thorn-like naked, hooked seta on distal corner of gnathobases of tl III − tl V, LAn – length of lower antennal branch, *n* - number of filtering setae of endopodite and gnathobase of thoracic limbs, p − not setulated setae on proximal corner of gnathobases of tl II − tl V; Pa – pales of molar surface, Pe – pegs of molar surface, PL – length of postabdomen, PSL – length of postabdominal setae, tl I…tl VI − thoracic limbs of first…sixth pairs, UAn – length of upper antennal branch.

DESCRIPTION AND REMARKS

Diaphanosoma hamatum **sp. nov.**

Body measurements of specimens are presented in Table 1.

Parthenogenetic female. Body oval-elongated with comparatively small head (length 32.1 – 37.5% and height 22.7 – 30.8% of body length), having massive and slightly protruding dorsal part (Figs 1a and 1b) and quite developed triangular rostrum (Figs 1b and 1c) (in two studied populations the shape of rostrum was slightly different, being more sharply narrowed in representatives from population No. 2). Eye comparatively very small (2.3 – 3.4% of body length), consisting of 10 ommatidia, and situated closer to the ventral head margin (Figs 1a and 1b). Antennules small situated close to rostrum's base and with sensory seta sitting on the prominent apical end of their base (Figs 1b and 1d).

Swimming antennae long (63.8 – 75.4% of body length) with massive basipodite, having long, naked

Table 1. Measurements of body size and body parts' proportions of *Diaphanosoma hamatum* from a claypan No. 1 near Onslow, 15 February 2009 (n = 17) (in each column from top to down: range, M, SD, CV).

BL	HL: BL, %	HH: BL, %	AnL:BL, %	UAn:BaL, %	LAn:BaL, %	DE:BL, %	PL:BL, %	PSL:BL, %
0.82-1.16	32.1-37.5	22.7-30.8	63.8-75.4	71.2-87.7	46.2-56.5	2.3 - 3.4	13.8-18.9	51.1-64.2
0.95	34.5	27.1	69.3	79.5	51.0	2.9	16.0	59.0
0.09	1.8	2.4	3.5	5.0	2.9	0.3	1.4	4.2
10.0	5.2	8.8	5.1	6.3	5.8	10.0	8.7	7.1

Figure 1. *Diaphanosoma hamatum* sp. nov., parthenogenetic females, claypan No. 1 near Onslow (Western Australia). a– general lateral view; b– head, lateral view (rostrum is indicated by arrow); c– head, ventral view (rostrum is indicated by arrow); d– antennule; e– basal part of antennal basipodite, dorsal view; f– distal part of antennal basipodite, outer side; g– the same, inner side; h– distal part of proximal segment of upper antennal branch; i– apical part of distal segment of upper antennal branch, inner side; j– the same, outer side; k– distal part of lower antennal branch; l– maxillula (mx I) and maxilla (mx II).

Proc. Linn. Soc. N.S.W., 133, 2011

3

seta on dorsal side of its base (Fig. 1e). Distal part of antennal basipodite with rather long and stout spine on its outer middle side and small prominence in front of upper branch, and with a small correspondent prominence on the basal part of the latter as well (Fig. 1f). Inner side of basipodital distal end with long feathered seta (Fig. 1g). Upper two-segmented antennal branch (exopodite) comparatively long (71.2 – 87.7% of basipodite length), its proximal segment with dorsally large spine and wide rounded prominence laterally (Fig. 1h). Distal segment of this branch apically with a very long, massive, distally curved spine, bearing dorsally a row of tiny denticles (14.2 – 14.5% of body length and 20.5 – 21.3% of antennae length) (Figs 1i and 4a). Three small prominences near the base of this spine, one on outer side of segment's apical end (Fig. 1j) and two on its inner side (Fig. 1i). All lateral setae of both segments armed uniformly with comparatively stout setules of swimming type while two longest apical setae armed proximally with similar setules but distally – with thin sparsely situated setules of sensory type. Lower three-segmented antennal branch (endopodite) shorter (46.2 – 56.5% of basipodite length), its second segment most developed, long and stout, bearing apically one long seta and a strong spine while distal segment with four long setae, one spine and small prominence near the base of middle apical seta (Figs 1k and 4b). Apical setae of the branch armed distally with thin, sparsely situated setules of sensory type similar to those of apical seta of upper antennal branch. Formula of antennal setae: 4 – 8 / 0 – 1 – 4. In juvenile specimens with body length about 0.6 mm, the proximalmost seta of both segments of upper antennal branch rudimental.

Mouthparts of maxillules (mx I), each with 6 – 7 densely situated feathered setae incurved forward, small maxillae (mx II) (Fig. 1l) situated just near base of tl I, having seta-like outgrowth in the middle of its anterior side and opening of maxillary gland on its posterior side, and mandibles. Right mandible (Fig. 4d) with triangular molar plate, having one large thorn (peg – Pe) posteriorly, a row of about seven conical prominences (pales – Pa) along dorsal margin which soon disappear and then appear again on the anterior margin of the mandible as three short, massive prominences with some apical digitiform appendages. Ventral margin of the mandible apparently lacks any prominences; central part deeply concave with parallel rows of ribbed diagonals (D). Left mandible (Fig. 4c) wider, with a group of pegs, consisting of two, larger and conical, and two other ones, both thinner with small apical prominences, at its dorso-posterior angle. Some parallel rows of wide pales mostly fused

together and forming almost entire ventral molar margin. Small group of long fishbones with divided apical ends near pegs. Most parts of molar surface with some parallel diagonals, diminishing in size anteriorly and becoming smoother.

Shell with arched dorsal side, having two strong dorso-lateral muscular bands (Figs 1a and 2a) and a conspicuous dorso-posterior angle. Valves with rather short posterior margin smoothly connected with ventral margin (Fig. 2b) and forming narrow inner inflexion bearing about 12 long feathered setae with very thin setules. Ventro-posterior valve margin armed with numerous small marginal and submarginal spinules, becoming even more submarginal dorsally, and a row of 10 – 12 long, thin setula-like setae (Fig. 2b and 2c). Posterior valve margin with wide rounded or bilobed prominence and a group of usually three, rarely two or four, thorn-like finely denticulated setae on its inner side (Figs 2b and 2d).

Six pairs of thoracic limbs, all with epipodites. Their structure and armament are shown in Table 2. Exopodite of tl I comparatively narrow at its end (Fig. 3a) while from tl II to tl VI epipodite widened terminally (Figs 3b and 3f). Endopodites of tl I and tl II more or less clearly subdivided in four parts ("segments"), the proximal part the largest (I), bearing numerous filtering setae (29 – 50), while three terminal segments (II – IV) with from four to eight such setae each. Terminal segment (IV) from tl II to tl V and subterminal segment (III) from tl I to tl V with also outer setae each, similar with those of exopodite, of which usually the former one, except tl I, especially long (Figs 3a and 3b). No small naked seta on the end of basal segment IV above the row of filtering setae. Endopodital filtering setae with a fascicle of more rough setules terminally (Fig. 3c). Gnathobases of tl I with outer row of 8–9 filtering finely setulated setae, setules of which apparently disposed in two rows situated under the right angle one to another together with a parallel row of small sharp denticles (Fig. 3g). Inside of these filtering setae the gnathobase with two other setae, one of which (I) is long, two-segmented with short setules distally and another one (i) curved and setulated as well. Gnathobase of tl II large with 33–36 filtering setae, ending proximally with one small naked seta (p) and distally with one long, two-segmented setae with quite rough setules (Fig. 3b). Gnathobases of tl III – tl V smaller, bearing only 16–20 filtering setae each, one small naked seta proximally (p) (Fig. 3e), and one additional naked, hooked seta distally (J) near long setulated seta (Fig. 3d). Tl VI small and strongly modified (Fig. 3f). Its exopodite reduced up to terminal plate, arming with six marginal setae.
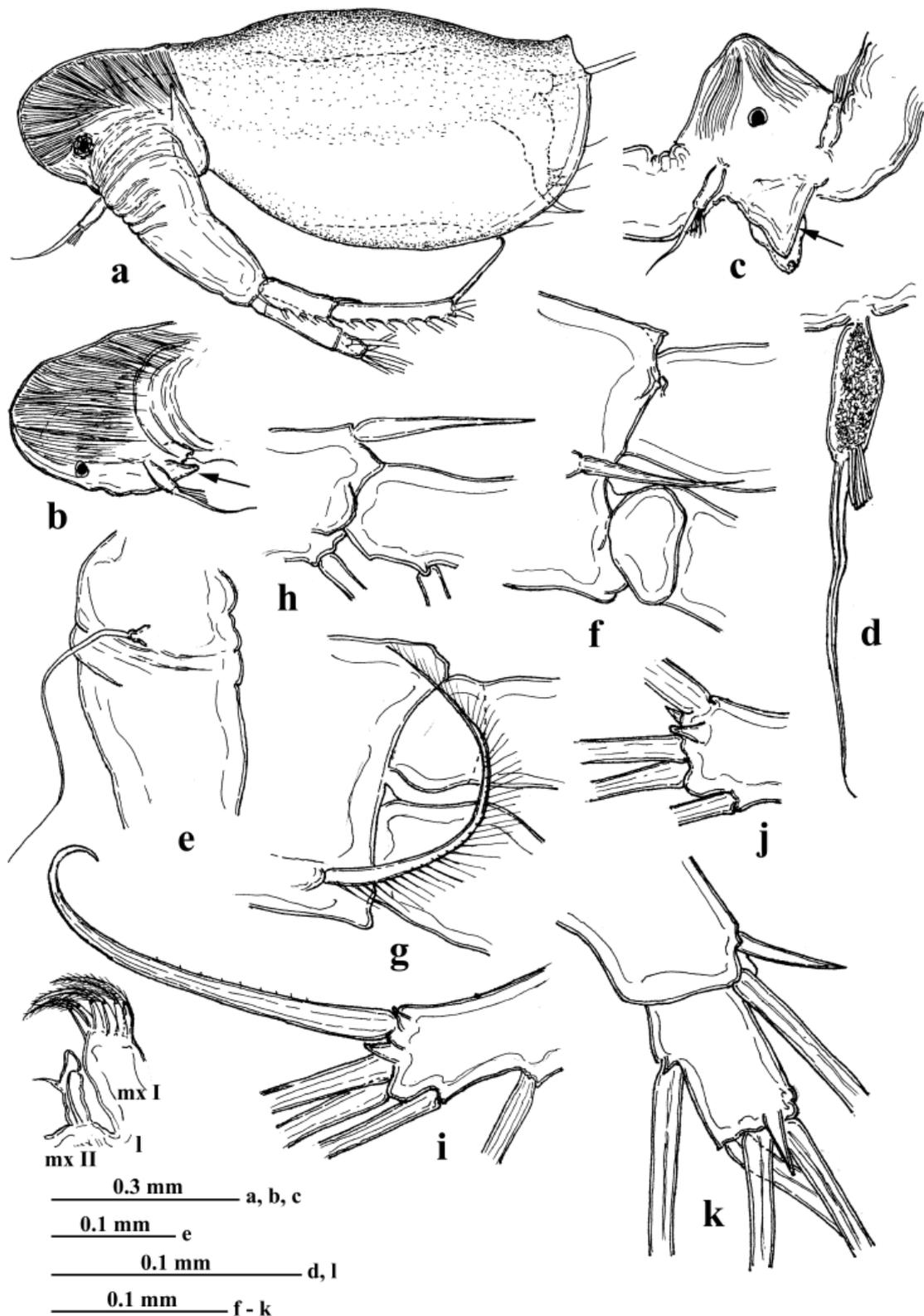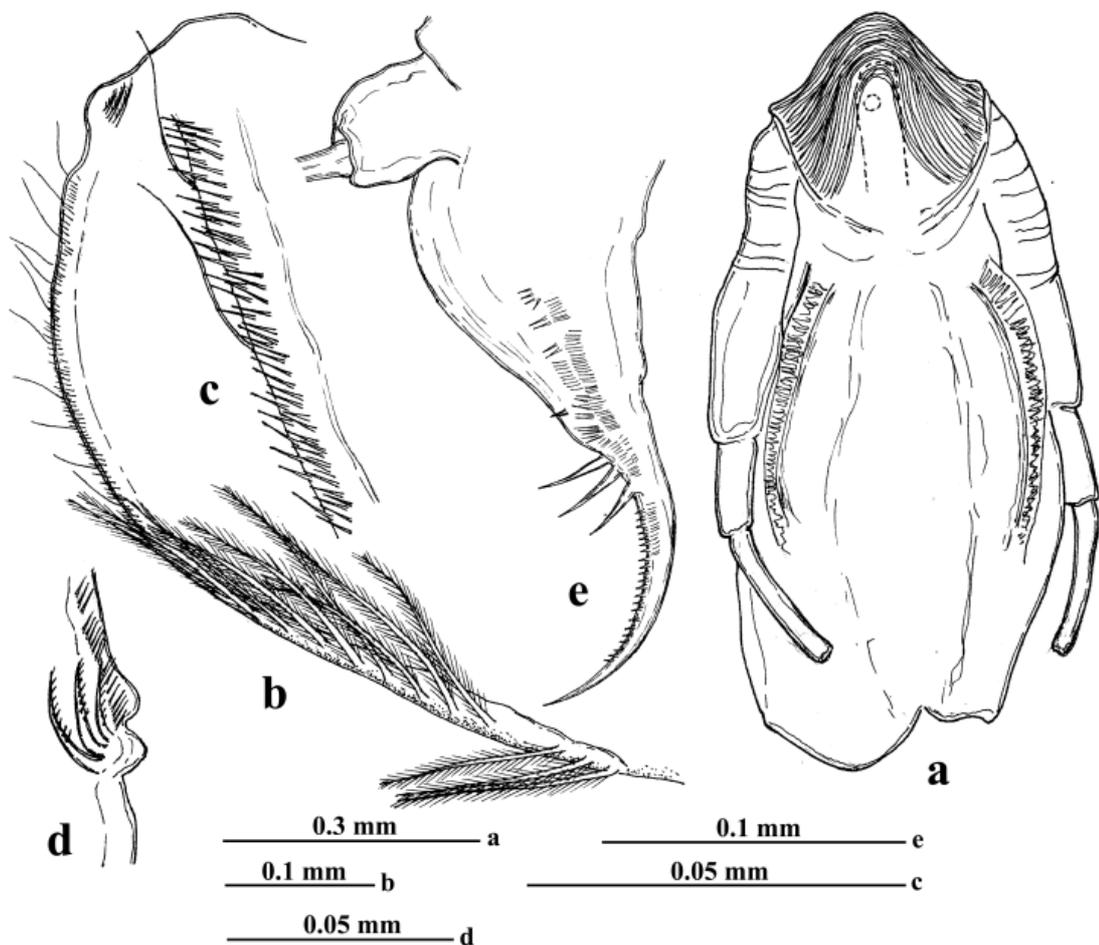
4

Proc. Linn. Soc. N.S.W., 133, 2011

Figure 2. *Diaphanosoma hamatum* sp. nov., parthenogenetic females, claypan No. 1 near Onslow (Western Australia). a – general dorsal view; b – structure and armament of shell valve, inner view; c – armament of ventro-posterior valve margin; d – thorn-like setae near posterior valve margin; e – postabdomen, lateral view.

Endopodite with seven similar setae and one thorn, situating proximally. Gnathobase with two long setae and three thorns of different shape.

Postabdomen comparatively short (13.8 – 18.9% of body length) and cone-shaped with long postabdominal setae (51.1 – 64.2% of body length) (Fig. 2e). Postabdomen armed with longitudinal rows of rough spinules and small, thin anal teeth (Figs 2e and 4e) whose number and disposition vary considerably, from few to numerous and form solitary to clustered (Fig. 4e). In specimens from population No. 2 these teeth were more numerous. Terminal postabdominal claws with three long basal spines of almost equal size, though the distal one seems slightly shorter (Figs 2e and 4f). A row of rough spinules near the basal spines. Distally claws with a dorsal row of comparatively large denticles, diminishing terminally.

Body length 0.82 – 1.16 mm. All females lacked eggs or embryos in their brood pouches. Gamogenetic females and males are not known.

Differential diagnosis

The described new species differs from all known species of the genus by the presence of well developed rostrum, very small eye, and unusual long hooked spine on the end of upper two-segmented antennal branch. The closest species, *D. unguiculatum* (see Korovchinsky 1981, 1992), has a larger body size (up to 1.51 mm), and similar long spines on the end of antennal basipodite and on the ends of each segment of antennal branches. However its terminal spine of the upper branch is not so developed and possesses only tiny rudimental hook. The eye of the latter species is large and anal teeth are larger and usually more numerous.

Proc. Linn. Soc. N.S.W., 133, 2011

5

Table 2. Data on structure and armament of thoracic limbs of Diaphanosoma hamatum from claypan No. 1 near Onslow (WA)

Limb pairs	Exopodite (apical+ lateral setae)	Endopodite	Gnathobase	Epipodite
I	6 + 5	$(n6–8)+(n4+1)+(n4n)+(n48–50)$	$n8 + (I + i)$	+
II	7 + 5	$(n8+1)+(n4–5+1)+(n29–30)$	$n33–36 + p + (I)$	+
III	7 + 4	$n39 +1 + 1$	$n19 + p + (I + J)$	+
IV	7 + 4	$n33 + 1 + 1$	$n18–20 + p + (I + J)$	+
V	6 + 4	$n27–28 + 1 + 1$	$n16–18 + p + (I + J)$	+
VI	5 + 1	7 + one thorn	2 + three thorns	+

Etymology

The species name '*hamatum*' meaning 'supplied with a hook' in Latin, is suggested by the presence of a large hooked spine on the apex of the upper antennal branch.

DISCUSSION

The new species occurs only in claypans of the Onslow area, not in other local biotypes, and is one of the characteristic species of this biotype along with *Calamoecia halsei, Daphnia projecta* Hebert, 1977, *Branchinella pinderi, B. mcraeae* Timms, 2007 and the clam shrimp *Caenestheria sarsii* (Sayce, 1903). It was present in most claypans for most of their hydroperiod, unlike the large branchiopods which only live for the first few weeks of the hydroperiod.

Certainly, this species is highly specialized ecologically as well as morphologically. As it was described above, *D. hamatum* has well developed rostrum which probably protects the area of mouth parts from the mechanical damage possible at life in such shallow turbid environment, the water of which is saturated with inorganic clay particles. All other known species of Diaphanosoma lack a rostrum except *D. freyi* which possesses two rostrum-shaped prominences on the ventral side of head (Korovchinsky 2004b). The presence of a small eye with only 10 ommatidia is also understandable because light hardly penetrates such turbid water. The structure of the eye differs sharply from that of other species of the genus, having normally large eye with 50 – 67 ommatidia (see Korovchinsky 2004a). Interestingly another crustacean inhabitant

of these very turbid claypans, *Branchinella pinderi*, also has markedly reduced eyes (Timms, 2008). The unusual dorso-lateral bands of shell valves possibly serve for their better closing needed to protect the filtering structures of thoracic limbs. Meanwhile, the adaptive significance of enormous hooked spine on the end of upper antennal branch is not clear. It may be suggested that it serves for the attaching to the substrate but judging by body structure of the species and structure and armament of its appendages (elongated body, large head with developed dorsal muscular part, small antennules, long and powerful swimming antennae with long terminal setae on both branches, having differentiated setular armament, and long postabdominal setae), *D. hamatum* seems to be purely planktonic. On the other hand, such mode of life requires a minimum body weight so that the presence of such massive structure, having no vital significance, is presently inexplicable. Many claypans of the area, including the second claypan, have some aquatic macrophytes, which may allow the new species to temporarily anchor to a plant. All other cladocerans, having the attaching organs, are littoral- or bottom-dwellers. For instance, some littoral-benthonic Sididae have attaching structures but of different types – as the head anchoring organs (*Sida*) or long antennal setae with hooked ends (*Pseudosida, Latonopsis, Sarsilatona*) (Korovchinsky 2004a). The representatives of *Simocephalus* (Daphniidae) and *Moinodaphnia* (Moinidae) use for the attachment the special modified seta or enlarged spine situated apically on the upper antennal branch (Fryer 1991; Orlova-Bienkowskaja 2001). The enlarged terminal antennal spine of *Moinodaphnia* mostly resembles that
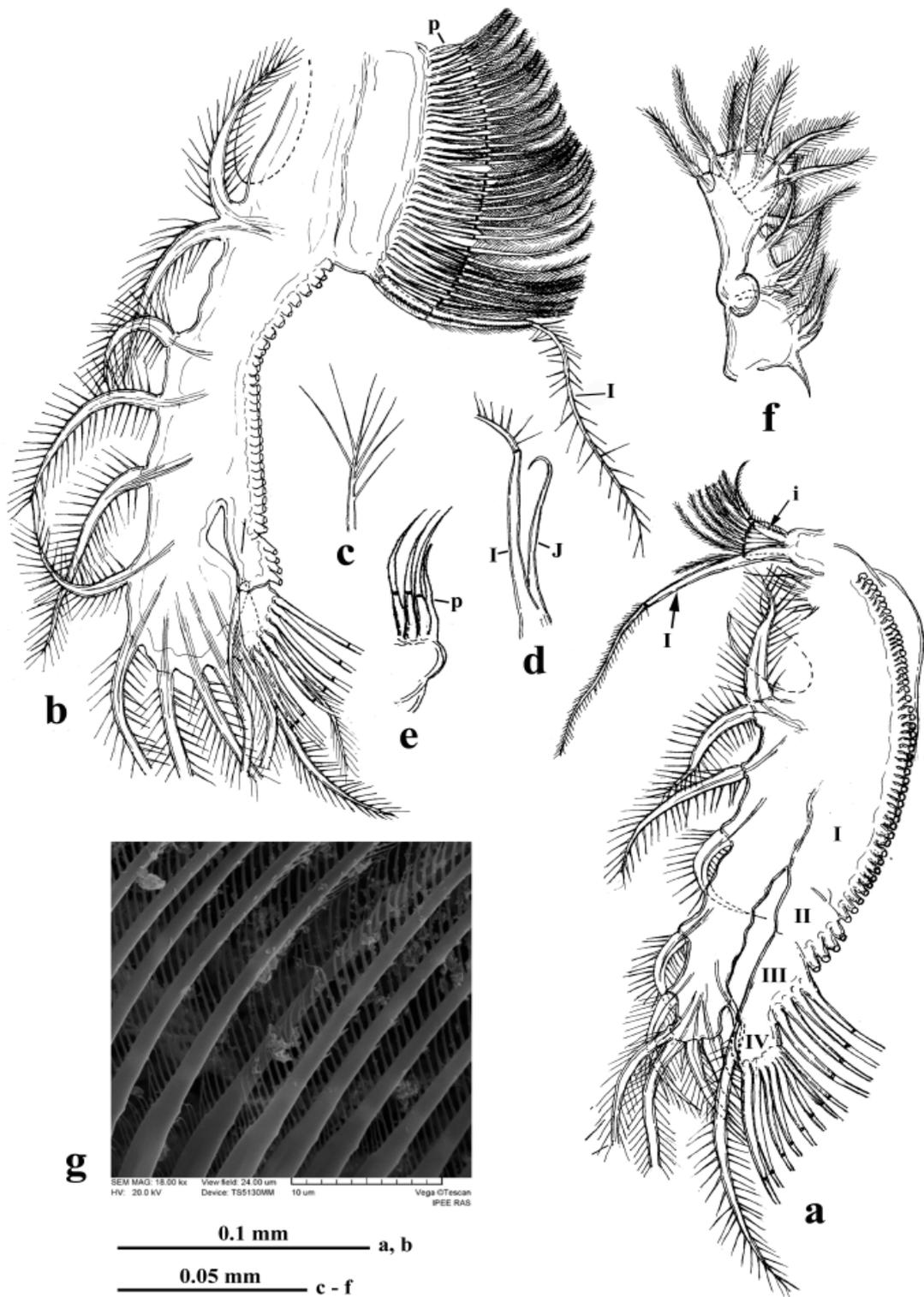
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Proc. Linn. Soc. N.S.W., 133, 2011

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Figure 3. *Diaphanosoma hamatum* **sp. nov., parthenogenetic females, claypan No. 1 near Onslow (Western Australia) (I – IV – numbers of endopodital segments, other explanations see in "Abbreviations"). a – thoracic limb of first pair; b – thoracic limb of second pair; c – fascicle of rough setules on the end of endopodital filtering setae; d – setae on the distal corner of gnathobase of tl III; e – setae on the proximal corner of gnathobase of tl IV; f – thoracic limb of sixth pair; g – armament of gnathobasic setae.**
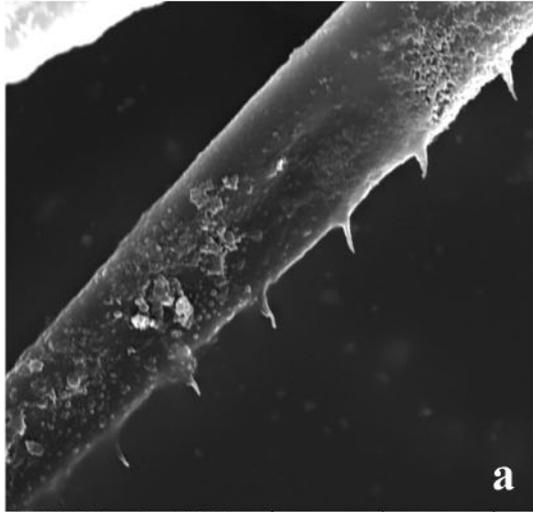
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7

8

Proc. Linn. Soc. N.S.W., 133, 2011
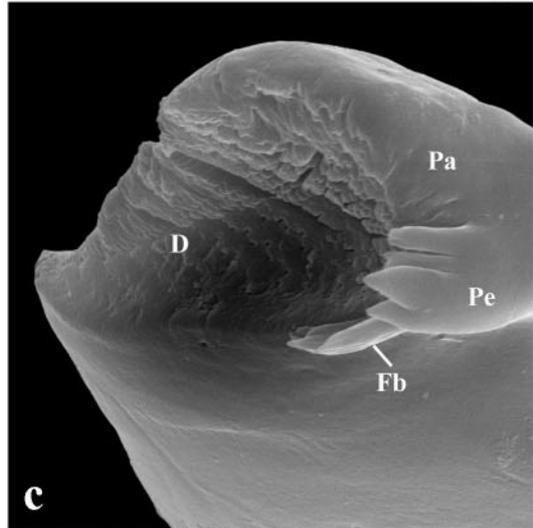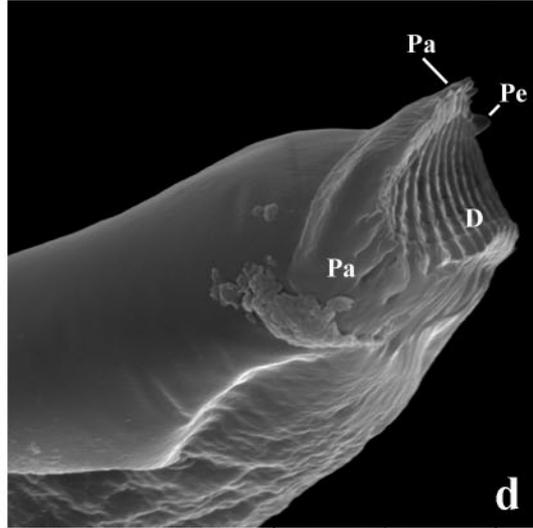
hamatum. Probably only the direct observation of the living animals can resolve the problem.

One another specific feature of *D. hamatum* is the sharp difference in number of gnathobasic filtering seta between tl II with 33–36 such setae and tl III–tl V with only 16–20 setae. In other diaphanosomas studied in this respect (*D. brachyurum* (Lievin, 1848)*, D. freyi* Korovchinsky, 2002*, D. amurensis* Korovchinsky et Sheveleva, 2009) the patterns of gnathobasic setation of different limbs are more similar (see Korovchinsky 2004a, b; Korovchinsky and Sheveleva 2009). Again, this peculiarity may indicate specialization in the new species.

In spite of having a number of specialized probably apomorphic features (small reduced eye, large hooked spine of the upper antennal branch), the primitive (plesiomorphic) characteristics in *D. hamatum* seem to predominate. The latter includes the rostrum (though it may be also suggested its secondary origin), long antennal spines, poor development of the ventral valve inflexion and its uniform setae armament, presence of some thorn-like setae near the posterior valve margin, anal denticles on postabdomen (their state seem more advanced than in *D. unguiculatum* due to comparatively smaller size and small number), and large uniform basal spines of terminal claws.

Undoubtedly *D. hamatum* demonstrates the closest morphological similarity with the Australian species *D. unguiculatum* in armament of swimming antennae, structure and armament of shell valves, postabdomen and postabdominal claws. This implies that within the genus both species have the commonest evolutionary relationship. At the same time, ecological preferences and geographic distribution of these species are different. The latter of them lives in various types of water bodies, demonstrating the high tolerance to the environmental factors, all over the Australian continent and possibly even in New Guinea (Korovchinsky 2004a) while *D. hamatum* is probably adopted for living in quite specific water bodies situated in restricted region of north-west Australia. In this respect it is reminiscent of *D. australiensis* also narrowly distributed in the region of Cape York (the extreme north of Queensland). Together with *D. unguiculatum* and *D. australiensis, D. hamatum* constitutes the small set of the Australian endemics of the genus.

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Figure 4 (opposite). ***Diaphanosoma hamatum*** **sp. nov., parthenogenetic females, claypans No. 1 and 2 near Onslow (Western Australia) (explanations see in "Abbreviations").**
a – tiny denticles on the lateral side of large hooked apical spine of upper antennal branch; b –apical part of distal segment of lower antennal branch; c – molar plate of left mandible; d – molar plate of right mandible; e – armament of lateral side of postabdomen; f – basal part of postabdominal claws.

Proc. Linn. Soc. N.S.W., 133, 2011

9

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10

Proc. Linn. Soc. N.S.W., 133, 2011

A new species of *Calandrinia* (Portulacaceae) from Northern Territory, Australia.

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A new species *of Calandrinia* Humb., Bonpl and Kunth (Portulacaceae) from Northern Territory Australia is described, and compared with other closely related species. Distribution map, scanning electron micrographs of pollen and seed are provided.

INTRODUCTION

The genus *Calandrinia* (Portulacaceae) is confined to Australia and Western America. The genus contains about 100 species with approximately 34 endemic to Australia. *Calandrinia* is defined morphologically by having two persistent sepals and a many-seeded, usually 3-valved, or sometimes 4 to 6-valved, capsule. The first complete monograph of the Australian species was by Bentham (1863) in which he described 20 species. Von Peollnitz (1934) reviewed the Australian species of *Calandrinia,* and he described 3 new species and recognized 8 sections in his taxonomic treatment.

The senior author, while reviewing the Australian *Calandrinia,* examined all the available herbarium collections of this genus which are held in Australian herbaria and in some American and European herbaria (for detail see acknowledgements), including type specimens.

There are many studies on Australian *Calandrinia:* Syeda (1979), Syeda and Carolin (1988) and Syeda and Ashton (1989, 1990, 1996) have determined cladistic relationships among the species of *Calandrinia* and provided detailed information on variation and correlations in seed and pollen characters.

TAXONOMY

Calandrinia oblonga Syeda Saleha Tahir and Roger C. Carolin. sp.nov.

Herba carnosa decumbens scapis 25-40 cm longis. Folia basalia linearia. Flores pedicellis patulis. Petala 6 oblanceolata. Stamina plus quam 20. Stigmata 4 linearia libra usque ad basin. Capsula late ovata valves 4 usque ad basin dehiscens. Semina pauca, vel raro unum oblonga nigra laevia impolita ca 1.5 mm longa.

Holotype
Northern territory**,** Delissaville, Cox's Peninsula R.L.. Specht 103, 27-3-1948 (AD 96148219).

Isotype
(BRI 1018021)

The specific epithet refers to the shape of the seed.

Fleshy decumbent herb with a very short stem. Scapes numerous, branched, 25-40 cm long. Leaves basal, few, linear, sessile, acute, 9-13 cm long, 1.5-1.7 mm broad. Flowers arranged in loose monochasia;

pedicel spreading at fruiting stage, 5-31 mm long; bracts alternate, scarious, subulate or acuminate, 0.75-1.50 mm long, ca 0.5 mm broad.

Sepals ovate, acuminate, 2.1-2.8 mm long, 1.4-1.8 mm broad. Petals 6, pink, oblanceolate, 2.5-4.7 mm long, 0.75-1.40 cm broad. Stamens more than 20; filaments connate at the base forming a ring around the ovary, 0.5-3.5 mm long; anther oblong, versatile, 0.5-0.7 mm long, 0.3-0.4 mm broad. Ovary globular, thick, 0.75-1.10 mm long; stigmata 4, free to the base, linear, 0.7-0.9 mm long; ovules 5-6, oblong, 0.4-0.5 mm long, 0.2-0.3 mm broad. Fruit a capsule, broad-ovate, as long as sepals, 4-valved to the base. Seeds few or rarely 1, oblong, black, dull, rough, smooth or with slight pattern, 1.4-1. 5 mm long, 0.9-10 mm broad.

Habitat

On sandy soil in *Eucalyptus tetrodonta* open forest in Arnhem Land, Northern Territory, Australia (Fig. lA).

POLLEN MORPHOLOGY
(Fig. 1 D,E)

Pollen grain spherical in shape, circular in outline, 33.0-34.6 μm diameter, 25 or more panto colpate, operculate. Colpi short, elliptical, ca. 5.7 μm long and 2.6 μm broad. Operculum protruding, elliptical with a few small sparsely to irregularly distributed spinules; the spinules variable in diameter. Sexine tectate, ca 2.4 μm thick in the centre of mesocolpium and gradually thinner towards the aperture. Tectum granulate to spinulose, punctate; granules small and broad, irregularly to densely spaced, mostly collapsed, variable in size, spinules small few, arranged mostly towards and around the apertures. Punctae very few but distinct, sparsely spaced, unequal in size. Bacula indistinct. Nexine ca 1.6 m thick. Voucher specimen, Craven 6645 (CANB).

SEED MORPHOLOGY
(Fig. 1 B,C)

Seeds black, oblong, dull, rough, surface pattern smooth-colliculate, few in each capsule, *lA-I.* 5 mm long, 0.9-1. 0 mm broad. Voucher specimen. Northern territory Delissaville, Coxis Peninsula, R.L. Specht 103, 27-3-1948. (AD 96148219).

DISCUSSION

This new species is placed in sect. Basales which was recognized by Von Poellnitz (1934) and Syeda (1996, 1979). The main attributes which delimit this section from other section are: 4 stigmatic branches free to the base on a 4-valved capsule mostly opening by terminal valves. This new species has quite different seeds which are oblong with very dull and rough, smooth or slight patterned surface. These types of seed have not yet been found in any other species of *Calandrinia,* however, it is close to C. *quadrivalvis* but can be easily separated from that species by its seeds which are black, much larger in size and with rough to smooth surface.

Keeping in view that *Calandrinia* is a complicated genus with features of significance that are difficult to assess in the herbarium material, the following key is provided to distinguish closely related species.

KEY TO THE RELATED TAXA

1. Ovules 5-6 in each locule; seeds oblong with dull surface. Pollen grains with few tectal punctae, spinules crowded and many collapsed......*C. oblonga*
- Ovules more than 6 in each locule; seeds obovoid with glossy surface. Pollen grains with numerous tectal punctae; spinules spreading and not collapsed. .... (2)
2 Leaves with papillae on the upper surface, Petal 6; Pollen grains panto colpate ....*C. quadrivalvis*
-- Leaves without papillae on the upper surface. Petal 8; Pollen grams pantoporate .....*C..pleiopetala.*

specimens examined
Delissaville, Cox's Pen, R.L. Specht 103, 27-03-148 (AD 96148219 and BRI 053299);East Alligator River, C. Dunlop 3260, 16-2-1973 (NT 42007).

12

Proc. Linn. Soc. N.S.W., 133, 2011
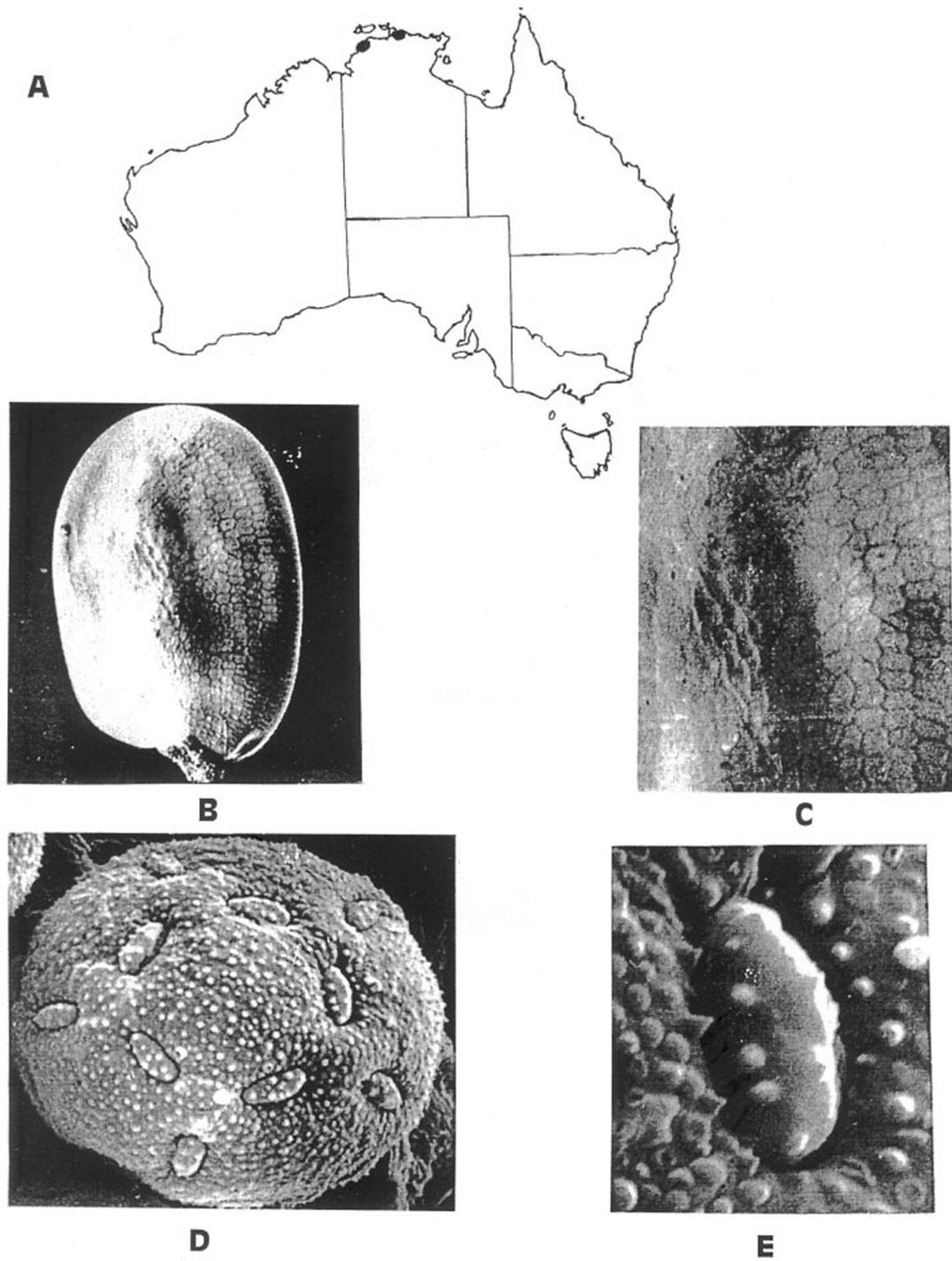
Fig. 1. A. map showing the distribution of *C. oblonga* Sp. Nov. B. Seed (x45) C. Seed surface pattern (x100) D. Pollen grain (x2600) E. Pollen surface (x5300).

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Microalgal Blooms in the Coastal Waters of New South Wales, Australia

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We investigated the frequency and causative taxa of observed microalgal blooms in New South Wales (NSW) coastal waters from 2000 to 2009 and compared these to an earlier bloom inventory from 1990 to 1999. The majority of recurrent blooms are harmless water discolourations caused by *Noctiluca scintillans* and *Trichodesmium erythraeum*. The recent reporting period witnessed the first blooms of *Astrionellopsis glacialis*, *Guinardia* sp., *Skeletonema* sp., cf. *Heterocapsa* sp., *Dinophysis caudata*, *Prorocentrum dentatum*, *Prorocentrum rhathymum*, *Fibrocapsa japonica*, *Gymnodinium catenatum*, *Oscillaroria* sp., and *Anabaena circinalis*.

The frequency of blooms appears to have increased over time with a shift in maximum bloom activity from January (1990 to 1999) to October (2000 to 2009). Peak bloom years correspond with El Niño episodes, the most significant being 1997 to 1998 and 2002 to 2003. No significant difference was found between the causative species or spatial distribution of dominant taxa over two decades. Differences were observed in bloom type in estuaries with more 'potentially harmful to marine organisms' blooms during 1990 to 1999 and more 'harmless' blooms during 2000 to 2009. More 'unidentified' blooms were reported during 2000 to 2009 compared to 1990 to 1999, for both marine and estuarine waters. We emphasize that although algal bloom reports are ad hoc in their nature, they can contribute valuable baseline information, which may suggest causative relationships for evaluating trends in phytoplankton ecology.

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KEYWORDS: biotoxins, harmful algal blooms, human health, microalgal blooms, phytoplankton.

INTRODUCTION

When microalgae (phytoplankton) significantly increase in number, deviating from their species–specific cycle of biomass, they are said to "bloom" (Smayda 1997). Three major types of algal blooms have been distinguished – those that are harmless water discolorations, those that are harmful to marine organisms (e.g. fish kills due to clogging of gills and/or anoxic conditions) and those that produce toxins that bioaccumulate in seafood products (Hallegraeff et al. 2003). The most important public health problems caused by algal toxins are Amnesic Shellfish Poisoning (ASP), Ciguatera Fish Poisoning (CFP), Diarrhetic Shellfish Poisoning (DSP), Neurotoxic Shellfish Poisoning (NSP) and Paralytic Shellfish Poisoning (PSP).

Algal blooms are driven by a combination of hydroclimatic conditions, nutrient influx and/or species specific triggers (e.g. micronutrient availability) and while the rapid growth of microalgae can be a natural phenomenon, it is considered that the prevalence of algal blooms worldwide is increasing (Hallegraeff 2010). Progressive oceanic warming is projected to further alter the biogeography, composition, phenology and physiology of microalgae, and will occur on timescales of decades to centuries (IPCC 2007). Rising sea-surface temperatures (SSTs) may decrease or increase microalgal abundance depending on global location. Tropical and midlatitude nutrient-

limited environments are predicted to experience a reduction in microalgal abundance, while higher latitude environments (light-limited) are expected to experience the inverse (e.g. Reid et al. 1998, Edwards et al. 2006, Doney 2006, Moore et al. 2008, Hallegraeff 2010, Gladan et al. 2010). Changing water chemistry, as exemplified by an increase in dissolved CO_2 and a concomitant decrease in pH i.e. "Ocean Acidification" (Cubillos et al. 2007, Hare et al. 2007, Rost et al. 2008), and the supplementation of micronutrients via precipitation and dust deposition (Shaw et al. 2008, Hallegraeff 2010), are also predicted to alter phytoplankton abundance and composition, favouring some taxa over others. Geographical range extensions in microalgae are already being documented, with some species increasing their habitat range from tropical and temperate waters to colder environments, while certain coldwater assemblages are retracting (reviewed in Hallegraeff 2010). An earlier onset of the spring productivity period has already been observed in terrestrial environments (Inouye et al. 2000), but is now being reported for phytoplankton in the marine environment (Kahru et al. 2011). This shift, however, may not always be clear in the aquatic environment, with variations among trophic units, functional groups, phytoplankton physiology, cell size and elementary stoichiometry all expected to alter with progressive warming (Peperzak 2003, Edwards and Richardson 2004, Hays et al. 2005, Ducklow et al. 2008, Wasmund 2008, Finkel et al. 2010).

Microalgal blooms in Australia have been predominantly a freshwater problem to date. In 1991, 1000 km of New South Wales (NSW) Barwon-Darling River experienced the world's largest cyanobacterial (blue green algal) bloom. Warm temperatures and an influx of sulphate-rich saline groundwater were implicated as the bloom drivers for this massive toxic event (Donnelly et al. 1997). Algal blooms in NSW coastal marine waters, on the other hand, have been significantly smaller in scale and generally non-toxic. In 1993, however, Hallegraeff suggested that there had been an apparent increase in the frequency, strength and extent of visible algal blooms between the years 1984 and 1993 with few bloom reports prior to 1984. Further investigation demonstrated that for the period up until 1999, blooms in NSW coastal waters were indeed becoming more frequent and occurring most commonly during the late summer, early autumn period, when cold, nutrient-rich water was transported (upwelled) into the warm surface layers (Ajani et al. 2001a, 2001b). Microalgal blooms during this time were dominated by the harmless dinoflagellate, *Noctiluca scintillans* and the filamentous cyanobacterium *Trichodesmium erythraeum*.

With over half a century of physical and chemical data from NSW coastal waters now under review, trends in water chemistry (declining silicate, increasing salinity and nitrate), temperature (increasing) and physical circulation (stronger flowing East Australian Current, EAC) are emerging, with consequences predicted for phytoplankton in south-eastern Australian waters – increasing biomass in autumn and early winter coupled with an increasing component of flagellates in the autumn bloom period (Thompson et al. 2009). In the absence of any continuous phytoplankton composition data from these waters, our study investigates the frequency and causative taxa of observed algal blooms from 2000 to 2009 and, in combination with previous bloom reports (1990 to 1999), we explore changes in seasonal and annual occurrence of blooms, causative taxa, bloom types and the spatial occurrence of two dominant species over the past two decades. Whilst it is recognised that blooms are spatially patchy, and reporting is intrinsically subjective (often lacking details such as bloom magnitude and duration), the collation of this historical information provides valuable baseline data, which may suggest causative relationships for future hypothesis testing. The case for more systematic reporting and unambiguous identification of algal blooms in Australian coastal waters to further strengthen this valuable, long-term dataset is discussed.

MATERIALS AND METHODS

Algal blooms collated for this study were those which occurred in the marine and estuarine coastal waters of New South Wales, Australia (28ºS to 37ºS) from the period 2000 to 2009 (Fig. 1). The majority of blooms were visual water discolorations reported to government agencies, local councils, water authorities and universities from members of the public, local council officers or beach life guards. Other potentially harmful bloom reports, not evident as visible water discolorations, were captured as a result of limited phytoplankton monitoring programs carried out by local councils, NSW Industry and Investment (NSW Food Authority) and the NSW shellfish industry. The NSW Office of Water also provided bloom reports from Regional Algal Coordinating Committees (RACCs) which manage the response to algal bloom events in NSW. Where possible, algal bloom 'observers' were asked to complete an Algal Bloom Data Sheet (Office of Environment and Heritage, OEH) that included: date and time of bloom; location, extent and duration of bloom; colour/appearance/odour of bloom, weather conditions and sample details. If a
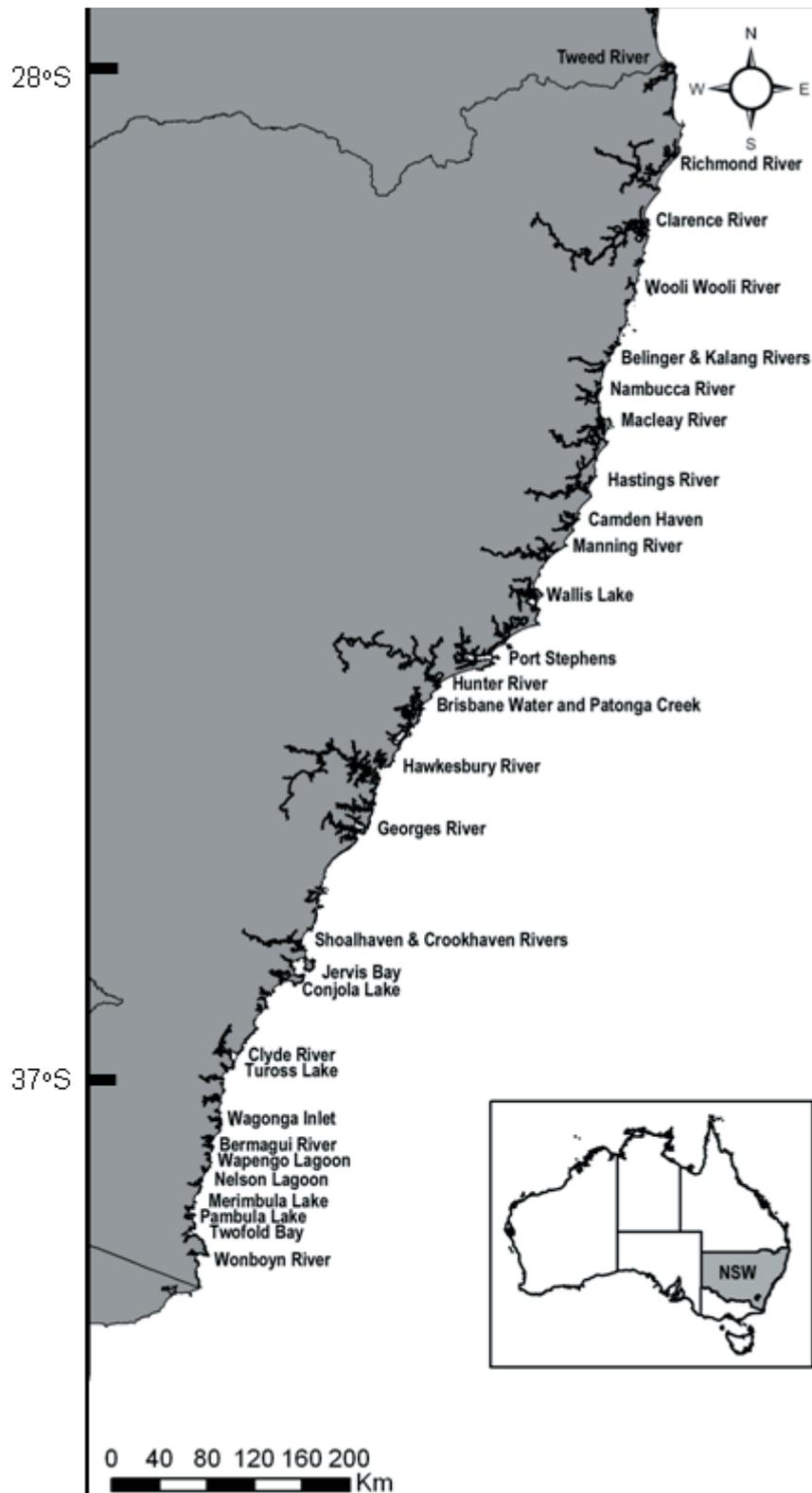
16

Proc. Linn. Soc. N.S.W., 133, 2011

Fig. 1. Map of New South Wales, Australia, showing major rivers and estuaries.

Proc. Linn. Soc. N.S.W., 133, 2011

17

water sample was collected, it was submitted to an appropriate laboratory (as advised by the RACCs or OEH), and the causative organism(s) identified by suitably qualified microalgal taxonomists.

For the purposes of data assessment, blooms were collated by date, location and causative taxa (these were the only data variables common to all reports across the sampling period) and classified into three recognised bloom types–'harmless', 'potentially harmful to marine organisms' and 'potentially harmful to humans' (Hallegraeff et al. 2003). Where a causative organism belonged to a genus that contained both toxic and non-toxic species e.g. *Pseudo-nitzschia*, and it was not possible to identify down to the species level, the bloom was classified conservatively into 'potentially harmful to humans'. Blooms that were not microscopically examined, that is, no sample was taken from the bloom or the sample deteriorated prior to examination, were classified as 'unidentified'. We included these 'unidentified' bloom reports in the final dataset for two reasons – to provide a more accurate measure of bloom frequency and to provide a historical record of bloom occurrences and their locations in NSW coastal waters.

In order to gain a longer-term perspective of reported bloom occurrences, algal blooms for the 2000 to 2009 reporting period were then pooled with bloom data from the period 1990 to 1999, as documented in the antecedent summary by Ajani et al. (2001a). To explore any potential relationship between the frequency of bloom events and regional oceanographic variability, the number of reported blooms was compared to a six-month running average of the Southern Oscillation Index (SOI). SOI values were obtained from the Australian Governments' Bureau of Meteorology website at http://www.bom.gov.au/climate/current/soi2.shtml. Decadal differences were examined for annual and seasonal bloom frequency, causative taxa, bloom type and any potential latitudinal trend in the major taxa (arbitrarily partitioned as being north or south of Sydney). A paired t-test was applied for causative taxa comparisons and Pearson's Chi-square tests for all other comparisons.

RESULTS

Current Reporting Period: 2000 to 2009

A total of 157 algal blooms were recorded for the 2000 to 2009 reporting period (Tables 1-4). Reported blooms ranged from four in 2007 to 34 in 2003 (Fig. 2). Blooms were most frequent in October and least frequent in July (Fig. 3). The majority of blooms were

'harmless' water discolorations (n=85), followed by those that were 'unidentified' (n=49), those 'potentially harmful to humans' (n=19) and those 'potentially harmful to marine organisms' (n=4).

Noctiluca scintillans and *Trichodesmium erythraeum* were the two most commonly occurring bloom species during this reporting period. In addition to these taxa, novel blooms of the following taxa were identified: the 'harmless' *Asterionellopsis glacialis* (marine), cf. *Heterocapsa* sp. (estuarine), *Guinardia* sp. (marine), *Skeletonema* sp. (estuarine) and *Prorocentrum dentatum* (estuarine); the 'potentially harmful to marine organisms' taxa *Dinophysis caudata* and *Fibrocapsa japonica*; and those that are 'potentially harmful to humans' being *Oscillaroria* sp. *Anabaena circinalis, Prorocentrum rhathymum* and *Gymnodinium catenatum* (Table 5).

Decadal comparison: 1990-1999 to 2000-2009

To examine longer-term trends in bloom frequency and causative taxa, we pooled data from the current reporting period with data from the previous decade. Over the twenty year reporting period a total of 280 blooms (n=123, 1990 to 1999; n=157, 2000 to 2009) were reported. The frequency of blooms ranged from zero in 1990 to 34 in 2003 with peak bloom years occurring between 1997 to 1998 and 2002 to 2003 (Fig. 2). These peak bloom events corresponded to years of sustained negative SOI values (Fig. 4).

Blooms occurred most frequently from January to March during 1990 to 1999, and from October to November during 2000 to 2009 (Fig. 3). A Pearson's Chi-square test was conducted to investigate this shift in maximum bloom occurrence, revealing a significant difference between the two decades ($X^2 = 99.3$, $p < 0.05$).

Dominant bloom-forming taxa over the twenty year period were *Noctiluca scintillans*, *Trichodesmium erythraeum* and those belonging to the 'unidentified' group. Five other recurrent taxa were noteworthy - *Mesodinium rubrum*, *Gymnodinium* spp., *Heterosigma akashiwo*, *Alexandrium* spp., *Pseudo-nitzschia* spp. and *Gonyaulax polygramma* (Fig. 5). 'Other' blooms were those that only occurred once across the sampling period. To examine if there had been any significant change in the dominant bloom-forming taxa overtime, a paired t-test was conducted and found to be not significant (t = 0.49, p>0.05).

When blooms were examined by type, both marine and estuarine waters were dominated by 'harmless' blooms (Fig. 6a). To examine if bloom type had changed between the two sampling periods, a Pearson's Chi-square test was performed on pooled marine and estuarine data, revealing a significant

18

Proc. Linn. Soc. N.S.W., 133, 2011

P. AJANI, T. INGLETON, T. PRITCHARD AND L. ARMAND

Table 1. 'Harmless' algal blooms reported from New South Wales marine (M) and estuarine (E) waters 2000-2009*

Date	Location	Bloom Taxa
29-Feb-2000	Bondi Beach to Clovelly Beach (Sydney) (M)	*Noctiluca scintillans*
14-Mar-2000	Sailors Bay, Long Bay, Willoughby Bay (Sydney Harbour) (E)	*Skeletonema* sp.
12-Apr-2000	Lake Macquarie (E)	*Noctiluca scintillans*
03-May-2000	Evans Head (M)	*Trichodesmium erythraeum*
26-Sep-2000	Ballina Beach to Coffs Harbour (M)	*Asterionellopsis glacialis*
3-Oct-2000	Shelley Beach, Ballina (M)	Mixed diatoms
29-Oct-2000	Lake Illawarra (E)	*Noctiluca scintillans*
01-Nov-2000	Port Hacking River (Sydney) (E)	*Noctiluca scintillans*
20-Nov-2000	Tweed Coast (M)	*Trichodesmium erythraeum*
23-Nov-2000	Brunswick River to Richmond River (M)	*Trichodesmium erythraeum*
28-Nov-2000	Boambee Beach Coffs Harbour (M)	*Trichodesmium erythraeum*
10-Dec-2000	Hastings River, Port Macquarie (E)	*Trichodesmium erythraeum*
15-Dec-2000	Lake Illawarra (E)	*Noctiluca scintillans*
17-Dec-2000	Shelley Beach, Manly (M)	*Noctiluca scintillans*
02-Jan-2001	Cudgen Creek, Kingscliff (M)	*Trichodesmium erythraeum*
14-Jan-2001	Coogee (Sydney) (M)	*Noctiluca scintillans*
27-Feb-2001	Byron Bay (M)	*Trichodesmium erythraeum*
29-Aug-2001	Georges River (Sydney) (E)	*Heterocapsa* sp.
21-Sep-2001	North Head, Sydney Harbour (M)	*Mesodinium rubrum*[#]
29-Sep-2001	Richmond River, Ballina (E)	*Trichodesmium erythraeum*
15-Oct-2001	Byron Bay (M)	*Trichodesmium erythraeum*
26-Oct-2001	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
22-Jan-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
09-Aug-2002	Colloroy Beach (M)	*Noctiluca scintillans*
30-Aug-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
02-Sep-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
09-Sep-2002	Farm Cove, Sydney Harbour (E)	*Noctiluca scintillans*
12-Sep-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
07-Oct-2002	Blacksmiths Beach (near Lake Macquarie) (M)	*Guinardia* sp.
12-Oct-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
14-Oct-2002	Middle Harbour, Sydney (E)	*Noctiluca scintillans*
30-Oct-2002	Byron Bay (M)	*Trichodesmium erythraeum*
01-Nov-2002	Ballina (M)	*Trichodesmium erythraeum*
01-Nov-2002	Whale Beach to Kiama (M), Sydney Harbour (E)	*Mesodinium rubrum*[#]
07-Nov-2002	Richmond River, Ballina (E)	*Trichodesmium erythraeum*
12-Feb-2003	Austinmer Beach (M)	*Noctiluca scintillans*
18-Feb-2003	Merimbula Lake (E)	*Noctiluca scintillans*
20-Feb-2003	Northern Beaches to Botany Bay (M)	*Noctiluca scintillans*
12-Mar-2003	North Harbour (Sydney Harbour) (E)	*Noctiluca scintillans*
14-Mar-2003	Kurnell (M)	*Noctiluca scintillans*
26-Mar-2003	Mereweather Beach (Newcastle) (M)	*Noctiluca scintillans*

Proc. Linn. Soc. N.S.W., 133, 2011

19

Table 1 continued

27-Mar-2003	Kurnell (M)	*Noctiluca scintillans*
07-Apr-2003	Bermagui Harbour (E)	*Noctiluca scintillans*
08-Apr-2003	Shelley Beach, Manly (M)	*Noctiluca scintillans*
23-Apr-2003	Port Hacking (M)	*Trichodesmium erythraeum*
24-Apr-2003	Port Hacking (M)	*Trichodesmium erythraeum*
07-May-2003	Berowra Creek (E)	*Prorocentrum dentatum*
23-Jul-2003	Parsley Bay (Sydney Harbour) (E)	*Mesodinium rubrum*
21-Oct-2003	Rose Bay (Sydney Harbour) (E)	*Noctiluca scintillans*
18-Nov-2003	Lake Illawarra (E)	*Noctiluca scintillans*
28-Nov-2003	Botany Bay (M)	*Noctiluca scintillans*
4-Dec-2003	Middle Harbour (E) and Manly (M)	*Noctiluca scintillans*
29-Dec-2003	Belmore Basin (E)	*Noctiluca scintillans*
2-Jan-2004	Manly Cove (M)	Mixed diatoms
2-Feb-2004	North Head, Sydney Harbour (M)	*Noctiluca scintillans*
5-Feb-2004	Bundeena (M)	*Noctiluca scintillans*
4-Mar-2004	Cabbage Tree Bay (M)	*Noctiluca scintillans*
12-Aug-2004	Castlecrag, North Sydney and Cockle Bay, Syd Harbour (E)	*Noctiluca scintillans*
25-Aug-2004	Clontarf Beach (Sydney Harbour) (E)	*Noctiluca scintillans*
04-Feb-2005	La Perouse (M)	*Trichodesmium erythraeum*
22-Apr-2005	Como/Oately, Port Hacking (E)	*Noctiluca scintillans*
29-Apr-2005	Wyong (E)	*Noctiluca scintillans*
18-Aug-2005	Newcastle Beaches (M)	*Noctiluca scintillans*
18-Aug-2005	Plantation Point, Jervis Bay (M)	*Noctiluca scintillans*
9-Sep-2005	Rose Bay, Balmoral Beach (M)	*Noctiluca scintillans*
22-Nov-2005	Bate Bay (M)	*Noctiluca scintillans*
23-Nov-2005	Sydney Northern Beaches and Newcastle (M)	*Noctiluca scintillans*
24-Oct-2006	Commonwealth Reserve, Solitary Islands (M)	*Trichodesmium erythraeum*
11-Nov-2006	Fairy Bower, Manly (M)	*Noctiluca scintillans*
20-Nov-2006	Solitary Islands (M)	*Trichodesmium erythraeum*
1-Dec-2006	Sydney South Coast Beaches (M)	*Noctiluca scintillans*
6-Dec-2006	Solitary Islands (M)	*Trichodesmium erythraeum*
12-Nov-2007	Mermaid Reef, Diamond Head (M)	*Trichodesmium erythraeum*
24-Dec-2007	Richmond River (E)	*Trichodesmium erythraeum*
6-Mar-2008	Lake Illawarra (E)	*Noctiluca scintillans*
24-Sep-2008	Paramatta River, Birkenhead Point (Sydney Harbour) (E)	*Noctiluca scintillans*
1-Oct-2008	Iron Cove, Clontarf Beach (Syd Harbour) (E)	*Noctiluca scintillans*
2-Oct-2008	Manly (M)	*Noctiluca scintillans*
3-Oct-2008	Woolloomooloo Bay (E), Seaforth (M)	*Noctiluca scintillans*
1-Jan-2009	Lake Macquarie (E)	*Noctiluca scintillans*
20-Feb-2009	Shelley Beach; Toowoon to Bateau Bay (M)	*Noctiluca scintillans*
25-Apr-2009	Solitary Islands (M)	*Anaulus australis*
21-May-2009	Stockton Beach, Newcastle (M)	*Anaulus australis*
21-Aug-2009	Manly Cove (M)	*Noctiluca scintillans*
20-Oct-2009	Park Beach, Coffs Harbour (M)	*Trichodesmium erythraeum*

#*Mesodinium rubrum* = ciliate with microalgal symbionts
*Office of Environment and Heritage unpublished data.

Table 2. 'Potentially harmful to marine organisms' algal blooms reported from New South Wales marine (M) and estuarine (E) waters 2000-2009*

Date	Location	Bloom Taxa
24-Nov-2000	Port Hacking (M)	*Scrippsiella* sp.
21-Oct-2002	Redhead Beach, Newcastle (M)	*Thalassiosira* spp.
29-Oct-2003	Sydney Harbour (E)	*Dictyocha octonaria*
18-Jan-2006	Calabash Bay, Hawkesbury River (E)	*Dinophysis caudata*

*Office of Environment and Heritage unpublished data.

Table 3. 'Potentially harmful to humans' algal blooms reported in New South Wales marine (M) and estuarine (E) waters 2000-2009*

Date	Location	Bloom Taxa
Dec -Mar 2001	Bombah Broadwater, Myall Lakes (E)	*Microcystis aeruginosa/Anabaena circinalis*
16-Mar-2000	Drummoyne, Sydney Harbour (E)	*Prorocentrum cordatum*
22-Dec-2000	Lake Illawarra (E)	*Gymnodinium* sp.
18-Apr-2001	Parramatta River, Sydney Harbour (E)	*Pseudo-nitzschia* sp.
14-May-2001	Balmain & Five Dock, Sydney Harbour (E)	*Heterosigma akashiwo*
27-Sep-2001	Narrabeen Creek (Sydney) (E)	*Oscillatoria* sp.
05-Oct-2001	Calabash Bay (Berowra Creek) (E)	*Heterosigma akashiwo*
05-Apr-2002	Iron Cove, Sydney Harbour (E)	*Karlodinium micrum*
02-Apr-2003	Twofold Bay (M)	*Dinophysis acuminata*
02-Apr-2003	Wopengo Lake (E)	*Dinophysis acuminata*
09-May-2003	Wallaga Lake (E)	*Fibrocapsa japonica*
22-Oct-2003	Rose Bay, Sydney Harbour (E)	*Alexandrium catenella*
18-Nov-2004	Botany Bay (M)	*Alexandrium* sp.
26-Nov-2005	Botany Bay (M)	*Alexandrium* sp.
23-Mar-2007	Lake Illawarra (E)	*Prorocentrum rhathymum*
27-Aug-2007	Richmond River (E)	*Anabaena/Anabaenopsis* sp.
18-Jan-2008	Calabash Bay, Hawkesbury (E)	*Pseudo-nitzschia delicatissima* gp*; Dinophysis caudata; Lingulodinium polyedrum*
2-Oct-2009	Central coast beaches (M); entrance to Hawkesbury River; Brisbane Waters; Botany Bay (E)	*Alexandrium catenella*
15-Dec-2009	Berowra Creek (E)	*Gymnodinium catenatum*

*Office of Environment and Heritage unpublished data.

Proc. Linn. Soc. N.S.W., 133, 2011

21

Table 4. 'Unidentified' algal blooms reported from New South Wales marine (M) and estuarine (E) waters 2000-2009*

Date	Location	Bloom Taxa
26-Jun-2000	Lake Macquarie (E)	Unidentified species
14-Sep-2000	North Head, Sydney Harbour (M)	Unidentified species
29-Sep-2000	Crescent Head to Port Macquarie (M)	Unidentified species
30-Sep-2000	Tuncurry Beach (M)	Unidentified species
05-Oct-2000	Beach from Nelson lagoon to Wapengo lagoon (M)	Unidentified species
30-Nov-2000	Lake Illawarra (E)	Unidentified species
07-Dec-2000	Maroubra Beach to Coogee Beach (M)	Unidentified species
13-May-2001	Jones Beach, Mollymook (M)	Unidentified species
04-Oct-2001	Lennox Head (M)	Unidentified species
05-Oct-2001	Elizabeth Beach, Pacific Palms (M)	Unidentified species
10-Oct-2001	Port Hacking (M)	Unidentified species
28-Oct-2001	Little Boulder Beach, Ballina (M)	Unidentified species
29-Oct-2001	Quakers Hat Bay, Sydney Harbour (E)	Unidentified species
25-Jan-2002	Tallows Beach, Byron Bay (M)	Unidentified species
02-May-2002	Bennetts Beach, Hawks Nest (M)	Unidentified species
21-Aug-2002	Yamba (M)	Unidentified species
23-Aug-2002	Dee Why (M)	Unidentified species
27-Aug-2002	Newport and Avalon Beaches (M)	Unidentified species
17-Sep-2002	Rushcutters Bay, Sydney Harbour (E)	Unidentified species
25-Sep-2002	Sydney Fish Markets, Sydney Harbour (E)	Unidentified species
11-Oct-2002	Sharpes Beach, Ballina (M)	Unidentified species
30-Oct-2002	One Mile Beach, Forster (M)	Unidentified species
31-Oct-2002	North Harbour, Manly (E)	Unidentified species
17-Nov-2002	Yamba Beach (M)	Unidentified species
19-Nov-2002	Collaroy/Narrabeen (M)	Unidentified species
22-Nov-2002	Drummoyne, Sydney Harbour (E)	Unidentified species
16-Dec-2002	Manly (M)	Unidentified species
01-Jan-2003	Huskisson to Vincentia, Jervis Bay (M)	Unidentified species
02-Jan-2003	North Creek, Ballina (E)	Unidentified species
02-Jan-2003	Light House Beach, Ballina (M)	Unidentified species
17-Mar-2003	East Corrimal Beach (M)	Unidentified species
25-Mar-2003	Little Manly Cove, South Steyne Beach (M)	Unidentified species
27-Mar-2003	Terrigal Haven (M)	Unidentified species
28-Mar-2003	Dover Heights (M)	Unidentified species
01-Apr-2003	Manly Beach, Whale Beach, Bungan Beach (M)	Unidentified species
07-Aug-2003	Watsons Bay (E)	Unidentified species
02-Sep-2003	Shelley Beach, Ballina (M)	Unidentified species
10-Oct-2003	Bronte to Bondi Beaches (M)	Unidentified species
17-Jun-2004	Manly Lagoon (E)	Unidentified species
26-Oct-2004	Seven Mile Beach, Lennox Head (M)	Unidentified species
18-Nov-2004	Silver Beach, Kurnell (M)	Unidentified species
21-Sep-2005	Bungan Beach (M)	Unidentified species
22-Nov-2005	Pittwater (E) and Northern Beaches (M)	Unidentified species
4-Sep-2006	Jervis Bay (M)	Unidentified species
5-Nov-2006	Yamba (M)	Unidentified species
4-Mar-2009	Cabbage Tree Bay, Norah Head (M)	Unidentified species
18-Sep-2009	Frazer Park, Budgewoi (M)	Unidentified species
1-Oct-2009	Bawley Point (M)	Unidentified species
1-Oct-2009	Terrigal, North Avoca (M)	Unidentified species

*Office of Environment and Heritage unpublished data
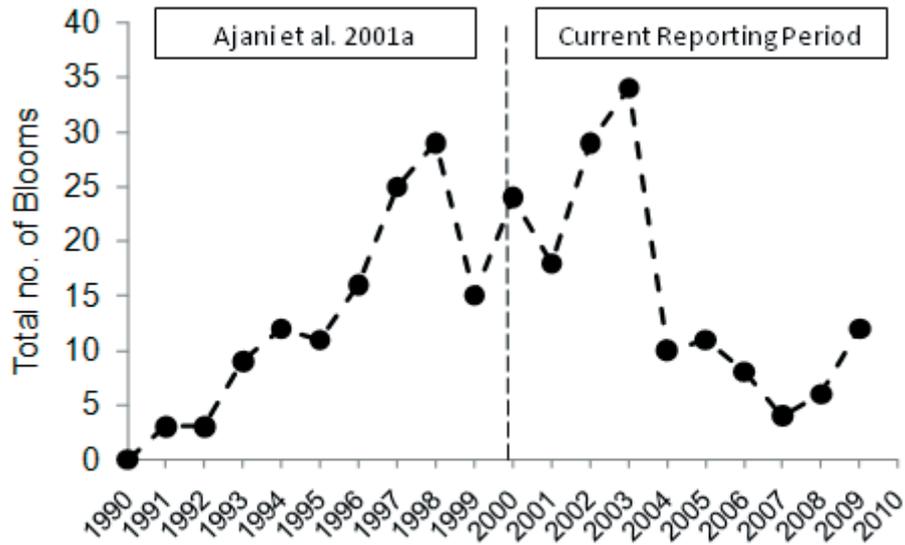
Figure 2. Total number of reported blooms per year for the previous reporting period 1990-1999 (Ajani et al. 2001a) and the current reporting period (2000-2009).
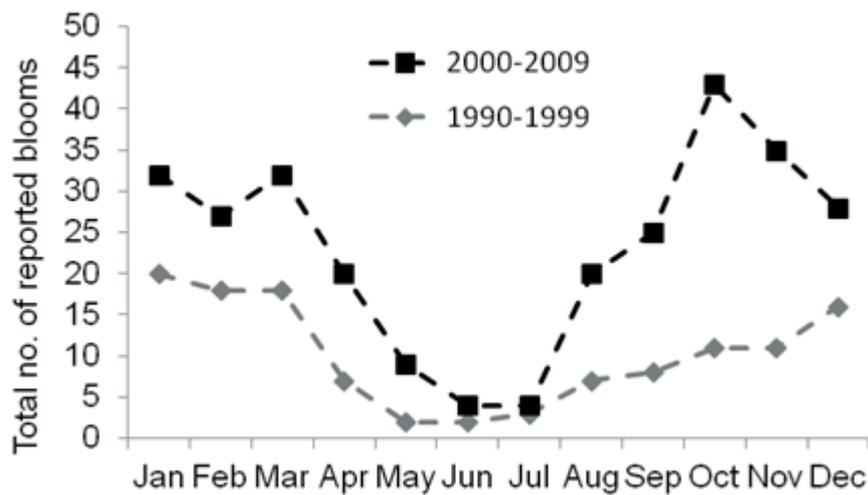

Figure 3. Monthly distribution of total number of reported blooms for the previous reporting period 1990-1999 (grey line) and the current reporting period (2000-2009, black line).

Proc. Linn. Soc. N.S.W., 133, 2011

23

Table 5. Phytoplankton taxa responsible for observed blooms in New South Wales marine and estuarine waters (1990–2009) inclusive of first recorded bloom events for both reporting periods.

Bloom Type	Functional Group	Taxa	Bloom Occurrence in Marine and/or estuarine waters	First Report during 1990-1999#	First Report during 2000-2009
Harmless	Cyanobacteria	*Trichodesmium erythraeum* Ehrenberg	M,E	*	
	Diatoms	*Anaulus australis* Drebes & Schulz	M	*	
		Asterionellopsis glacialis (Castracane) Round	M		*
		Guinardia sp. Peragallo	M		*
		Pseudo-nitzschia cf. *pungens* (Cleve) Hasle	E	*	
		Pseudo-nitzschia cf. *calliantha* Lundholm, Moestrup & Hasle	E	*	
		Skeletonema sp. (Greville) Cleve	E		*
	Dinoflagellates	*Gymnodinium sanguineum* Hirasaka	E	*	
		cf. *Heterocapsa* sp. Stein	E		*
		Noctiluca scintillans (Macartney) Kofoid & Swezy	M,E	*	
		Prorocentrum dentatum Stein	E		*
	Coccolithophorids	*Gephyrocapsa oceanica* Kamptner	M	*	
	Protozoans	*Mesodinium rubrum* Lohmann	M,E	*	
Potentially harmful to marine organisms	Diatoms	*Chaetoceros* sp. Ehrenberg	E	*	
		Thalassiosira spp. Cleve	M,E	*	
		Thalassiosira parrheneia Schrader	M	*	
		Thalassiosira weissflogii (Grunow) Fryxell & Hasle	E	*	
	Dinoflagellates	*Dinophysis caudata* Saville-Kent	E		*
		Gonyaulax sp. Diesing	E	*	
		Gonyaulax polygramma Stein	M	*	
		Gymnodinium cf. *mikimotoi* Miyake & Kominami ex Oda	E	*	
		Scrippsiella sp. Balech ex Loeblich III	M,E	*	
	Silicoflagellates	*Dictyocha octonaria* Ehrenberg	M,E	*	
	Raphidophytes	*Fibrocapsa japonica* Toriumi & Takano	E		*
		Heterosigma akashiwo (Hada) Hada ex Hara & Chihara	E	*	

Table 5 continued

Bloom Type	Functional Group	Taxa	Bloom Occurrence in Marine and/or estuarine waters	First Report during 1990-1999#	First Report during 2000-2009
Potentially harmful to humans	Cyanobacteria	Anabaena circinalis Rabenhorst ex Bornet & Flahault	E		*
		Microcystis aeruginosa (Kützing) Kützing	E	*	
		Oscillatoria sp. Vaucher ex Gomont	E		*
	Diatoms	Pseudo-nitzschia spp. Peragallo	E	*	
		Pseudo-nitzschia delicatissima gp (Cleve) Heiden	E	*	
		Pseudo-nitzschia cf. multiseries (Hasle) Hasle	E	*	
	Dinoflagellates	Alexandrium sp. Halim	E	*	
		Alexandrium catenella (Whedon & Kofoid) Balech	M	*	
		Dinophysis acuminata Claparède & Lachmann	M,E	*	
		Gymnodinium catenatum Graham	E		*
		Gymnodinium sp. Stein, emend. Hansen & Moestrup	E		*
		Karlodinium micrum@ (Leadbeater & Dodge) Larsen	E	*	
		Prorocentrum cordatum* (Ostenfeld) Dodge	E	*	
		Prorocentrum rhathymum Loeblich III, Sherley & Schmidt	E		*
	Raphidophytes	Chattonella globosa Hara & Chihara	E	*	
		Haramonas sp. nov. Horiguchi	E	*	

Ajani et al. (2001a)
@Previously Gymnodinium galatheanum Braarud sensu Kite & Dodge
*Previously Prorocentrum minimum (Pavillard) Schiller

Proc. Linn. Soc. N.S.W., 133, 2011

25
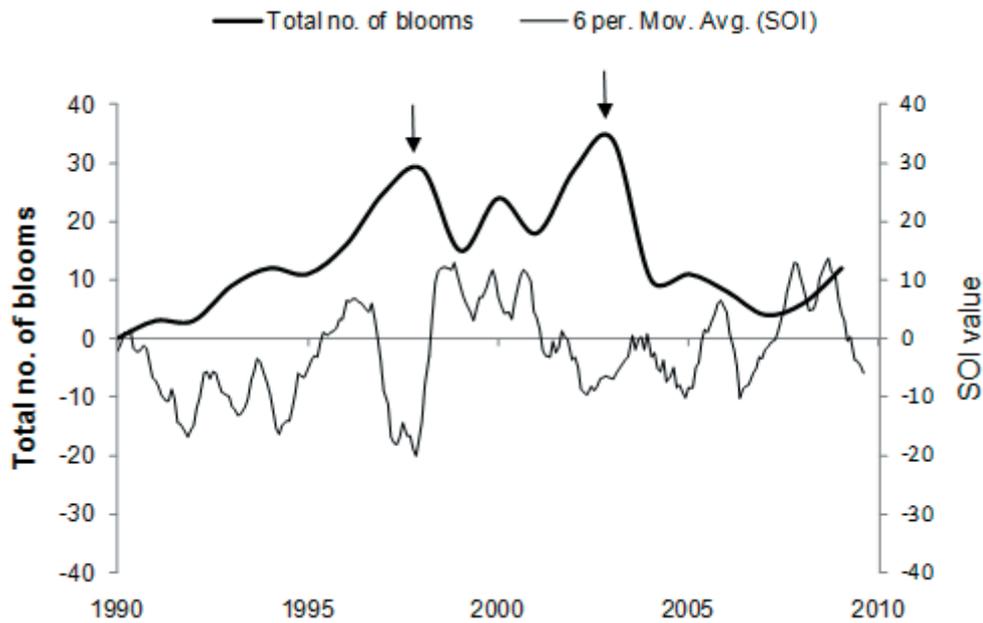
Figure 4. Total number of reported blooms per year (left axis) and six month running average of the Southern Oscillation Index value (right axis). Arrows show peak bloom years corresponding to sustained negative SOI values (El Niño episodes).
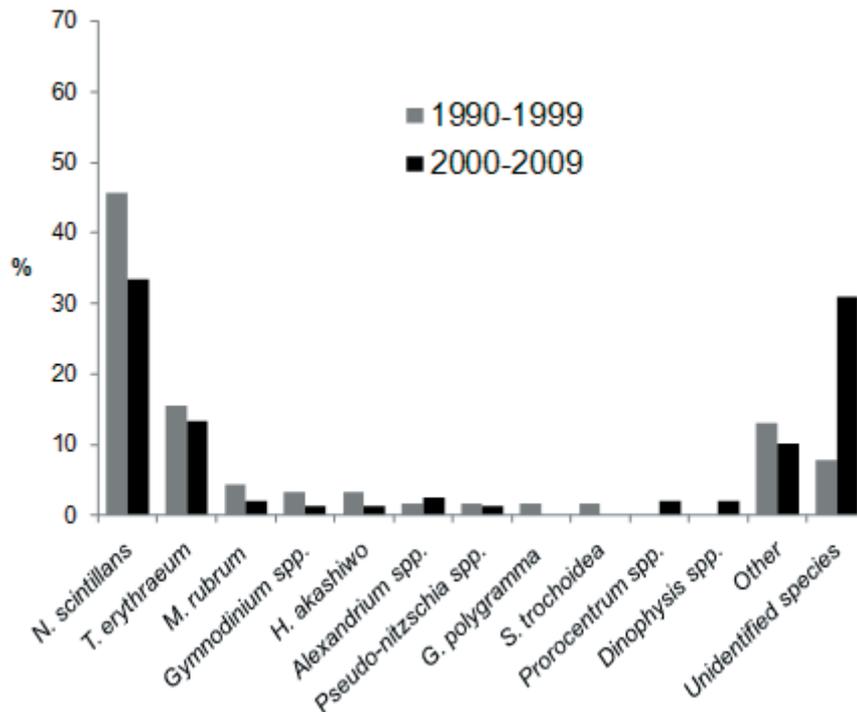
Figure 5. Percentage frequency of bloom reports for major microalgal taxa across the two reporting periods; grey bar=1990-1999; black bar=2000-2009; abbreviations *N. scintillans* = *Noctiluca scintillans*; *T. erythraeum* = *Trichodesmium erythraeum*;
M. rubrum = *Mesodinium rubrum*; *H. akashiwo* = *Heterosigma akashiwo*;
G. polygramma = *Gonyaulax polygramma*; *S. trochoidea* = *Scrippsiella trochoidea*.
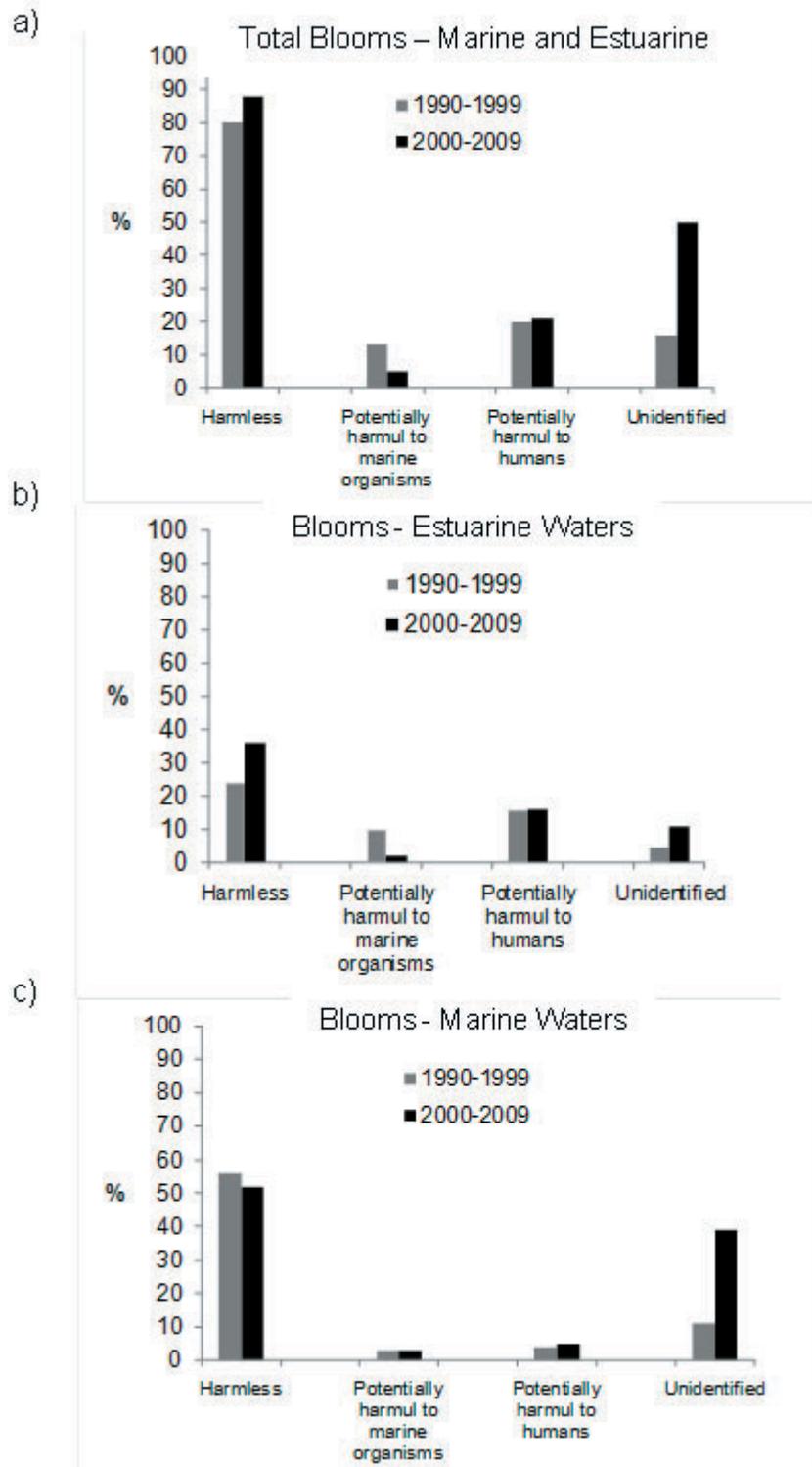
Figure 6. Percentage contribution of reported blooms to bloom type categories in a) total contribution of marine and estuarine blooms; b) estuarine waters only; and c) marine waters only; grey bar=1990-1999; black bar=2000-2009.

Proc. Linn. Soc. N.S.W., 133, 2011

27

Figure 7. North (grey bar) and south (black bar) distributions of total number of reported blooms for the two dominant bloom forming taxa, *Noctiluca scintillans* and *Trichodesmium erythraeum* for the earlier reporting period 1990-1999 (grey bar) and the current reporting period (2000-2009). Images x100 magnification.

difference between decades (X^2 = 78.0, p < 0.05). To further elucidate where these differences lie, marine and estuarine bloom types were examin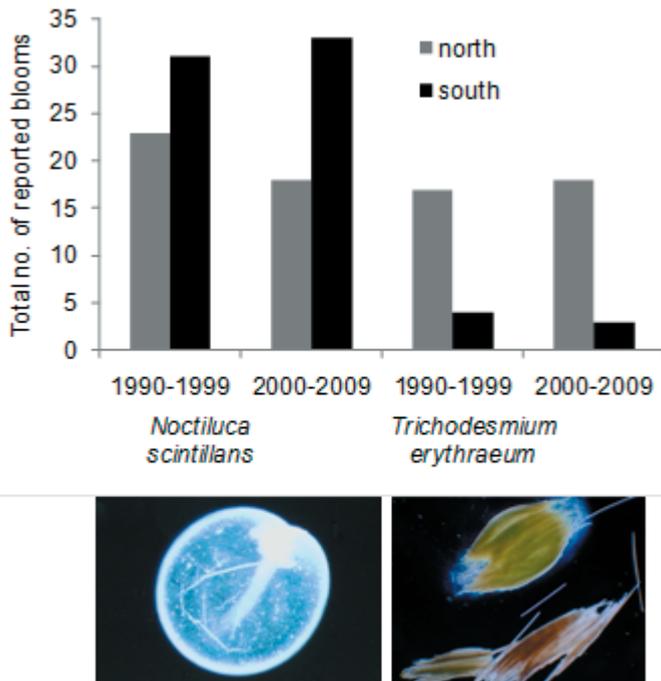ed separately. Chi-square tests were applied to each dataset to examine if there had been any change overtime in either of these environments. For those blooms principally occurring in waterways identified as estuaries, significant differences were revealed between decades (X^2 = 19.6, p < 0.05), with significantly more 'potentially harmful to marine organisms' blooms reported during 1990-1999, a higher frequency of 'harmless' blooms during 2000 to 2009, and a greater number of 'unidentified' blooms during 2000 to 2009 (Fig 6b). For those occurring in the marine environment, a significant difference was also seen between 'unidentified' blooms, with a greater number being reported in the current reporting period (X^2 = 71.8, p < 0.05) (Fig. 6c).

As shown in Fig. 5, two species remained dominant throughout both reporting periods - *Noctiluca scintillans* and *Trichodesmium erythraeum*. Given the emphasis on increasing SST as a potential driver for species range extensions and retractions, we sought to test for a latitudinal trend in their reported bloom frequency. The number of blooms for each taxon was partitioned as occurring north or south of Sydney. A Chi-square test was performed on this latitudinal frequency distribution, revealing no significant difference for either *Noctiluca scintillans* (X^2 = 1.22, p >0.05) or *Trichodesmium erythraeum* (X^2 = 0.31, p >0.05) overtime (Fig 7).

DISCUSSION

Microalgal blooms in NSW coastal waters are frequently reported to government agencies, water authorities and local councils. We have shown that these reported blooms are dominated by harmless water discolourations, the majority of these being caused by the large dinoflagellate *Noctiluca scintillans* and the cyanobacterium *Trichodesmium erythraeum* and this remains unchanged over the past twenty years. Whilst historically *Noctiluca scintillans* has always been a relatively minor component of the phytoplankton community (Dakin and Colefax 1940, Jeffrey and Carpenter 1974, Hallegraeff and Reid 1986), its presence in NSW coastal waters has significantly increased in more recent years (Murray and Suthers 1999, Ajani et al. 2001a) and its range expanded into the waters of Tasmania, South Australia, Western Australia and Queensland (Hallegraeff 2010). Reported bloom data presented covering the past twenty years suggests that *Noctiluca scintillans* remains a consistent red tide organism in NSW coastal waters.

Although our data also suggests little change in the frequency of *Trichodesmium erythraeum* blooms over the past twenty years (Fig 4e), this taxon is predicted to be a major beneficiary of long term warming (Hallegraeff 2010). During a severe dust storm in Queensland coastal waters in 2002, Shaw et al. (2008) concluded that tropical cyanobacteria, such as *Trichodesmium erythraeum*, were the phytoplankton group that most likely accounted for the stimulation in satellite-derived chlorophyll a concentrations. The authors hypothesized that these dust storms delivered a critical source of dissolved iron into the water column and increased the standing stock by natural fertilisation. It is anticipated that with further drought predictions set to increase the number of severe dust storms in Australia (Shao et al. 2007), and an increase in the poleward extension of the EAC

(bringing subtropical water further south) (Ridgway 2007), *Trichodesmium erythraeum* blooms will increase in frequency, and/or shift their interannual timing, in NSW coastal waters.

While *Noctiluca scintillans* and *Trichodesmium erythraeum* are both 'harmless' bloom taxa, microalgal bloom type requires more focused investigation in relation to ocean warming (Moore 2008, Hallegraeff 2010). Our limited understanding of marine ecosystem function and how it will respond to climate warming, coupled with a limited knowledge of phytoplankton physiology and ecology in NSW coastal waters, make it difficult to predict how the frequency of these bloom types we detail in this work will change over time. Estuarine data from our study show more 'potentially harmful to marine organisms' blooms during 1990 to 1999 compared to 2000 to 2009, and more 'harmless' blooms during 2000-2009 compared to previous years. Whilst it is difficult to explain these results in light of potential bloom drivers, the greatest increase in bloom frequency in these waters occurred in the 'unidentified' bloom type. The increasing number of 'unidentified' blooms in our dataset highlights the need for more systematic reporting and unambiguous identification of the causative species of blooms in NSW coastal waters. Accordingly, data such as bloom magnitude, bloom duration and spatial extent of each bloom would provide a more robust dataset for predicting interannual and long term trends in bloom types, and may provide a clearer understanding of species range extensions or retractions.

Within the annual cycle of reported blooms, the frequency of blooms appears to have altered over the past two decades. Maximum bloom activity occurred in January during the 1990 to 1999 reporting period, and shifted to October during the more recent period. In the absence of a continuous phytoplankton community dataset with which to test the certainty of this observed shift, the seasonal bloom data allows us to hypothesise that the spring diatom bloom observed regularly in these waters is experiencing an earlier onset. This in turn may trigger an earlier, secondary trophic effect resulting in an increase in abundance of the heterotrophic, *Noctiluca scintillans*. Further detailed studies would be required to test this hypothesis.

Our data indicates that the frequency of reported blooms in NSW coastal waters has increased over time. However, on decadal timescales, the El-Niño-La Niña climatic cycle could be a major factor in bloom frequency and may confound the overall increase seen in reported blooms. Peak bloom periods in our study were found to occur between 1997 to 1998 and 2002 to 2003 (Fig. 4). These correspond to periods of sustained negative SOI values, indicating El Niño episodes. While three El Niño episodes occurred during our sampling period, the two most significant of these warming phases were during 1997 to 1998 and 2002 to 2003, when warmer than average sea surface temperatures, a reduction in rainfall and a decrease in the strength of the Pacific Trade Winds in eastern Australia were documented. Thompson et al. (2009) found that SeaWIF (Sea-viewing Wide Field-of-View Sensor) chlorophyll a anomalies for southeastern Australian waters were associated with the transition from negative to positive SOI and were also recorded during these years, 1997 to 1998 and 2002 to 2003. Maclean (1989) suggested a similar relationship between bloom events and the El Niño-Southern Oscillation when reviewing red-tides in the Indo-Pacific region during the 1970s to 1980s. Elsewhere in the Pacific region, the relationship between bloom events and El Nino has also been raised. A bloom of the toxic dinoflagellate *Karenia concordia* along the north-eastern coast of New Zealand in 2002 occurred with El Niño conditions prevailing, providing wind and upwelling conditions favorable for phytoplankton growth (Chang and Ryan 2004). Yin et al. (1999) also reported that a series of red tides in Hong Kong, causing millions of dollars loss due to fish kills, occurred during the El Niño event of 1997 to 1998. These blooms were linked to the dramatic change in oceanographic conditions observed during this phase.

Given the uncertainties associated with bloom data, the relationship between bloom events and SOI cannot be considered causative. Nevertheless, it allows us to hypothesize that future peak bloom activity in south-eastern Australian coastal waters is likely to be coupled to shifts in the El Niño-Southern Oscillation cycle. To test such a hypothesis, a phytoplankton dataset would be required that consistently recorded bloom information such as species abundance and composition, bloom magnitude and bloom duration. Such basic information is necessary to quantify the spatio-temporal variability of these events. The collection of such accurate and systematic bloom data in NSW coastal waters requires localised, up-to-date and accessible bloom manuals. These manuals must be adequately resourced by the NSW government, by way of the Regional Algal Coordinating Committees (RACCs).

The case for historical/observational science, such as presented here, is strongly re-emerging as an important supplement to experimental science (Francis and Hare, 1994; Sagarin, 2001, 2008). With considerable knowledge gaps, and a critical need to hastily understand the changes that a warmer

Proc. Linn. Soc. N.S.W., 133, 2011

29

world is bringing, Sagarin (2008) argues that non-traditional data, such as presented here, can provide meaningful temporal and spatial associations about our shifting environment. Despite the limited nature of this anthropogenically derived bloom data, such as a rise in bloom reports due to an increase in public awareness, population growth, urbanisation of the coastal zone, increased reliance on fisheries resources, and/or weather patterns etc. (see review Ajani et al. 2001a), microalgal bloom reports can contribute valuable historical information, suggest causative relationships for testing and highlight key data requirements for evaluating future trends in phytoplankton phenology. The value of this type of data has recently been recognized with the formation of a global Harmful Algae Event Database (HAEDAT). When fully established, this information system will consist of data on harmful algal events, harmful algae monitoring and algal bloom management systems used throughout the world (http://iodeweb6.vliz. be/haedat/index.php). It is anticipated that an algal bloom dataset such as presented in this study will be one of the first contributions from Australian waters towards this global endeavour.

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30

Proc. Linn. Soc. N.S.W., 133, 2011

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Proc. Linn. Soc. N.S.W., 133, 2011

31

Silurian Brachiopods from the Historic Woolshed Creek Area, Canberra, Australia

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The brachiopod fauna of seven species from the Canberra Formation at Woolshed Creek near Duntroon, Canberra, is revised. Four species were collected by W.B. Clarke in 1844 and represent the first formal recognition of Silurian rocks in Australia. Referred to European species and genera by de Koninck in 1876, these are now recognised as *Mesoleptostrophia (Mesoleptostrophia) oepiki*, *Morinorhynchus oepiki*, *Apopentamerus clarkei* n.sp. and *Atrypa (Atrypa) duntroonensis*. The last dominates the fauna, and was first described by Mitchell and Dun in 1920; a Canberra atrypid compared by Strusz in 1985 to the Victorian Early Devonian species *Spinatrypa perflabellata* is now known to be *A. (A.) duntroonensis*. *Salopina mediocostata*, *Hedeina oepiki*, and *Spirinella caecistriata* are also present, together with uncommon trilobites (mostly *Batocara mitchelli*), corals, gastropods and bryozoans, some of which are illustrated. The fossils occur in repeated crowded layers which probably represent storm deposits. The age is most likely to be Homerian (latest Early Silurian).

INTRODUCTION

Woolshed Creek runs south to join the Molonglo River a little to the east of Royal Military College, Duntroon (eastern Canberra), where it is crossed by Fairbairn Avenue. Duntroon was the family home of Robert Campbell, a wealthy merchant and grazier who first took up land along the Molonglo River in 1825. The property was managed by James Ainslie; Campbell only lived at Duntroon after his wife's death in 1833, and died there in 1846. In 1844, Rev. W.B. Clarke, pastor and geologist, visited the area during his travels in southern New South Wales on behalf of the colonial government, and undoubtedly stayed with Campbell (whom he would have known from his period as headmaster of the Kings School from 1839 to 1841, a school established partly at Campbell's instigation). While at Duntroon, Clarke collected fossils from the vicinity, and from Yarralumla a few kilometres to the west. He recognised that these fossils were of undoubted Silurian age, a conclusion he published in 1848. This was the first published identification of Silurian fossils in Australia, and much later led to an area along Woolshed Creek, including the original outcrop, being registered as a Geological Heritage Site. Clarke's fossil collections were subsequently examined by L.G. de Koninck of Leuven University (Belgium), and published by him in 1876-7. The collections were destroyed in the Garden Palace fire of 1882 in Sydney. Mitchell and Dun recollected Clarke's site, and in 1920 described *Atrypa duntroonensis* based on three rather poor specimens. Öpik (1958, figs 19, 20), published photos of the outcrop north of Fairbairn Avenue, at which time layers crowded with brachiopods could be seen. Unfortunately since then there has been much deterioration, so that the site is no longer as spectacular.

New material

At the beginning of the 21st Century traffic along Fairbairn Avenue became sufficiently heavy that the ACT government proposed duplicating the existing bridge across Woolshed Creek. This was to be sited just downstream of the existing bridge, in a part of the heritage site lacking outcrops - hence not disturbing the existing exposure. Excavations for the bridge

abutments were carried out in 2008, and yielded large quantities of fossiliferous material. Opportunity was taken to collect specimens, and these form the basis of the present paper.

The fauna is dominated by *A. duntroonensis*. The fossils occur in repeated layers crowded with shells, with mostly dissociated but unbroken or only slightly damaged convex upwards valves indicating that most layers are probably storm deposits from below normal wave base (Fig. 1). Occasional layers contain syringoporoid corals which appear to be in growth position, and are less crowded with shells, suggesting these were subject to less disturbance before being buried by silt. Seven species of brachiopod have been identified in the collections. Of these, only one - a very rare smooth pentameride - is new, and overall the fauna is typical of the Canberra Formation, as described by Strusz (1985a). Interestingly, four of the brachiopods (including the rare pentameride) were collected by Clarke and identified reasonably accurately as European Silurian species by de Koninck (1876-7), who consequently (but unfortunately) neither described nor illustrated them.

All the material is distorted, partly by compaction and partly due to tectonic forces. The degree of distortion is variable, probably because of different amounts of compaction depending on the amount and nature of the silt enclosing the fossils. Shells are randomly oriented on the bedding planes, so that analysis of size and proportions is feasible but can only be approximate (see remarks in Strusz 1985a:112-114).

Stratigraphy and age

The Woolshed Creek locality was included by Öpik (1958) in his Riverside Formation, which is now regarded as part of the lithologically variable Canberra Formation. Unfortunately there is no reliable evidence from conodonts or graptolites for the age of this unit, which must therefore be argued on the basis of stratigraphic correlation with the succession at Yass, north of Canberra; for a fuller discussion see Strusz (2010b). The most likely age for the Canberra Formation has been deduced to be late Sheinwoodian to early Homerian. From mapping by the Engineering Geology section of the former Australian Bureau of Mineral Resources (now Geoscience Australia), it is likely that the Woolshed Creek locality is high in the
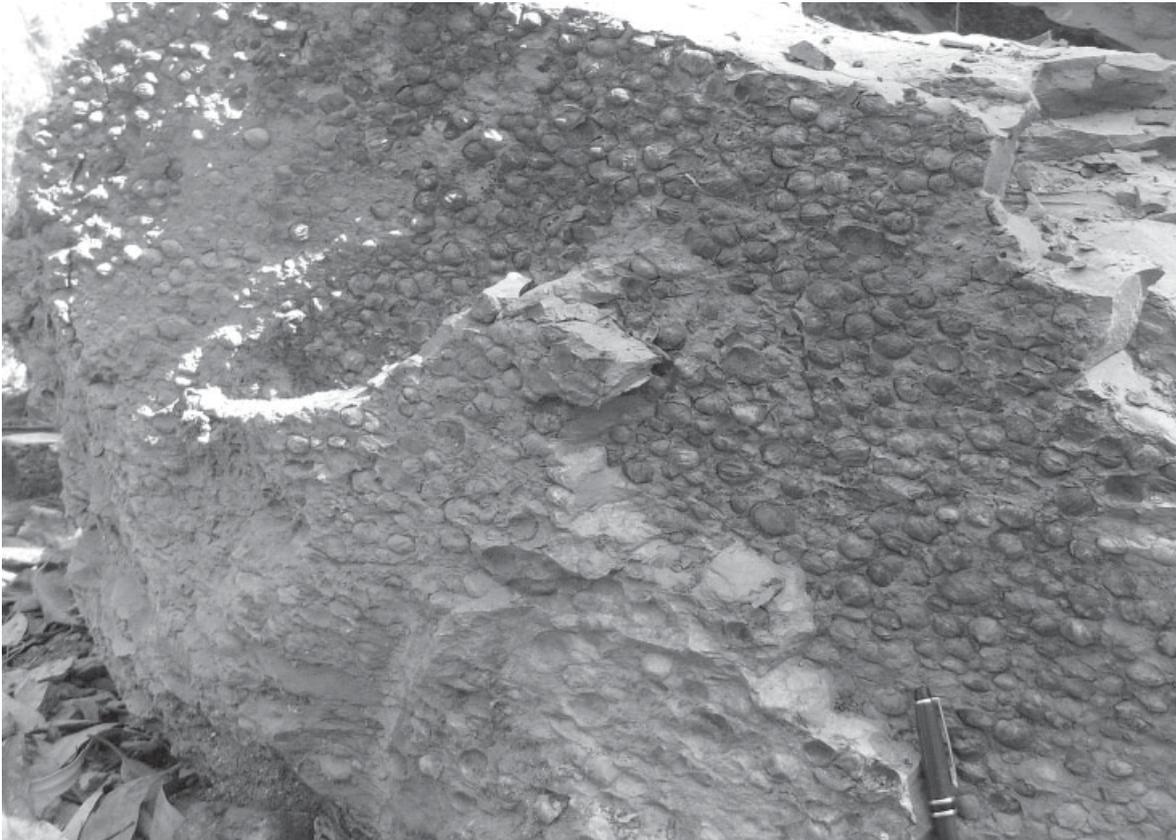

Figure 1. Large excavated slab of siltstone from Woolshed Creek, showing successive layers crowded with *Atrypa* valves and shells, mostly moulds and convex-upwards.

formation, which would indicate an early Homerian age (see Strusz and Henderson 1971, Henderson and Matveev 1980).

SYSTEMATIC PALAEONTOLOGY

Specimens registered with the Australian Museum, Sydney, have numbers prefixed AM F, those with the Department of Earth and Marine Sciences, Research School of Earth Sciences, Australian National University are prefixed ANU, and those in the Commonwealth Palaeontological Collection, Geoscience Australia, Canberra, are prefixed CPC. Geoscience Australia and the Research School of Earth Sciences, Australian National University, also hold unregistered bulk material.

Classification follows that in the Treatise on Invertebrate Paleontology, part H (Revised). References to supra-generic taxa can be found in the relevant parts of the Treatise. Only *Atrypa duntroonensis* and the new pentameride are fully described.

Class STROPHOMENATA Williams et al. 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily STROPHOMENOIDEA King, 1846
Family LEPTOSTROPHIIDAE Caster, 1939
Genus MESOLEPTOSTROPHIA Harper and Boucot, 1978
Subgenus MESOLEPTOSTROPHIA Harper and Boucot, 1978

Type species
Mesoleptostrophia kartalensis Harper and Boucot, 1978, p. 68 [= *Strophodonta (Leptostrophia) explanata* Paeckelmann and Sieverts, 1932, non Sowerby, 1842]. Early Devonian, Turkey.

Mesoleptostrophia (Mesoleptostrophia) oepiki
(Strusz, 1985)
Fig. 2

Synonymy
Leptaena compressa, J. de C. Sowerby; de Koninck 1876:27; non *Orthis compressa* J. de C. Sowerby, 1839, which is *Mesoleptostrophia (Mesoleptostrophia) compressa* - see Cocks 2008:70; de Koninck (transl. Dun in David, David and Dun) 1898:22.
Leptostrophia (Leptostrophiella) oepiki Strusz, 1985a:110-111, Figs 4-5.

Pholidostrophiidae? gen. et sp. indet. Strusz, 1985a:111, Fig. 6.
M. (Mesoleptostrophia) oepiki (Strusz); Strusz 2010b, Figs 2, 3K-M.

Type material
Holotype CPC24751, paratypes CPC24744-24750, 24752-24783, 24877, 24880-24883, 24903-24905, 24917-24922. Canberra Formation, Fyshwick, ACT. Wenlock.

Woolshed Creek material. AM F.110137-110141, 110193-110196, 110212-110214, 110225-110226, 110253-110254, 110259, 110263, 110268, 110276-110280, 110316-110318, 110350, 110368, 110413-110418, 110423-110424.

Diagnosis (new)
Moderately concavo-convex *Mesoleptostrophia* of medium to large size, uniformly costellate, with long narrow alae, denticulation to 1/3 width of corpus; low ridges posterolaterally bounding subtriangular, posteriorly strongly impressed ventral muscle field, lateral to which valve floor is coarsely tuberculate; fine ventral myophragm; prominent notothyrial platform continuous with dorsal myophragm and pair of often prominent curved muscle-bounding ridges.

Discussion
The description given by Strusz (1985a) is generally adequate, except that the outline is erroneously described there as elongate (instead of transversely) semi-elliptical. Ls/Ws (excluding alae) varies in the Fyshwick material between 2/3 and 3/4. The material from Woolshed Creek agrees well with that from Fyshwick, although in some bands the distortion is greater.

Two species of *M. (Mesoleptostrophia)* are now known from the Silurian of the Yass-Canberra region (see Strusz, 2010b). *M. (M.) oepiki* differs from the somewhat younger *M. (M.) quadrata* (Mitchell, 1923) in its long, slender alae separated from the less quadrate corpus by weaker reentrants, coarser ribs, no anterior sulcus in gerontic shells, a fine ventral myophragm, and curved dorsal muscle-bounding ridges. *M. (M.) oepiki* is readily distinguished from the similarly alate *Mesopholidostrophia bendeninensis* (Mitchell, 1923) by its stronger ornament, weaker convexity, stronger ventral and dorsal muscle-bounding ridges, and stronger notothyrial platform.

The large dorsal valve (CPC24884) considered by Strusz (1985a) to be a probable pholidostrophiid is distinctive in that its strong muscle-bounding ridges and myophragm are supplemented by two distinct

Proc. Linn. Soc. N.S.W., 133, 2011

35
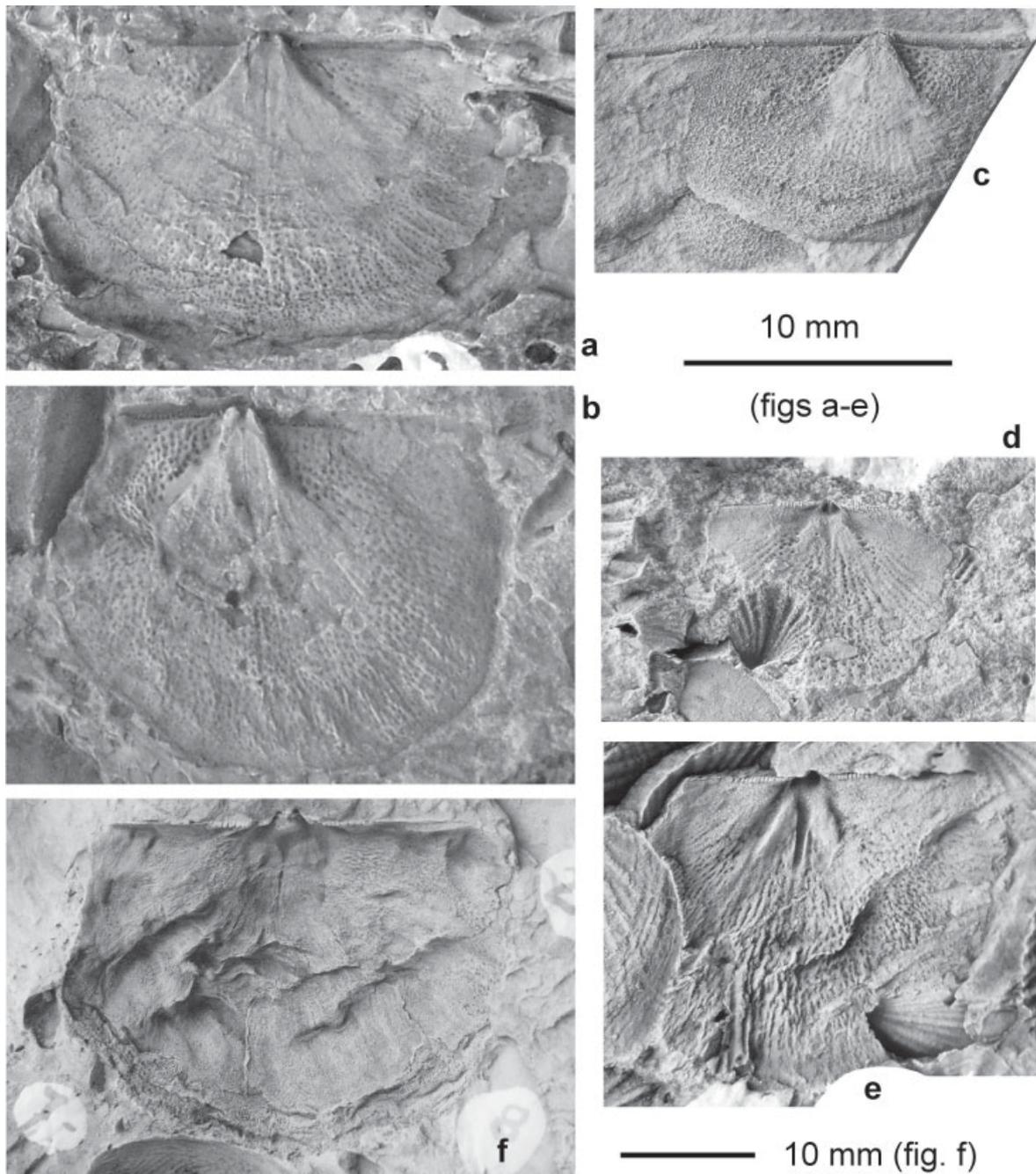
Figure 2. *Mesoleptostrophia* (*Mesoleptostrophia*) *oepiki* (Strusz, 1985); a, AM F.110193, ventral internal mould; b, AM F.110194, ventral internal mould; c, AM F.110141, incomplete ventral internal mould showing long narrow ala and concave lateral margin; d, AM F.110413, incomplete dorsal internal mould clearly showing bifid cardinal process, denticulate cardinal margin; e, AM F.110415, incomplete dorsal internal mould showing relatively robust myophragm and muscle-bounding ridges; f, AM F.110317, crushed gerontic dorsal internal mould showing more complex muscle field, including curved bounding ridges and short anderidia - compare CPC24884 (Strusz 1985a, fig. 6).

ridges within the adductor muscle field. One large dorsal internal mould from Woolshed Creek (AM F.110317, Fig. 2f) has a similar complex of structures, and I now think it is most likely that the Fyshwick specimen is a gerontic *M.(M.) oepiki*.

The specimens collected by Clarke from "Duntroon" and reported (but not figured) by de Koninck (1876) can confidently be referred to *M. (M.) oepiki*.

Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily CHILIDIOPSOIDEA Boucot, 1959
Family CHILIDIOPSIDAE Boucot, 1959
Subfamily CHILIDIOPSINAE Boucot, 1959
Genus MORINORHYNCHUS Havlíček, 1965

Type species

Morinorhynchus dalmanelliformis Havlíček, 1965, p. 291. Ludlow, Bohemia.

Morinorhynchus oepiki Strusz, 1982
Fig. 3

Synonymy

Strophomenes pecten, Linnaeus; de Koninck 1876:28; non *Anomia pecten* Linnaeus, 1767, which is *Coolinia pecten* - see Cocks, 2008:99; de Koninck (transl. Dun in David, David and Dun) 1898:22.

Morinorhynchus oepiki Strusz, 1982:119-122, Figs. 14-15; Strusz, 1985a:111-112, Fig. 7; Strusz, 1985b:681-682, Figs 3.1-9; Strusz 2003:31-32, Fig. 20; Strusz, 2010b, Figs 2, 3 K'-M'.

Morinorhynchus oepiki?; Strusz, 1985b:681-682, Fig. 3.10.

Type material

Holotype CPC20987, paratypes CPC20415-20419, 20988-20994. Walker Volcanics, Canberra. Late Wenlock.

Woolshed Creek material

AM F.110165, 110297, 110335, 110346, 110369-110370

Diagnosis

Thin, nearly planoconvex to slightly resupinate *Morinorhynchus* with fine unequally parvicostellate ornament (Strusz 2003).

Figure 3. *Morinorhynchus oepiki* Strusz, 1982; a, AM F.110297, incomplete and rather strongly distorted ventral internal mould; b, AM F.110346, small ventral internal mould; c, AM F.110335, dorsal external mould; d, AM F.110370, dorsal internal mould.

Remarks

The few small specimens from the Woolshed Creek excavations are very similar to those described

Proc. Linn. Soc. N.S.W., 133, 2011

37

by Strusz (1985a) from the Canberra Formation in Fyshwick, and the remarks made therein still apply. It is an uncommon species at all known localities.

This is almost certainly the species from "Duntroon" referred by de Koninck (1876) to *Anomia pecten* Linnaeus, 1767, a species which has since been referred to the related and quite similar genus *Coolinia* Bancroft, 1949.

Class RHYNCHONELLATA Williams et al., 1996
Order ORTHIDA Schuchert and Cooper, 1932
Suborder ORTHIDINA Schuchert and Cooper, 1932
Superfamily ENTELETOIDEA Waagen, 1884
Family DRABOVIIDAE Havlíček, 1950
Subfamily DRABOVIINAE Havlíček, 1950
Genus SALOPINA Boucot in Boucot et al., 1960

Type species

Orthis lunata J. de C. Sowerby, 1839. Ludlow, Shropshire.

Salopina mediocostata Strusz, 1982
Fig. 4

Synonymy

Salopina mediocostata Strusz,1982:111-114, Figs 5-7; Strusz 1984:125-126, Figs 2-3; Strusz, 1985a:108, Fig. 3; Strusz 2002:67-70, Figs 11-13; Strusz, 2010b: Figs 4, 5 M-P.

Type material

Holotype CPC20337, paratypes CPC20253-20336, 20338-20344, 20932-20942. Walker Volcanics, Wenlock, Canberra.

Woolshed Creek material

AM F.110127-110132, 110227, 110255, 110371-110374, 110396-110397.

Remarks

This species is not common at Woolshed Creek, and nearly all of the specimens are quite small - the largest measured is AM F.110227 with a width of 7.2 mm, but most are less than 4 mm across. However, they are closely comparable with previously published specimens, especially the similarly distorted Fyshwick material (Strusz 1985a) e.g. compare the ventral internal mould of AM F.110130 (Fig. 4a) with CPC24731 (1985a, fig. 3C), and the dorsal internal mould AM F.110227 (Fig. 4c) with CPC24913 (1985a, fig. 3G). Unfortunately all available external moulds are incomplete and not well preserved, so
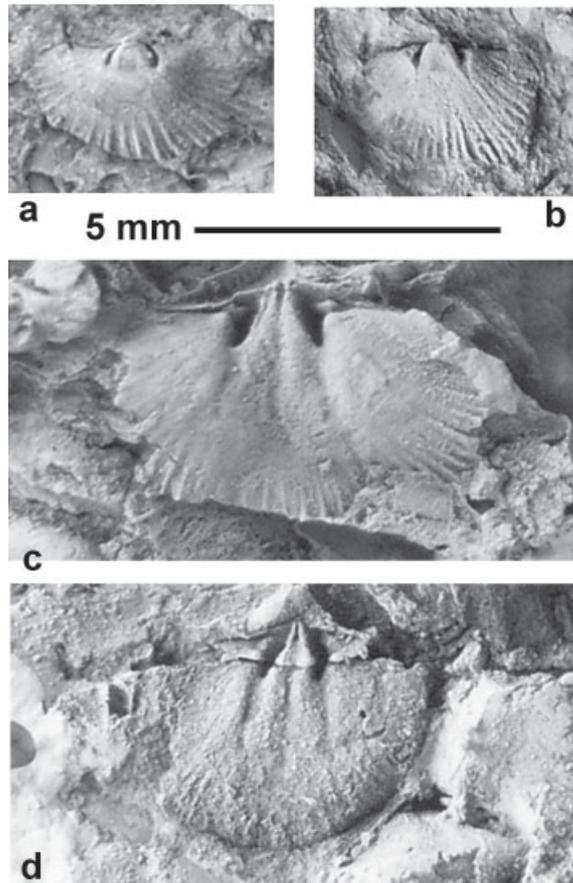
Figure 4. *Salopina mediocostata* Strusz, 1982; a, AM F.110130, small ventral internal mould - compare Strusz, 1985a, fig. 3C; b, AM F.110372, small ventral internal mould; c, AM F.110227, incomplete dorsal internal mould - compare Strusz, 1985a, fig. 3G; d, AM F.110374, dorsal internal mould.

the presence of the enlarged median costella on the dorsal valve, characteristic of the Walker Volcanics specimens, cannot be confirmed.

Order PENTAMERIDA Schuchert and Cooper, 1931
Suborder PENTAMERIDINA Schuchert and Cooper, 1931
Superfamily PENTAMEROIDEA M'Coy, 1844
Family PENTAMERIDAE M'Coy, 1844
Genus APOPENTAMERUS Boucot and Johnson, 1979

Type species

Apopentamerus racinensis Boucot and Johnson, 1979. Wenlock, Wisconsin, USA.

38

Proc. Linn. Soc. N.S.W., 133, 2011

Diagnosis (new)

Smooth non-lobate pentamerine, moderately to strongly biconvex with ventral valve usually deeper than dorsal valve; outline transversely oval to pyriform; ventral median septum long, supporting narrow spondylium; inner hinge plates subparallel, long, their junction with outer hinge plates smooth, without flanges.

Discussion

The diagnosis is based on the original diagnosis of Boucot and Johnson, plus the discussion of pentamerine relationships by Rong, Jin and Zhan (2007) analysed below.

Boucot and Johnson erected *Apopentamerus* for a Wisconsin pentameride species differing from *Isovella* Breivel and Breivel in Antsigin et al., 1970, in the presence of a spondylium, and from *Harpidium* Kirk, 1925, in its significantly longer ventral median septum. The dorsal interior is as in *Pentamerus* J. Sowerby, 1813. Sapel'nikov (1985) considered *Isovella* and *Apopentamerus* to be synonyms of *Harpidium*.

Boucot, Rong and Blodgett (in Kaesler, 2002), treated *Isovella* as a subgenus of *Harpidium*, characterised by a moderately long ventral median septum and substantial thickening in the ventral umbo. They considered *Apopentamerus* to be a synonym of *H. (Isovella)*, and *Sulcipentamerus* Zeng, 1987, to be a third subgenus of *Harpidium* characterised by its elongate and markedly ventribiconvex shell, and a short ventral median septum.

Sulcipentamerus has been extensively revised on the basis of large collections by Rong, Jin and Zhan (2007) and Jin, Harper and Rasmussen (2009). In their discussion of generic relationships, they noted that *Isovella* has laterally projecting crural bases (the flanges of Boucot et al. in Kaesler 2002) at the junction of inner and outer hinge plates - flanges not seen in *Harpidium*, *Apopentamerus*, and *Pentamerus* itself. As this is a feature previously recognised as taxonomically useful, Rong et al. (2007: 248) noted 'This implies that *Apopentamerus* is either a valid genus or a subgenus of *Harpidium* and that *Isovella* is most likely to be a genus independent of *Harpidium*.'. These authors also pointed out that Boucot et al. (in Kaesler 2002) regarded *Sulcipentamerus* as a subgenus of *Harpidium* on the assumption that it lacked trilobation. However, the strong variability shown by the large Chinese collections (including species with a weak tendency in large shells to trilobation), and also by collections of *Pentamerus oblongus* J. de C. Sowerby, 1839, from Estonia and Norway (ranging from non-lobate to markedly

trilobate), '..suggests that *Sulcipentamerus* is more closely related to *Pentamerus* than to *Harpidium*.' (Rong et al. 2007:249). It seems to me, from the above, that *Apopentamerus* is best treated as a valid genus distinct from both *Pentamerus* and *Harpidium*.

Apopentamerus clarkei n.sp.
Fig. 5

Synonymy

Pentamerus oblongus, J. Sowerby; de Koninck 1876:31; Jenkins 1879:26, 30, pl. 6, fig. 3; Mitchell 1887:1198; de Koninck (transl. Dun in David, David and Dun) 1898:24-25.
Pentamerus australis M'Coy; Etheridge 1892:51-52, non M'Coy 1877 (which is *Meristella* - Gill 1951:32).

Etymology

In honour of the Rev. W.B. Clarke, who first collected this species from Woolshed Creek.

Type Material

Holotype AM F.110260, Paratypes AM F.110168, 110298-110299, 110314-110315, 110343-110345, 110358, 110398-110399.

Other Material

ANU46537, from Yass locality KC48 (see Strusz 2002), is tentatively identified as *A. clarkei*.

Distribution

Canberra Formation, Canberra; basal Bowspring Limestone and probably Yarwood Siltstone Member, Yass. Early Homerian to early Ludfordian.

Diagnosis

Large strongly pyriform ventribiconvex *Apopentamerus* with prominent ventral beak, long ventral median septum, narrow spondylium, very long subparallel inner hinge plates.

Description

Moderately sized, smooth, ventribiconvex shell of pyriform to subtriangular outline with prominent postero-dorsally directed ventral beak, low dorsal beak. Ventral area small, triangular, gently concave, sharp-edged; delthyrium partly closed by concave crescentic pseudodeltidium. Anterior commissure (where preserved) appears to be broadly and very gently sulcate, and in one dorsal valve there is a possible faint sulcus. The largest, rather strongly distorted, specimen is 25.4 mm long and about 44 mm wide.
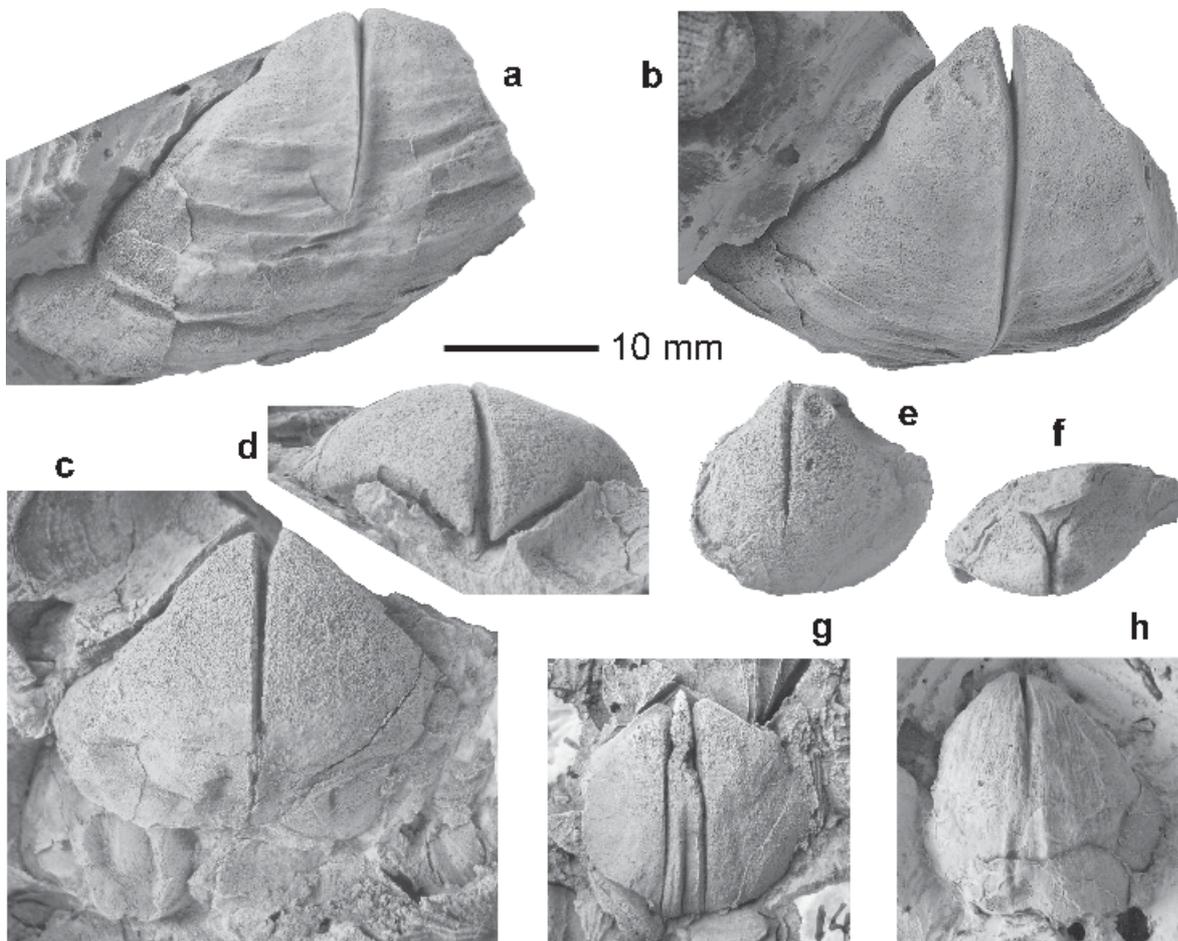
Figure 5. a-g, *Apopentamerus clarkei* **n. sp., Canberra Formation, Woolshed Creek, probably early Homerian; a, b, holotype AM F.110260, ventral internal mould in ventral and postero-ventral views, the latter clearly showing the narrow spondylium; c, d, paratype AM F.110345, damaged ventral internal mould in ventral and posterior views, the latter revealing the small pseudodeltidium; e, f, paratype AM F.110344, small ventral internal mould in ventral and posterior views; g, paratype AM F.110168, dorsal internal mould showing the very long subparallel inner hinge plates; the anterior median furrow suggests the possibility of a similar external furrow. h, ?***Apopentamerus clarkei***, ANU46537, Yarwood Silt-stone Member, Black Bog Shale, Yass (locality KC48), early Ludfordian; incomplete ventral mould in ventral view, showing the long septum supporting a narrow spondylium.**

Ventral median septum high, extending to between 1/3 and 2/3 but generally about half valve length; spondylium narrow, upwardly flaring, of uncertain length but apparently not reaching mid-length. There may be a little thickening umbonally in large specimens. Teeth unknown.

Inner hinge plates subparallel and fairly close, extending along valve floor to near anterior valve margin; posteriorly they are gently medially convex, and merge smoothly with more strongly convex outer hinge plates. Crural bases obscure; no flanges. Dental sockets narrow, diverge at about 90°. Outer socket ridges flat-topped. Low, narrow median ridge between hinge plates anterior to mid-length in some specimens.

Discussion

From the previous discussion of generic relationships, these few specimens are most likely to be either *Sulcipentamerus* or *Apopentamerus*. The former is highly variable externally, with some species being noticeably trilobate while others are non-lobate; the shell is markedly ventribiconvex, the dorsal valve sometimes flat or concave, and more generally bears a gentle sulcus. *Apopentamerus* is much less strongly ventribiconvex, and characteristically has a

40

Proc. Linn. Soc. N.S.W., 133, 2011

faint median furrow on each valve, giving a slightly emarginate outline. Moreover, the general shell shape in *Sulcipentamerus* is elongate, even subcylindroidal, whereas *Apopentamerus* is generally transverse, often subpyriform. Internally, the median septum in *Sulcipentamerus* is shorter than in *Apopentamerus*, while the spondylium is wider and relatively long. On balance, therefore, I consider the Woolshed Creek specimens belong in *Apopentamerus*.

This species is undoubtedly that identified by de Koninck (1876) as *Pentamerus oblongus*, an equally smooth northern hemisphere species from which it clearly differs in its wide pyriform shape. The incomplete dorsal internal mould from near Hattons Corner, Yass, figured by Jenkins (1879, pl. 6, fig. 3) as *Pentamerus oblongus* is almost identical to specimens AM F.110314. 110315 and 110344. Etheridge (1892:1198) thought Jenkins' specimen could be identified with *Pentamerus australis* M'Coy, 1878, but that species, from the Early Devonian of Lilydale, Victoria, was transferred to *Meristella* by Gill (1951:320) and is clearly unrelated. ANU46537, a single incomplete ventral internal mould from Yass locality KC48 and previously thought unidentifiable, is now recognised to be probably *A. clarkei*, and is figured here (Fig. 5h).

Apopentamerus clarkei differs from the type species *A. racinensis* Boucot and Johnson, 1979, in a rather longer ventral median septum, and an upwards-flaring spondylium. From *A. szechuanensis* Rong et al., 2007, it differs in its much greater convexity, gently sulcate anterior commissure, and lack of median furrows on ventral and most dorsal valves. It differs from *A. muchuanensis* Rong et al., 2007, also in its longer ventral median septum and inner hinge plates.

Order ATRYPIDA Rzhonsnitskaya, 1960
Suborder ATRYPIDINA Moore, 1952
Superfamily ATRYPOIDEA Gill, 1871
Family ATRYPIDAE Gill, 1871
Subfamily ATRYPINAE Gill, 1871
Genus ATRYPA Dalman, 1828
Subgenus ATRYPA Dalman, 1828

Type species

Anomia reticularis Linnaeus, 1758; Ludlow, Gotland.

A. (Atrypa) duntroonensis Mitchell and Dun, 1920
Figs 6-9

Synonymy

Atrypa reticularis, Linnaeus; de Koninck 1876:35; de Koninck (transl. Dun in David, David and Dun) 1898:26.

?*Atrypa? hemisphaerica*, J. de C. Sowerby; de Koninck 1876:35; de Koninck(transl. Dun in David, David and Dun) 1898:26-27.
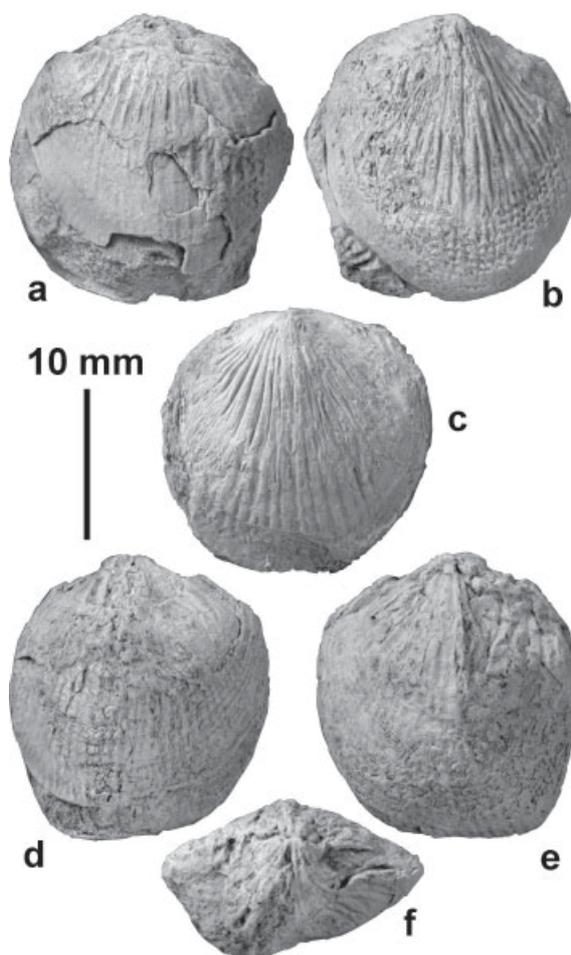
Figure 6. *Atrypa* (*Atrypa*) *duntroonensis* **Mitchell and Dun, 1920; a, b, paralectotype AM F29202 in dorsal and ventral views - original of Mitchell and Dun, pl. XVI, figs 9, 12; c, paralectotype AM F29201 in ventral view - original of pl. XVI, fig. 8; d-f, lectotype AM F29203 in dorsal, ventral and posterior views - original of pl. XVI, fig. 10. Note the significant distortion of the ventral valve visible in the posterior view of the lectotype.**
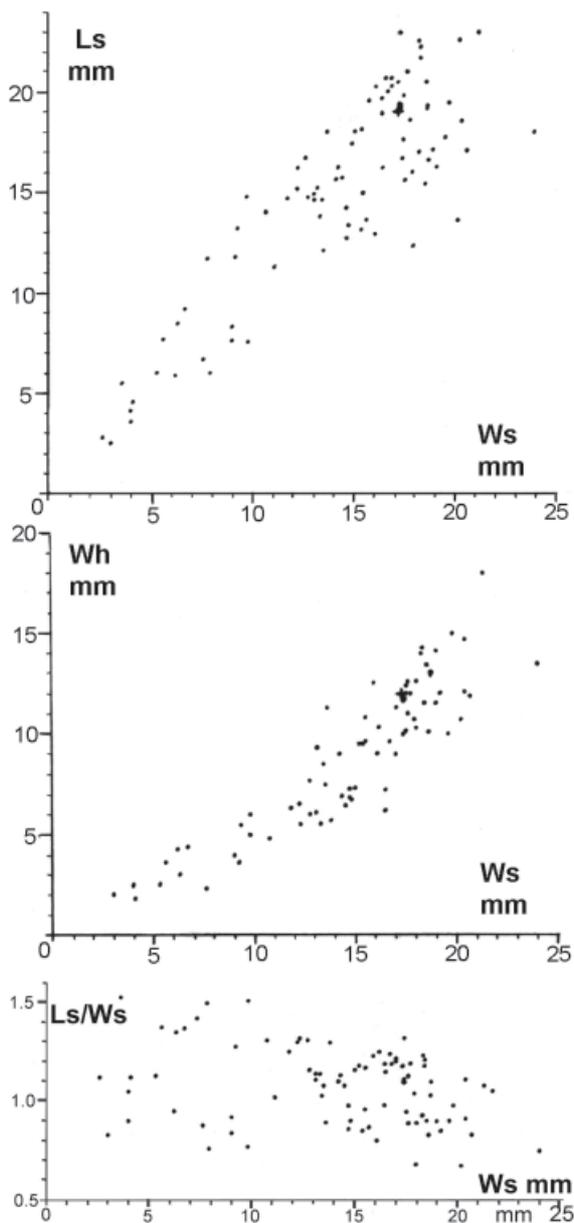
Figure 7. *Atrypa* (*A.*) *duntroonensis*; **plots of shell length Ls, hinge width Wh, and the ratio of shell length to width against shell width Ws - the cross in the first two is the lectotype. The significant change in slope in the plot of Wh:Ws suggests that maturity, indicated by an increasingly wide cardinal margin, is reached at a width of about 12-13 mm.**

Atrypa duntroonensis; Mitchell and
    Dun,1920:270-271, pl. XVI, figs 8-12.
Atrypa sp. cf. *perflabellata* (Talent, 1963); Strusz
    1985a:112-114, figs 8A-S.
Spinatrypa sp. cf. *perflabellata*; Strusz 2010b,
    figs 6, 7U-W.

Type material

Mitchell and Dun did not designate a holotype, and figured four specimens, which are thus syntypes. The originals of Plate XVI, figs 8-10 are registered with the Australian Museum as AM F29201-29203; the original of fig. 11 is missing. I here designate F29203, the original of Pl. XVI, fig. 10, as lectotype. The remaining syntypes thus become paralectotypes.

Type locality

Mitchell and Dun described their locality as 'near Duntroon homestead....' The only fossiliferous outcrops in that area are in Woolshed Creek, which flows south into the Molonglo River just east of the Royal Military College, Duntroon. De Koninck reported that the specimens collected by Rev. W.B. Clarke in 1844 and examined by him came from Duntroon, and Mitchell and Dun were quite certain that their species was the same as that collected by Clarke. The outcrop where preservation matches that of the type specimens is just north of Fairbairn Avenue where it crosses Woolshed Creek; this locality is now a designated Geological Heritage Area.

New material

Large numbers of specimens have been collected from the excavations (see Introduction) about 20 m along strike from the type locality: only those providing useful information for the redescription of this species have been registered. These are AM F.110119-110126, 110145-110150, 110154-110155, 110166-110167, 110173-110192, 110207-110211, 110217, 110228-110231, 110235-110251, 110257-110258, 110264-110265, 110269-110272, 110282-110294, 110300-110310, 110325-110331, 110336-110342, 110347-110349, 110359-110366, 110375-110386, 110400-110409, 110419.

Horizon, age

Canberra Formation, Wenlock. In the absence of conodonts and graptolites, the precise age cannot be determined, but as discussed above the most likely age for the Woolshed Creek locality is early Homerian.

Diagnosis (new)

Small to medium sized biconvex to dorsibiconvex *Atrypa* with short marginal frills, impressed ventral muscle field with raised anterior rim, relatively delicate teeth and crural plates, and dental cavities retained in adult shells.

Description - exterior

Adult shells biconvex to dorsibiconvex, moderately to strongly swollen, with outline varying
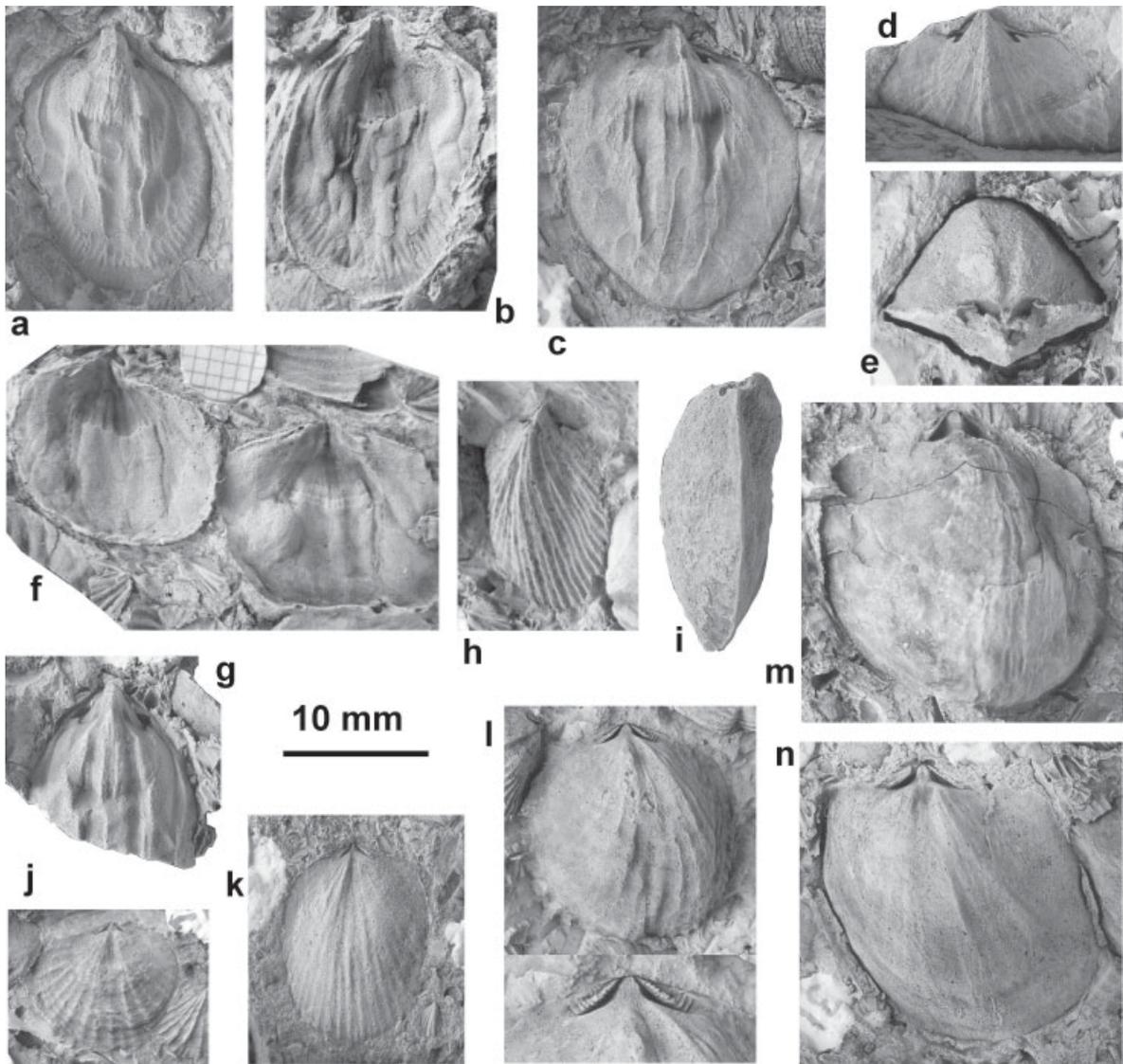
Figure 8. *Atrypa* (*A.*) *duntroonensis*; a, b, AM F.110210, ventral internal mould and latex replica showing strong vascular impressions; c, AM F.110207, ventral internal mould; d, AM F.110251, incomplete large ventral internal mould with weakly expressed muscle field (see also Fig. 9b); e, AM F.110328, partly exposed steinkern in posterior view with very convex dorsal valve, 3-ridged cardinal process; f, AM F.110419, latex replica of two adjacent ventral valves with deeply impressed anteriorly scalloped and somewhat raised muscle fields (see also Fig. 9c); g, AM F.110269, incomplete laterally compressed ventral internal mould showing impressions of narrow triangular teeth; h, AM F.110383, incomplete strongly laterally compressed juvenile ventral internal mould, showing relatively narrow cardinal margin; i, AM F.110342, moderately convex steinkern in lateral view; j, AM F.110147, longitudinally compressed juvenile dorsal internal mould; k, AM F.110408, laterally compressed juvenile dorsal internal mould; l, AM F.110329, dorsal internal mould - cardinalia enlarged below to show corrugated sockets and outer hinge plates; m, AM F.110124, large dorsal internal mould with robust crural plates; n, AM F.110407, large distorted dorsal internal mould. The infill of dental cavities is clearly visible in Figs 8c, d, g, h.
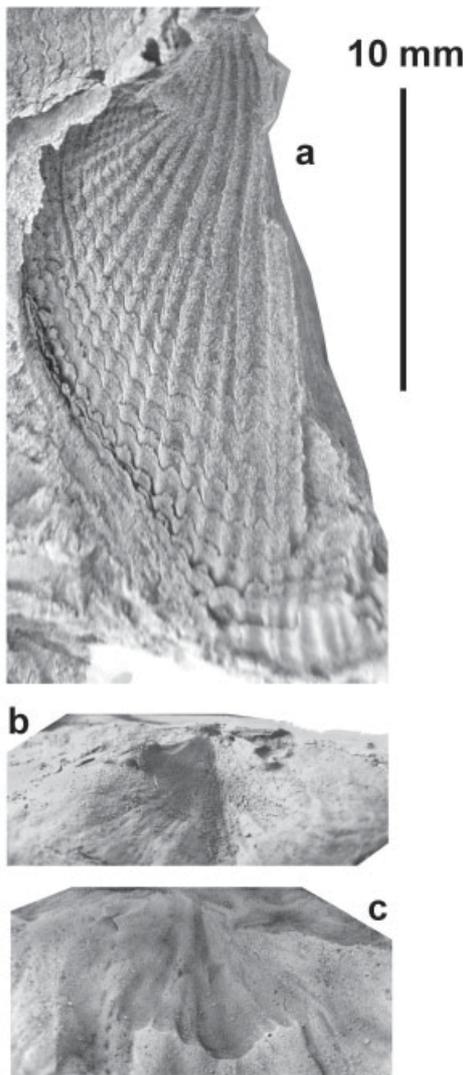
Proc. Linn. Soc. N.S.W., 133, 2011

43

Figure 9. *Atrypa* **(***A.***)** *duntroonensis***; detailed views of external and internal structures; a, AM F.110348, incomplete external mould showing short growth lamellae, and short marginal frill; b, AM F.110251, latex replica of large ventral valve in antero-dorsal view, showing dental cavities (that on the right was occupied by a bubble, so clearly shows the significant size); c, AM F.110419, latex replica of large ventral valve in antero-dorsal view, showing slit-like dental cavities, raised anterior margin to muscle field.**

from rounded to shield-shaped or subquadrate. Cardinal margin highly variable in width, and weakly to fairly strongly curved but not incurved. Most adult shells are 15 to 20 mm wide, with mean Ls/Ws 1.05 (overall mean is 1.066); a plot of Ls/Ws against Ws suggests a trend to less elongate shells with growth,

but variability is high. The two largest specimens are ventral valves with Ls 18.0 mm, Ws 24.0 mm, and Ls 23.0 mm, Ws 21.3 mm. Four steinkerns and two whole shells including the lectotype are between 15.0 and 22.0 mm wide, and their Ts/Ws varies between 0.46 and about 0.7. The least swollen specimens tend to be nearly equibiconvex, whereas in large swollen shells the dorsal valve can be twice the thickness of the ventral valve. In transverse profile ventral valve is medially rounded, may be weakly carinate posteriorly, and has almost planar flanks, while dorsal valve is evenly rounded. Anterior commissure gently to fairly strongly uniplicate. In longitudinal profile ventral valve is most convex posteriorly, flattening anteriorly, frequently forming very shallow sulcus which can extend dorsally as a tongue. Marginally, where growth lamellae are very crowded, valve surface often turned strongly dorsally. Dorsal valve evenly convex, frequently with flattened to upturned margins. Dorsal umbonal region with median depression which dies out anteriorly. Ventral beak low, wide, suberect to gently incurved, generally closely adpressed over extremely low dorsal beak. Large parabolic delthyrium occupies most of small apsacline ventral area, and mostly truncates beak.

Ribs low, 5-12 but mostly 6-8 in an arc of 5 mm at 5 mm radius, slightly coarser medially than laterally. Ventral valve has two raised ribs postero-medially, from length of about 6 mm separated by very fine single mid-rib. Increase is usually by splitting, always at growth lamellae, and most often episodic at radii of about 6-7 and 12-13 mm; there may be some intercalated ribs towards adult shell margins. Growth lamellae faint umbonally, then low, about 1 mm apart, becoming very crowded in narrow marginal zone, where they may form short oblique frills up to 1 mm long. The lamellae curve forward in inter-rib troughs, but do not form spinose outgrowths. A narrow skirt (about 2-3 mm) extending dorsally from ventral valve margin is occasionally preserved.

Interior

Teeth transversely elongate, of moderate size, separated by narrow transverse grooves from cardinal margin; well-preserved moulds show weak corrugations. Dental cavities slit-like cones, widely divergent, reduced but always present even in large shells. Muscle field medium to large, flabellate to subtriangular, variably but often strongly impressed, longitudinally furrowed with anteriorly raised rim which may be finely grooved. Adductor scars small, slightly raised either side of median depression posteriorly placed within muscle field. Pedicle callist weak, separated anteriorly from muscle field by fine

44

Proc. Linn. Soc. N.S.W., 133, 2011

concentric ridge; a few specimens show what appears to be a small pedicle collar at apex of delthyrium. Mantle canal system saccate, variably but sometimes strongly impressed on valve floor.

Cardinal pit deep, triangular in juveniles but slot-like in adults, with fine ridges at apex forming cardinal process, and floor raised a little above general valve floor. Crural plates robust in large shells, fine in small shells, forming deep triangular impressions in internal moulds. Sockets narrow, widely divergent, somewhat arcuate in all but smallest valves, corrugated; inner socket ridges flat-topped, often also corrugated; outer socket ridges fine, overhang sockets. Fairly prominent forward-expanding myophragm in juveniles, usually with fine median ridge, frequently becomes subdued or obscure in large shells. Mantle canal system obscure. Two medium-sized worn steinkerns show dorso-medially directed spiralia of 9-10 whorls; no further details are visible.

Ontogeny

Juvenile shells lenticular, rounded to elongate, with sharp nearly straight ventral beak, narrow curved cardinal margin, biconvex to somewhat dorsibiconvex profile. Ventral umbonal region generally moderately to fairly strongly carinate posteriorly, dorsal umbo with narrow sulcus. Margins without crowded frills or skirt. External sculpture strongly imprinted on valve floors in thin-shelled juveniles, generally lost in thicker-shelled adults. Dental cavities well developed, diverging at 90-120°, ventral muscle field generally not noticeably impressed. Sockets prominently corrugated. The size at which shell morphology changes from juvenile to adult appearance is highly variable, with some relatively large shells retaining an almost juvenile appearance apart from greater convexity and more deeply impressed ventral muscle field. Particularly for ventral valves, however, the change from juvenile to adult morphology is usually very marked.

Discussion

Morphological variation is considerable and, while overlain by post-burial distortion, it is apparent that in common with many species of *Atrypa* much of this is inherent variability. With the material now available it is quite clear that *A. (Atrypa) duntroonensis* is conspecific with the material from the Canberra Formation of Fyshwick compared by Strusz (1985a) with *Spinatrypa perflabellata* Talent, 1963, from the Pragian of Victoria. In my discussion in 1985 I considered Talent's species to be *Atrypa* rather than *Spinatrypa*, while in my recent biostratigraphic summary (Strusz 2010b) I chose to follow Talent,

Gratsianova and Yolkin (2001) in reverting to the original assignment, pending the results of the present study. The relationship between the Silurian and Pragian taxa is not clear, although on the basis of internal structures one could speculate that the latter could have been derived from the former.

A. (A.) duntroonensis is clearly the species identified by de Koninck (1876-7) as *A. reticularis*. While the destruction of Clarke's collections precludes absolute certainty, I am confident in the light of the variability shown by the current collections from Woolshed Creek that the specimens identified by de Koninck as *A. hemisphaerica* were juvenile *A. (A.) duntroonensis*.

As noted by many authors up to and including Copper (2004:35), distinguishing between species and even genera of Silurian atrypids can be difficult, and there has been considerable disagreement in deciding the boundaries between, and content of, the various genera and subgenera that have been erected. In general, I follow Copper (in Kaesler 2002; 2004). Doing so, however, leads me to recognise in the present species characters used to distinguish several Silurian genera: *Atrypa* itself, *Protatrypa* Boucot, Johnson and Staton, 1964, *Gotatrypa* Struve, 1966, *Rugosatrypa* Rzhonsnitskaya, 1975, and *Oglupes* Havlíček, 1987.

The dorsibiconvex shape of most larger *A. (A.) duntroonensis*, in which the anterior part of the ventral valve is flattened and even gently sulcate, is very typical of *A. (Atrypa)* but can also be seen in some *Oglupes* - e.g. *O. visbyensis* Copper, 2004 (see Copper's Pl. 12, figs a-e). Generally, though, *Oglupes* is a very globose form with a more even longitudinal convexity to the ventral valve, and more prominent ribs.

The Llandovery *Protatrypa* is small and lenticular, with a carinate ventral valve, very subdued growth lamellae, and dental cavities in adult shells - the last not generally known in *Atrypa*. Juvenile *A. duntroonensis* thus resemble adult *Protatrypa*, but adults can be readily distinguished by greater convexity, more prominent growth lamellae, and the presence of short marginal frills.

Gotatrypa is fairly small, biconvex to dorsibiconvex (Copper 2004, Pl. 10, fig. Bb), with short frills as in *A. duntroonensis*, but dental nuclei rather than dental cavities, and deltidial plates in juveniles. Moreover the ventral valve does not become flat or gently sulcate anteriorly, and the growth lamellae are projected as short spines in the inter-rib troughs.

Rugosatrypa is not well illustrated and the original description is brief, but it would appear to

Proc. Linn. Soc. N.S.W., 133, 2011

45

differ from *Atrypa* in smaller size, a lenticular profile, regular rather widely spaced concentric growth rugae but low growth lamellae not forming frills or a skirt, the presence of deltidial plates in adults, a weak pedicle callist, and prominent dental cavities. *A. (A.) duntroonensis* differs from it in a more swollen profile, no concentric rugae or deltidial plates, and reduced dental cavities in large shells.

On balance, therefore, I think the present species is best retained in *Atrypa (Atrypa)*, differing from other species by consistently retaining distinct dental cavities in adult shells.

Order SPIRIFERIDA Waagen, 1883
Superfamily CYRTIOIDEA Frederiks, 1924
Family CYRTIIDAE Frederiks, 1924
Subfamily EOSPIRIFERINAE Schuchert, 1929
Genus HEDEINA Boucot, 1957

Type species

Anomia crispa Linnaeus, 1758. Ludlow, Gotland.

Hedeina oepiki Strusz, 2010
(Figs 10-11)

Synonymy

Howellella sp. aff. *elegans* (Muir-Wood, 1925); Strusz 1982 partim (Fig. 27B only).
Cyrtiidae gen.? et sp. nov.; Strusz 1985a:115-117, Figs 11-12.
Hedeina oepiki Strusz, 2010a:103-104, fig. 13; Strusz, 2010b: Figs 6, 8 I-K.

Type material

Holotype CPC24671, paratypes CPC24831-24870. Canberra Formation, Fyshwick ACT; Wenlock.
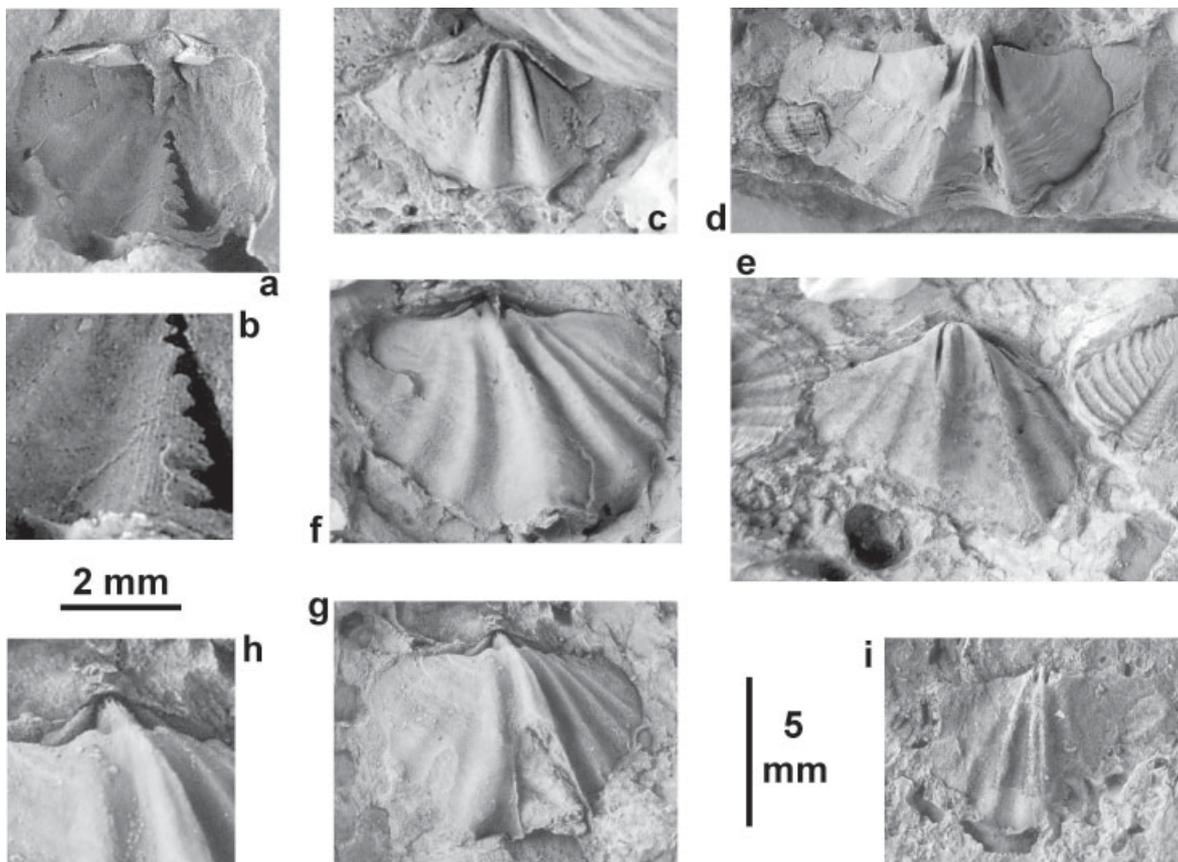
Figure 10. *Hedeina oepiki* Strusz, 2010; a, b, AM F.110252, ventral external mould with shape of dental lamellae shown by infill of the delthyrial cavity, and enlargement showing capillae preserved in the sulcus; c, AM F.110390, longitudinally compressed ventral internal mould with weak ribs on flanks; d, AM F.110355, ventral internal mould; e, AM F.110160, ventral internal mould; f, AM F.110135, distorted dorsal internal fold; g, h, AM F.110262, dorsal internal mould and enlargement showing ctenophoridium; i, AM F.110133, incomplete dorsal internal mould with well developed myophragm. 2 mm scale bar applies to Figs 10b, h.

Figure 11. *Hedeina oepiki* **Strusz, 2010; plot of shell length Ls against width Ws for specimens from the Canberra Formation at Woolshed Creek (●) and Fyshwick (x).**

Woolshed Creek material

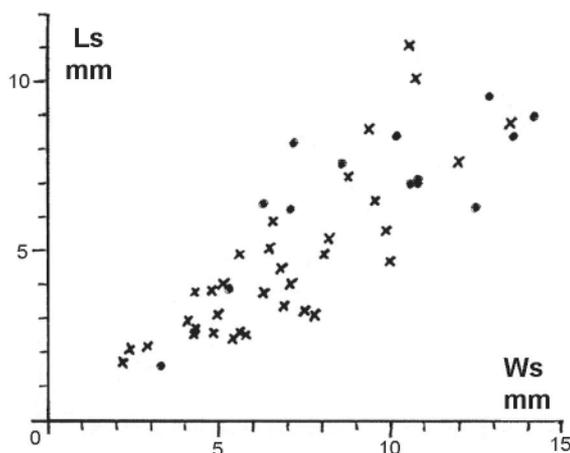AM F.110133-110135, 110142-110144, 110151-110152, 110156-110162, 110169-110171, 110197-110206, 110219-110224, 110252, 110262, 110267, 110273-110274, 110295-110296, 110319-110324, 110354-110357, 110387-110395, 110420-110421.

Distribution, age

Canberra Formation and Walker Volcanics, Canberra; Wenlock (late Sheinwoodian? to Homerian).

Remarks

The specimens from the Woolshed Creek locality show even greater variation in the degree of distortion than those described from Fyshwick. Allowing for that, and the effects it will have on any statistical comparison, the present material agrees in every important respect with *Hedeina oepiki* from Fyshwick (respective means for specimens from Fyshwick and Woolshed Creek: Ls/Ws 0.64 / 0.74, Wh/Ws 0.71 / 0.80, Wf/Ws 0.31 / 0.27). The ribs vary in form and number, but those flanking the ventral sulcus are always noticeably more prominent than the next lateral pair, and the dorsal fold is strong, its crest somewhat flattened. Internally, the ventral myophragm varies from low to quite strong; the dental plates are robust, clearly extrasinal, and extend to about one-third valve length. In the dorsal valve the crural plates are strongly recessive, and there is a low notothyrial platform supporting an apical ctenophoridium. There can be no doubt that populations of just one species occur at Woolshed Creek and Fyshwick. A comparison with the younger species *H. bruntoni* can be found in Strusz (2010a).

Strongly distorted small specimens with weak lateral ribs can be difficult to distinguish from *Endospirifer anxius* Strusz, 1982, in which one or rarely two faint lateral ribs are sometimes present. That species, however, has a suboval rather than subtriangular outline, less divergent dental plates which are barely extrasinal, and no notothyrial platform.

Superfamily RETICULARIOIDEA Waagen, 1883
Family RETICULARIIDAE Waagen, 1883
Subfamily RHENOTHYRIDINAE Gourvennec, 1994
Genus SPIRINELLA Johnston, 1941

Type species

Spirinella caecistriata Johnston, 1941. Late Wenlock, Yass, NSW.

Spirinella caecistriata Johnston, 1941
Fig. 12

Synonymy

Meristina (?) australis Shearsby 1912:112-113, *non* Dun 1904.
Spirinella caecistriata Johnston, 1941:161-167, Pl. VII, figs 1-11; Johnson, Boucot and Murphy 1976: Pl. 28, figs 17-27;
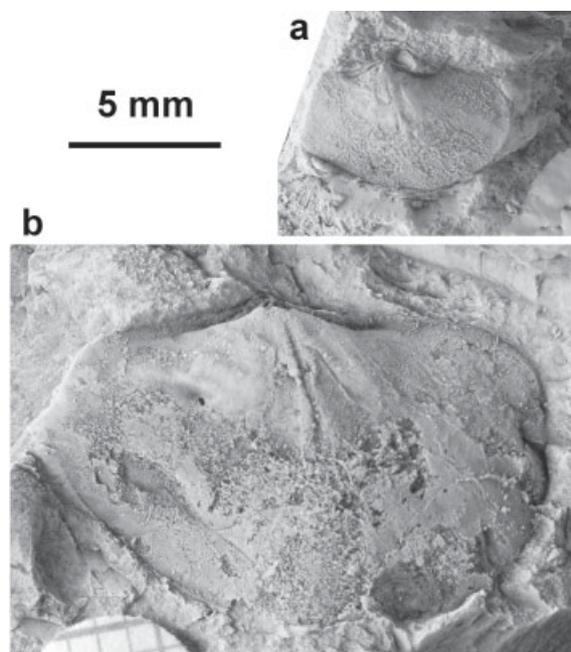

Figure 12. *Spirinella caecistriata* **Johnston, 1941; a, AM F.110234, small incomplete dorsal internal mould; b, AM F.110266, large dorsal internal mould - compare Strusz, 1985a, fig. 14C.**

Proc. Linn. Soc. N.S.W., 133, 2011

47

Strusz 1984:144-147, Figs 18-19; Strusz 1985a:117-118, Fig. 14; Strusz 2005:29-30, Fig. 1; Strusz, 2010a:112-117, Figs 18-20; Strusz, 2010b, Figs 6, 8V-X.
Reticulariopsis silurica Strusz, 1982:134-136, Fig. 28.

Type material

Holotype AM F39376. Paratypes AM F39378, 39379 and figured topotype AM F39377 have since been lost - see Strusz (1984, 2005). Yass Formation (Cliftonwood Limestone Member), Yass, NSW; Homerian.

Woolshed Creek material

AM F.110163-110164, 110172, 110215-110216, 110232-110234, 110266, 110311-110313, 110367, 110410.

Diagnosis (Strusz 2010a)

Suboval, moderately ventribiconvex *Spirinella* with prominent ventral umbo, erect to slightly incurved beak; interarea concave, weakly apsacline, not well delineated laterally. Teeth small, triangular; dental plates long, moderately divergent, continued anteriorly by grooves of *vascula media*; ventral muscle field generally somewhat impressed, elongate, longer than dental plates; delthyrial plate or apical thickening small, crescentic; crural plates narrow, triangular, more or less convergent downwards, rest posteriorly on small notothyrial platform; lanceolate dorsal adductor field and myophragm.

Remarks

Spirinella caecistriata is a minor component of the Woolshed Creek fauna. The few specimens are not well preserved, but are clearly conspecific with the similarly distorted specimens from Fyshwick. In particular, compare the dorsal internal mould AM F.110266 (Fig. 12b) with CPC24876, figured Strusz 1985a, Fig. 14C. The largest measurable specimens are over 16 mm wide, with Wh/Ws varying considerably around 0.73 - this compares well with the data from undistorted material in Strusz (2010a, tables 8 and 9).

ASSOCIATED FAUNA

Associated with the brachiopods, but none abundant, are trilobites, particularly the encrinurine trilobite Batocara mitchelli, rugose and tabulate corals of which a tryplasmatid, a columnar halysitid and a heliolitid are most common, gastropods and bivalves, and a strap-shaped bryozoan. The trilobites and some of the corals are shown in Fig. 13.

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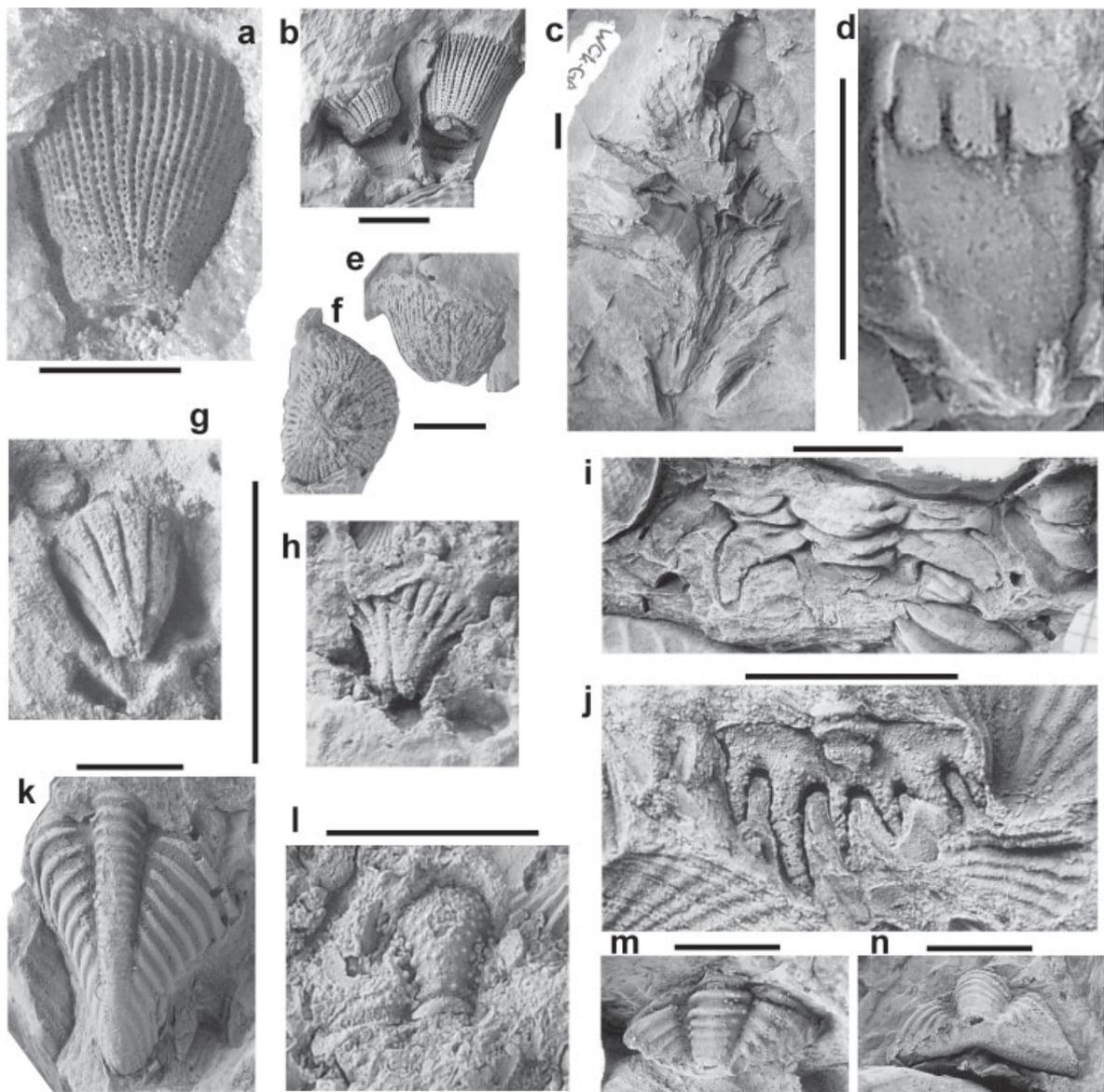
Figure 13. Moulds of corals and trilobites associated with the brachiopod fauna at Woolshed Creek; a-b, *Tryplasma* **sp., a, AM F.110218, b, AM F.110256; c-d,** *Halysites* **sp., AM F.110351, columnar corallum and enlargement of one smooth-sided palisade showing macrocorallites and intervening microcorallites; e-f,** *Entelophyllum***? sp., AM F.110261; g-h, undetermined diminutive cyathaxoniid?, g, AM F.110153, h, AM F.110281; i, cheirurine pygidium cf.** *Cheirurus* **sp. Chatterton and Campbell, 1980, AM F.110422; j,** *Uriarra kausi* **Chatterton and Campbell, 1980, AM F.110411, pygidium; k-l,** *Batocara mitchelli* **(Foerste, 1888), k, AM F.110275, pygidium, l, AM F.110136, small incomplete cranidium; m, n, indet. calymenid AM F.110332, small pygidium in dorsal and posterior views. All scale bars 5 mm long.**

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49

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Proc. Linn. Soc. N.S.W., 133, 2011

51

Morphometrics of the resting eggs of the fairy shrimp *Branchinella* in Australia (Anostraca: Thamnocephalidae).

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Branchinella resting eggs are characterised by having surface ridges arranged more or less in polygons and by almost all species having few, if any, spines. The eggs of 33 out of a known possible 40 species (including 4 out of 6 undescribed species) were studied by SEM. A few species are distinctive by being adorned with lighter coloured surface membranes often strengthened by ribs or sparse spines and one (*B. longirostris*) is regularly spinose. Those species known to be morphological variable also have variable egg morphologies. This makes it difficult to characterise specific egg morphology, but even so in some species eggs are distinct : *B. arborea, B. australiensis, B. budjiti, B. compacta, B. complexidigitata, B. hattahensis, B. kadjikadji, B. longirostris, B. lyrifera, B. occidentalis, B. pinderi* and *B. vosperi*. Most of the remainder are easily confused with at least one or more species. *Branchinella* egg morphology seems of little value in taxonomical studies and of restricted use in distinguishing eggs in dried sediments.

INTRODUCTION

The resting eggs of fairy shrimps have a tough outer layer, the tertiary envelope, which is often sculptured and may be specifically characteristic (Mura, 1986, 1991a, 1991b, 1992a, 1992b, 2001; Thiéry & Gasc, 1991, Thiéry et al., 2007; Brendonck & Coomans, 1994a,1994b; Hill & Shepard, 1997; Timms et al., 2004). One of the first egg shells to be described was of the Australian *Streptocephalus archeri* (Sars, 1986) and soon afterwards of *Branchinella australiensis* Richters, 1876 (as *B. eyrensis* Daday, 1910). These early descriptions used drawings based on microscopic observations, but in more recent times SEM technology has been used with great success (see references above). For Australia, Timms et al. 2004 provided an SEM study of 31 species, including 22 of *Branchinella*. This showed that the four genera naturally in Australia (*Australobranchipus, Branchinella, Parartemia* and *Streptocephalus*) have distinctive egg shapes and surface patterns and that within *Branchinella* many species, but not all, have distinctive morphology.

Optimism prevailed in the early 1990s that many species had an immutable unique pattern and hence the presence of a species at a dried site could be detected by examining bottom mud microscopically. Keys were constructed to aid this (eg Thiéry & Gasc, 1991). However further work showed problems in sampling eggs, and far too much variability within many species (Mura 1991b; Mura & Rosetti, 2010) for the widespread use of egg morphology. Moreover, in some species egg sculpturing maybe predator-inducible (Dumont et al., 2002) so masking any morphological relationships. Understandably, enthusiasm for egg studies waned. However environmental evaluations in recent times have needed to assess fauna in dried sites (eg Beladjal & Mertens, 2003; D.C. Rogers, pers. comm. for California; V. Campagna, pers. comm. for Western Australia) so that knowledge on resting eggs is a valuable aid, if the limitations are understood.

The aim of the present study is use detailed morphometrics to evaluate the eggs of as many species of *Branchinella* as possible, with a view to understanding which species have distinctive egg sculpturing, and how much this might be variable

in such widespread species as *B. australiensis* (Geddes, 1981) or species known to be otherwise variable as adults such as *B. longirostris* (Zofkova & Timms, 2009). A subsidiary aim is to gain further insight, within the limits of resting egg variability, of relationships between species as determined by morphology (Geddes, 1981).

MATERIALS AND METHODS

Of the presently 35 described species of *Branchinella*, 29 were available for study. In addition 4 undescribed species were also studied. For most species just one population was examined, but seven species had 2 to 5 populations studied and two species known to be particularly variable (*B. australiensis* and *B. longirostris*) had 7 and 8 populations examined respectively. Locality details for each are given in Appendix 1.

Resting eggs from each collection were removed from the brood pouches of 2 -3 mature ovigerous females which were preserved in 70% alcohol or 4% formalin, and then stored in 90 -95% alcohol for weeks to many months. This variable length of preservation may have affected the degree of hydration of the eggs. If the eggs seemed old or damaged as judged from the breakdown of the tertiary layer they were rejected (e.g. this happened for populations of *B. occidentalis* and *B. frondosa* in this study. Also eggs of *B. nana* had to be rejected as they were immature). Eggs were then air-dried and mounted on carbon tabs on aluminium stubs, gold sputter coated and then 10 per collection were photographed on a Zeiss Evo LS15 SEM using a Robinson Backscatter Detector. For each egg an average egg diameter was determined from three measurements and the character of the ridges and depressions noted. The later were counted on the visible side (whole depressions plus some only partly visible (scored as ¾ or ½ or ¼ according to how much is readily visible) and then doubled to obtain the total number of depressions per egg. For species with extremely numerous depressions (i.e > 100) only wholly visible depressions were counted. Accuracy was estimated at ± 3% when less than 100 depressions and at ± 6% when more than 100. The third quantitative parameter measured was the ratio of wall height to the average width of the depressions (wh:dw).

Some descriptive terms are used to describe the shapes of the depressions. While depression shape is basically polygonal, this term is used loosely; when the sides of the polygon is made up of five almost equal sides then the term pentagonal is used, but when the shape is irregular and hardly polygonal then the descriptors linear when main axis >2x axis at right angles or constricted when narrower in the middle than at the ends are used. Various terms are used to refer to the shape and thickness of the ridges that make up the walls of the depressions including triangular when the cross section is distinctly angular with straight sides, rounded when the cross section is an inverted U shape, punctuate when pitted, and ropey when uneven with regular bulges like a rope. The floor of the depressions may be flat or mildly, moderately or strongly concave. A mild concavity is one where depth is less than 0.1 of the diameter and a strongly concave surface has a depth greater than 0.5 of the diameter; intermediate values are considered to be moderate concave. However it is believed the degree of concavity is influenced to some degree by the state of hydration of the egg, so this character needs to be assessed with care. The surface of the depressions especially the floor, maybe smooth or dimpled (which may be small/weak, strong or even angled). Weak dimpling is defined as the height being less than the diameter of the dimple, and strong dimples have the height greater than the diameter. All these measurements have to be estimated by eye as there is no vertical scale readily available. Sometimes the depression walls or ridge crests are punctured with pores (simple or complex) or have minute spines. Some species have the crest ridges adorned with membranes or spines of various natures.

RESULTS

Descriptions of the eggs of 33 species are given below and in Tables 1 and 2 and illustrated in Figures 1 -5. For the majority of species, in which only one population was studied, the descriptions are short and may not encompass possible variability in that species. In an attempt to encompass variability, descriptions are longer for those where many populations were studied.

B. affinis Linder 1941 (Fig. 1a,b). Average size 215.3 µm, mean depression number 39.2. Size and number of depressions vary between east and west Australia. Depressions irregular, often invaginated and with dimpled floors and sides. Ridges usually distinct and rounded; if fully hydrated (Fig. 1b) then depression shallow (wall height:depression width ratio <0.2) and floors mildly concave, but if dehydrated (Fig. 1a) then depresssions much folded and deep (wh:dw >0.5) and floors markedly concave.

Table 1. Comparisons of egg sizes and depression numbers							
	egg sizes in ųm					depression numbers	
	Timms et al 2004			present study		present study	
Species	range	mean	n	mean	±SD	n	mean	±SD
B. affinis	95 - 134	113.2	20	215.3	44.21	30	39.2	7.29
B. arborea	183 - 201	191.6	10	214.9	4.65	10	20.7	1.64
B. australiensis	197 -222	213.5	20	310.1	50.58	70	21.2	8.11
B. basispina	225 - 275	253.5	10	248.3	8.20	10	31.8	1.48
B. buchananensis	204 -232	217.9	10	244.2	8.78	10	36.2	3.71
B. budjiti	141 -155	144.7	23	225.9	6.71	10	20.8	1.70
B. campbelli	162 - 194	172.3	20	191.6	4.95	10	29.2	2.53
B. clandestina				143.1	8.87	10	32.1	2.33
B. compacta				381.4	83.86	30	20.6	6.64
B. complexidigitata	211 - 307	251.0	40	268.0	5.54	10	127.8	4.05
B. denticulata				175.4	10.28	10	39.6	2.66
B. dubia	187 - 215	187.1	32	222.6	4.93	10	30.2	2.17
B. frondosa	185 - 211	191.1	10	202.0	8.29	10	32.7	2.54
B. halsei				189.9	12.07	50	44.2	22.67
B. hattahensis	254 - 289	268.9	20	257.9	6.20	10	44.4	4.41
B. kadjikadji	254	254.0	2	297.8	6.34	10	102.5	13.29
B. lamellata	124 - 180	147.6	31	182.0	12.94	10	47.1	1.90
B. longirostris	264 - 300	276.9	29	276.4	28.64	80	164.1	64.55
B. lyrifera	158 -183	171.5	20	213.4	14.52	20	615	88.68
B. mcraeae				175.0	7.63	10	35.4	2.20
B. nana	144 -158	152.3	19					
B. nichollsi	187 -247	202.3	30	295.3	5.72	10	34.4	1.84
B. occidentalis	550 - 571	565.3	20	492.2	24.46	20	53.1	17.69
B. papillata				293.9	7.80	10	33.0	2.47
B. pinderi				292.1	6.92	10	95.2	3.40
B. pinnata	173 -190	181.1	10	198.8	13.31	20	27.7	3.69
B. proboscida	158 - 187	174.9	19	220.0	8.32	10	72.7	5.65
B. simplex	144 - 201	176.4	32	301.4	12.32	10	41	3.93
B. vosperi				433.4	7.80	10	111.2	5.31
B. wellardi	158 - 176	168.4	30	181.1	8.44	10	47.2	4.69
B. new species K				160.1	8.45	10	41	3.27
B. new species M				223.7	6.08	10	41.5	4.16
B. new species S				169.5	10.43	10	50.4	6.18
B. new species Y				174.7	9.43	10	35.3	3.30

Proc. Linn. Soc. N.S.W., 133, 2011

55

Location	egg size in ụm		depressions	
	mean	±SD	mean	±SD
B. affinis				
Bloodwood Station, NSW	156.3	4.54	33.8	3.82
near Emu Rock, WA	258.3	6.38	47.7	4.74
Grass Patch, WA	231.3	9.11	36.0	2.75
B. australiensis				
L. Hutchinson, Qld	213.0	6.50	15.8	1.23
The Gums, Qld	332.4	7.06	15.0	1.00
Lake Goran, NSW	321.0	5.62	19.2	1.81
Snowleigh Station, NSW	377.8	8.27	17.1	1.62
Poodina, SA	274.3	12.03	39.1	2.88
Kau NR, Esperance WA	318.5	11.88	23.5	2.17
Laverton , WA	338.6	8.35	18.0	1.87
B. compacta				
Avon Lake, NSW	290.0	10.39	28.2	2.31
Little Unicup Lake, WA	485.2	14.32	13.4	2.70
Marchagee Rd, WA	369.1	4.85	20.2	1.00
B. halsei				
L. Hutchinson, Qld	199.3	4.36	31.4	1.85
Bloodwood Station, NSW	198.8	6.53	36.8	3.55
Ilparpa Claypan, NT	188.0	7.50	85.3	6.48
Lake Cronin, WA	173.9	8.66	22.6	1.33
Mundabullagana Station, WA	189.1	12.48	44.0	3.27
B. longirostris				
Walga Rock, WA	271.5	8.43	273.2	14.62
Wardagga Rocks, WA	311.7	11.25	144.0	10.09
Yorkrakine Rocks, WA	308.6	12.00	125.6	8.29
Elachbutting Rocks, WA	296.1	15.28	178.0	17.53
Andersons Rocks, WA	308.3	5.10	246.0	12.94
Mt Madden, WA	256.1	14.33	106.0	11.94
McDermid Rocks, WA	240.8	14.78	162.0	13.04
Yendeng Rocks, WA	218.4	9.47	78.0	11.94
B. occidentalis				
Rockwell Station, Qld	503.6	24.56	69.6	4.81
east of Carnarvon, WA	478.8	19.22	36.6	6.00
B. pinnata				
Lake Dunn, Qld	193.4	5.43	30.6	1.54
Bloodwood Station, NSW	204.3	14.49	24.8	1.76

Table 2 Measurements from populations of some highly variable species; measurements of 10 eggs from each site.
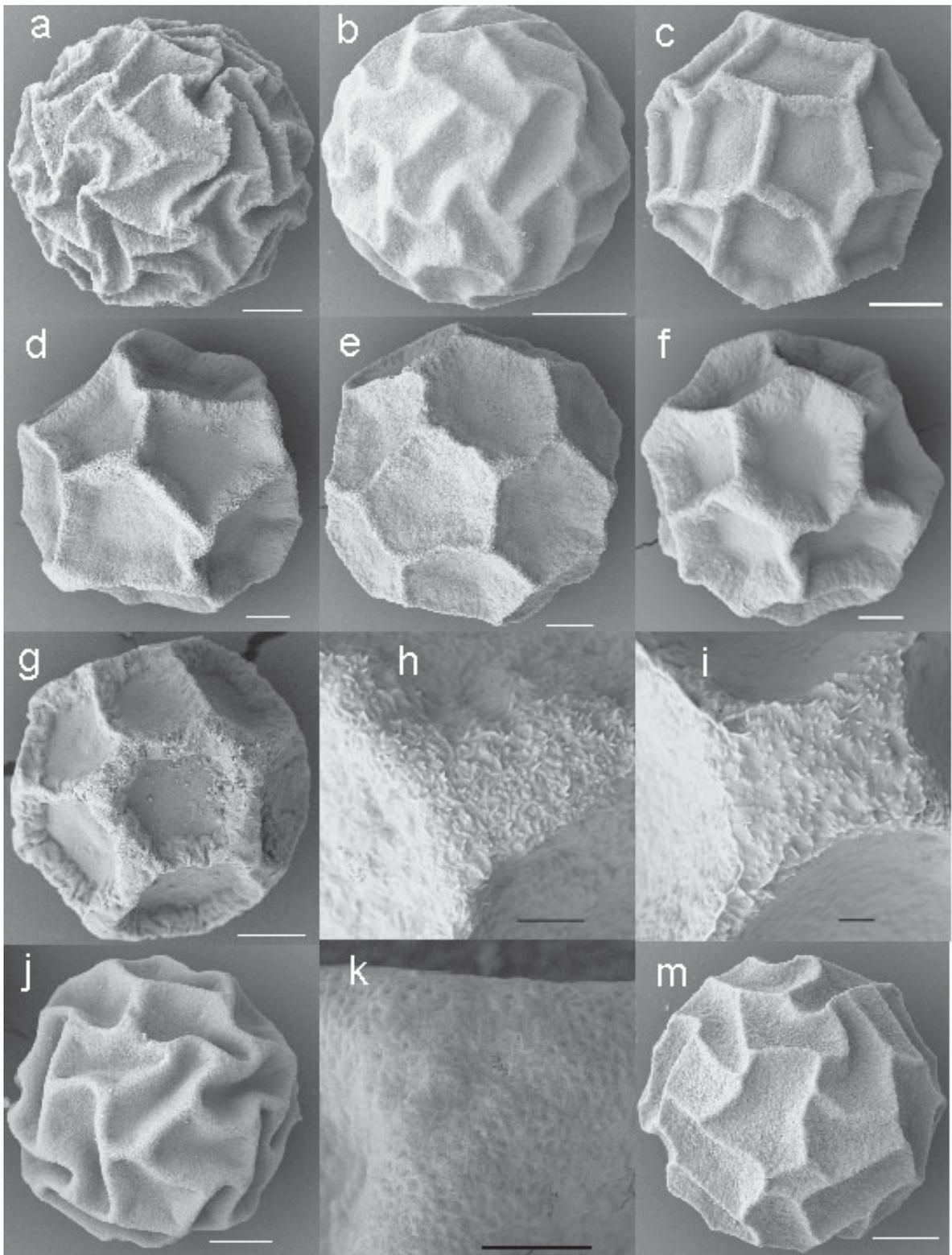
Figure 1. **a**, *B. affinis* Emu Rock; **b**, *B. affinis* Bloodwood; **c**, *B. arborea*, Yantabulla; **d**, *B. australiensis*, The Gums; **e**, *B. australiensis*, L. Goran; **f,** *B. australiensis* Bungarby; **g**, *B. australiensis,* Lake Hutchinson; **h**, *B. australiensis*, L. Goran, details of surface morphology; **i**, *B. australiensis,* Bungarby, details of surface morphology; **j**, *B. basispina,* Balladonia; **k**, *B. basispina,* Balladonia, details of surface morphology,; **m**, *B. buchananensis*, Bloodwood.   Scales: white bar 50 ųm, black bar 10 ųm.

B. arborea Geddes 1981 (Fig. 1c). Average size 214.9 μm, mean depression number 20.7. Most depressions polygonal, some near pentagonal, regularly sized, with distinct triangular ridges with rounded ridgetops and irregularly punctuate. Depressions shallow (wh:dw ratio <0.2) with floors subplanar, with small dimples.

B. australiensis (Richters 1876) (Figs 1d-i). Average size 310.8 μm, mean depression number 21.2. Most populations with eggs larger than 318 μm, and depressions fewer than 20 (Table 2). Depressions largely pentagonal, certainly polygonal (Fig. 1d,e,f,g). Ridges triangular (Fig. 1e) sometimes ropey (Fig. 1g), often with small spines (Fig. 1h,i). Depressions usually dimpled (Fig. 1d,e,f), sometimes smooth (Fig. 1g). Depressions range from shallow (wh:dw ratio <0.2) to moderately deep (wh:dw ratio >0.5) and associated floors vary in degree of concavity. Eastern (L. Hutchinson, The Gums, L. Goran, Bungarby) and western (near Esperance, Laverton) Australian populations with somewhat similar eggs, but the single population from Lake Poodina South Australia different (not illustrated, but see Table 2).

B. basispina Geddes 1981 (Fig. 1j). Average size 248.3 μm, mean depression number 31.8. Depressions polygonal, irregularly sized, with rounded punctuate ridges merging with floors (Fig. 1k). Depressions deep (wh: dw >0.5) and floors markedly concave.

B. buchananensis Geddes 1981 (Fig. 1m). Average size 244.2 μm, mean depression number 36.2. Depressions polygonal, irregularly sized, with triangular dimpled walls distinct from weakly concave, strongly dimpled floors. Depressions shallow (wh:dw <0.2).

B. budjiti Timms 2001 (Fig. 2a). Average size 225.9 μm, mean depression number 20.8. Depressions polygonal, fairly regularly sized, and shallow (wh:dw <0.2). Walls rounded and meeting the floors at a distinct break of slope. Ridges with transverse raised areas. Floors weakly concave and strongly dimpled.

B. campbelli Timms 2001 (Fig. 2b). Average size 191.6 μm, mean depression number 29.2. Depressions polygonal, somewhat irregularly sized. Ridges wide, with rounded crests and sloping walls into concave floors. Ridge crests often minutely pitted and walls and depression floors concave; ridge sides and floor strongly dimpled. Depressions shallow (wh:dw about 0.2).

B. clandestina Timms 2005 (Fig. 2c). Average size 143.1 μm, mean depression number 32.1. Depressions irregular, with dimpled floors and sides and thick ridges with rounded crests. Depressions deep (wh:dh >0.5) and floors markedly concave.

B. compacta Linder 1941 (Fig. 2d,e). Average size 381.4 μm, mean depression number 20.6. Size and depression number variable between locations, especially between east (L. Avon) and west (Little Unicup L., Coomberdale) Australia (Table 2). Depressions polygonal, often pentagonal. Ridge crest rounded in Avon Lake site (Fig. 2d), but sharp and ridge triangular in cross section in western sites (Fig. 2e). Floor concave and dimpled in both. Depressions shallow in all populations (wh:dw <0.2).

B. complexidigitata Timms 2002 (Fig. 2f,g). Average size 268.0 μm, mean depression number 127.8. Most depressions polygonal, similarly sized and shallow (wh:dw <0.2). Ridges narrow, steep sized and with a light coloured fringe midline extended irregularly into sharp points (Fig. 2g). No dimples on walls or on flat floors of depressions.

B. denticulata Linder 1941 (Fig. 2h). Average size 175.4 μm, mean depression number 39.6. Depressions irregular, often linear with steep-sided ridges and deep (wh:dw >0.5). Floors markedly concave to U-shaped. Ridges and depression floors weakly dimpled.

B. dubia (Schwartz 1917) (Fig.2i). Average size 222.6 μm, mean depression number 30.2. Depressions polygonal, many almost pentagonal. Ridges triangular in cross section, but with rounded crests. Floors of depressions flat; ridge walls and floors with elongated and angular dimples. Depressions shallow (wh:dw<0.2) .

B. frondosa Henry 1924 (Fig. 2j). Average size 202.0 μm, mean depression number 32.7. Depressions roughly polygonal, irregularly sized. Ridges with rounded crests and steep sides, though slightly sloping at base. Ridges and depression floors weakly dimpled. Depressions moderately deep (wh:dw ca 0.3 -0.5) and floor almost flat though slightly concave slopping near ridge bases.

B. halsei Timms 2002 (Fig. 3a-d). Average size 189.9 μm, mean depression number 44.2. Depression numbers variable between sites, the Ilparpa claypan
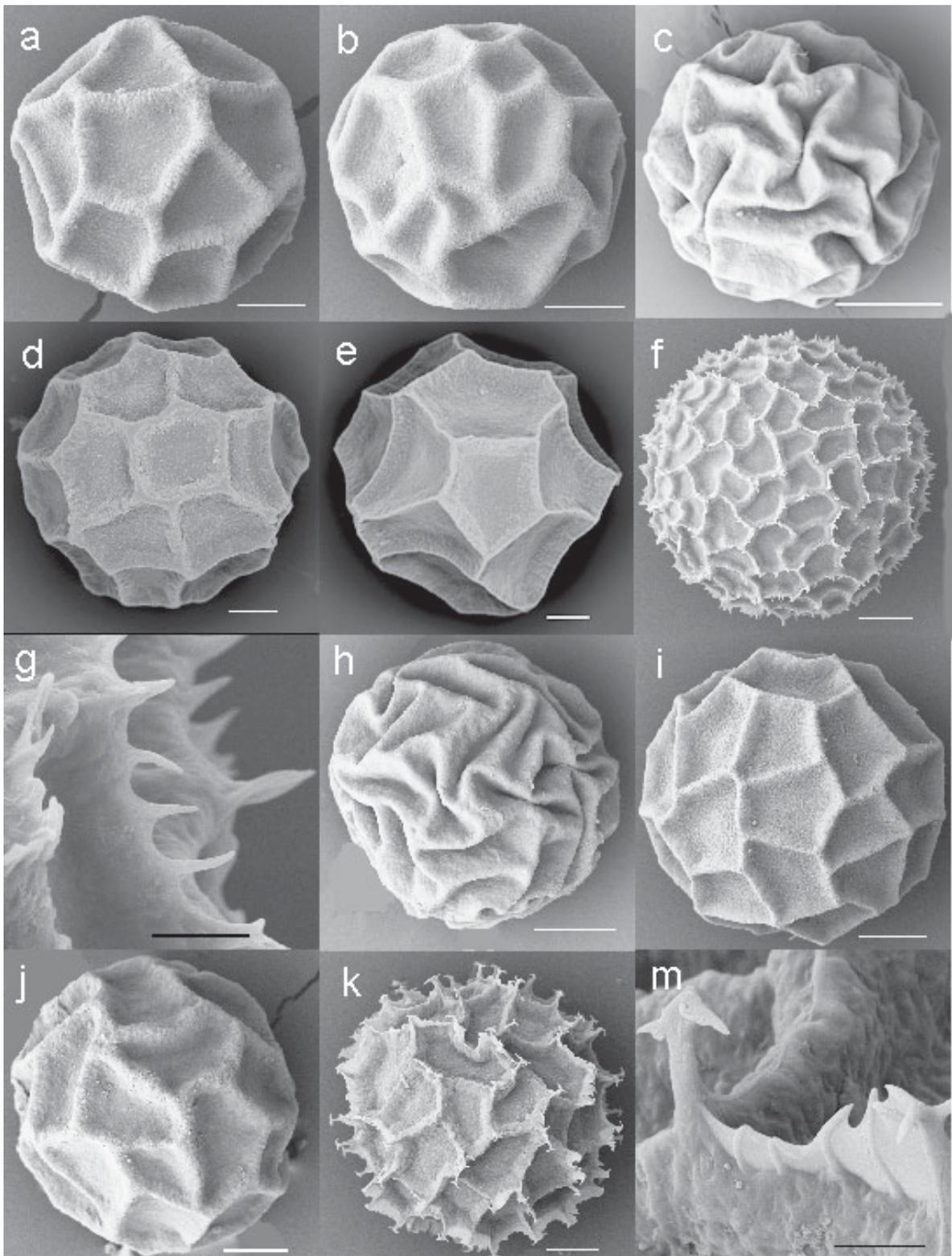
Figure 2. **a**, *B. budjiti*, Rockwell; **b**, *B. campbelli*, Bloodwood; **c**, *B. clandestina*, Yantabulla; **d**, *B. compacta*, Avon Lake; **e**, *B. compacta*, Moora; **f**, *B. complexidigitata*, L. Logue; **g**, *B. complexidigitata*, L. Logue, details of surface morphology; **h**, *B. denticulata*, Carnarvon; **i**, *B. dubia*, Derby; **j**, *B. frondosa*, Clifton Downs; **k**, *B. hattahensis*, Currawinya; **m**, *B. hattahensis*, Currawinya, details of surface morphology. Scales: white bar 50 ųm, black bar 10 ųm.

Proc. Linn. Soc. N.S.W., 133, 2011

59

near Alice Springs, NT, being the most atypical (Table 2); most have fewer than 40 depressions. Depressions irregular, often linear, with steep sided ridges and deep (wh:dw >0.5), but the Ilparpa eggs with shallow depressions (Fig. 3c). Floor and ridge sides dimpled and ridge crests with minute elongated pits (Fig. 3d).

B. hattahensis Geddes 1981 (Fig 2k,m). Average size 257.9 μm, mean depression 44.4. Depressions polygonal with triangular ridges and flat floors. Ridges often with white membranous extensions supported with spines slightly longer than the membrane, and often with three pronged anchor-like spines usually protruding at ridge wall junctions (Fig. 2m). Depressions tend to be moderate in depth (wh:dw 0.2-0.5) but some shallow (wh:dw <0.2). Depression floor and walls dimpled and sometimes adjacent depressions amalgamated.

B. kadjikadji Timms 2002 (Fig. 3e,f). Average size 297.8 μm, mean depression number 102.5. Depressions polygonal, with adjacent ones sometimes amalgamated. Ridges rounded with a marked break of slope to the flat floor. Crests of ridges extended into white membranes supported regularly with thickened spines slightly longer than the membranes (Fig. 3f). Floor and ridge walls slightly dimpled. Depressions shallow (wh:dw <0.2) if only the basic ridge is considered, but if its membrane is included then the ratio is increased to 0.2 – 0.4.

B. lamellata Timms and Geddes 2003 (Fig. 3g). Average size 182.0 μm, mean depression number 47.1. Depressions irregularly polygonal, with triangular ridges merging with depression floors to give moderate concavities. Ridge crests rounded, floors and walls slightly dimpled. Depressions moderately deep with wh:dw ratio 0.3 -0.5.

B. longirostris Wolf 1911 (Fig 4a-f). Average size 276.4 μm, mean depression number 164.1. Size and number of depressions variable between localities (Table 2). Depressions generally polygonal, but sometimes with some lateral amalgamations (Fig 4a), thin walled and with spines at junctions of walls. These spines generally bi-hooked (Fig 4a,c) but sometimes hookless (Fig. 4d), usually long and numerous (Fig 4a,f), but sometimes sparse, short and stumpy (Fig.4d). Sometimes walls between compartments almost absent (Fig. 4b), or triangular in cross section, so that compartments have markedly concave floors (Fig. 4e), rather than typically flat floors (Fig. 4a). Depression floors typically strongly dimpled (Fig 4a,c,d,e), but may be smooth (Fig. 4b).

Depressions generally moderately or markedly deep (wh:dw >0.5, often >0.8).

B. lyrifera Linder 1941 (Fig 3h,i). Average size 213.4 μm, mean depression number 615. Numerous small rounded pinnacles arranged around polygonal hollows, some amalgamated and many joined by low ridges. Each pinnacle with a few clumped white hair like structures thinning and largely absent from floor of depressions (Fig 3i). Height of pinnacles about half width of depressions. Depression floors concave and lumpy in the Bokeen claypan population (Fig 3h), but flat and smooth in the Plover pan population (not illustrated).

B. mcraeae Timms 2005 (Fig. 3j,k). Average size 175.0 μm, mean number of depressions 35.4. Depressions broadly polygonal, many constricted and linear. Ridges triangular, base merging into floor of depressions so that floor markedly concave. Floor and side walls and wall crest strongly dimpled; wall crest also with pores (Fig. 3k). Depressions moderately deep, (wh:dw 0.3-0.5).

B. nichollsi Linder 1941 (Fig. 3m). Average size 295.3 μm, mean number of depressions 34.4. Depressions polygonal, some pentagonal. Walls triangular and floors weakly concave. Walls and floors strongly dimpled. Depressions shallow, (wh:dw <0.2).

B. occidentalis Dakin 1914 (Fig. 4g,h). Average size 492.2 μm, mean number of depressions 53.1. Depressions irregular polygonal with steep walls and ridgetop with a fringe of short spines (Fig. 4h). Compound pores on ridge walls (Fig. 4h). Depressions deep (wh;Dw >0.5) and floors flat and dimpled (Fig. 4g) or markedly concave (Bulla claypan population). Depressions more numerous and deeper in east Australian population (Bulla claypan) than in population from the west (Carnarvon claypan).

B. papillata Timms 2008 (Fig. 4i). Average size 293.9 μm, mean number of depressions 33.0. Depressions polygonal, with narrow wall crests and wide bases merging with the floors so that floors weakly concave. Floors and walls moderately dimpled. Depressions shallow, wh: dw <0.2.

B. pinderi Timms 2008 (Fig. 4j,k). Average size 292.1 μm, mean number of depressions 95.2. Depressions regularly polygonal with some amalgamations. Thick walls with base merging with flat floors. Walls and depression floor covered with long hairs, more concentrated on the walls, otherwise almost smooth (Fig. 4k).
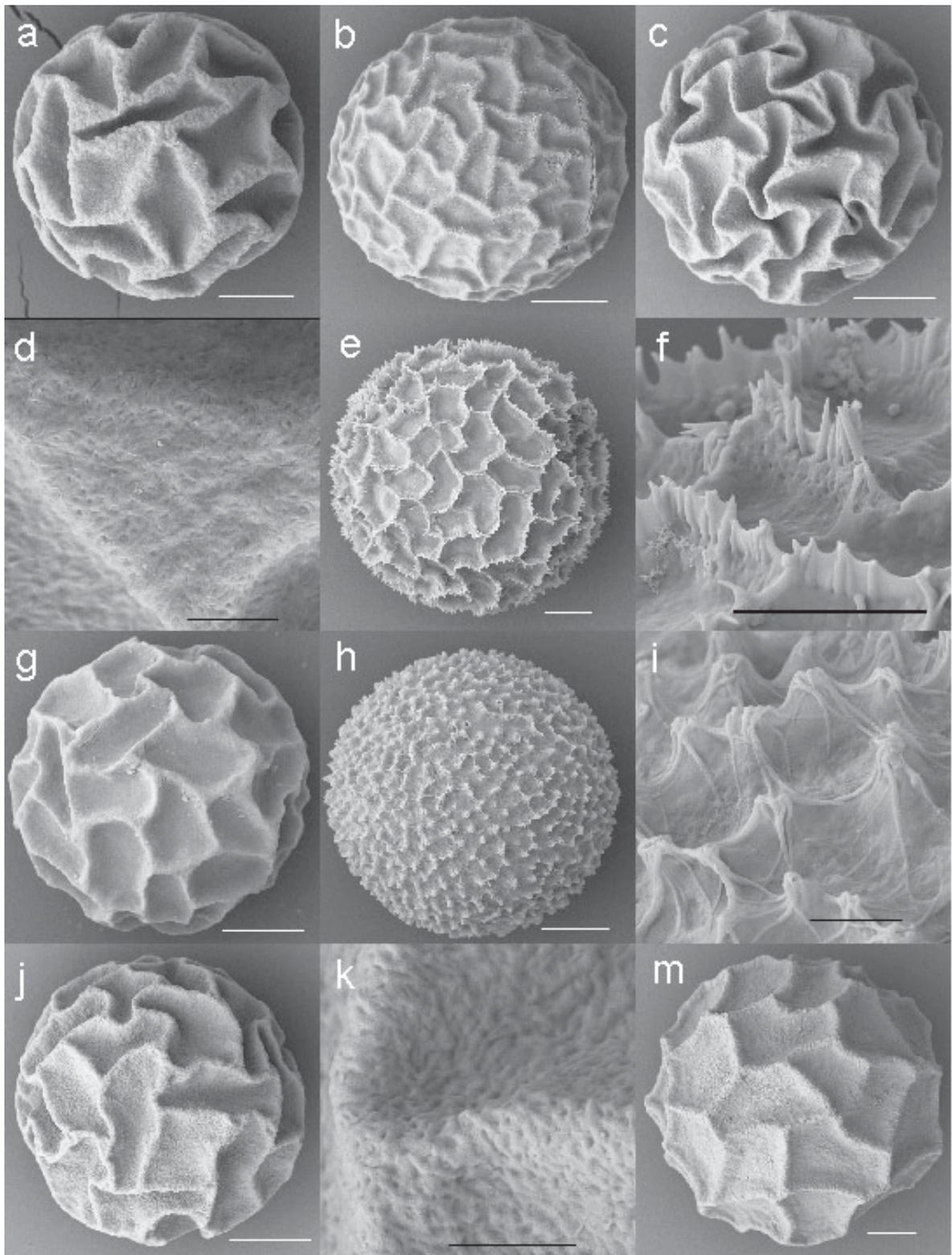
60

Proc. Linn. Soc. N.S.W., 133, 2011

Figure 3. **a**, *B. halsei*, L. Hutchinson; **b**, *B. halsei*, Alice Springs; **c**, *B. halsei*, Pilbara; **d**, *B. halsei,* L. Hutchinson, details of surface morphology; **e**, *B. kadjikadji*, Wyalkatchem; **f**, *B. kadjikadji*, L. Hutchinson, details of surface morphology; **g**, *B. lamellata*, Thargomindah; **h**, *B. lyrifera*, Bokeen claypan, Currawinya; **i**, *B. lyrifera*, Currawinya, details of surface morphology; **j**, *B. mcraeae*, Onslow; **k**, *B. mcraeae*, Onslow, details of surface morphology; **m**, *B. nichollsi*, Kalgoorlie. Scales: white bar 50 ųm, black bar 10 ųm.

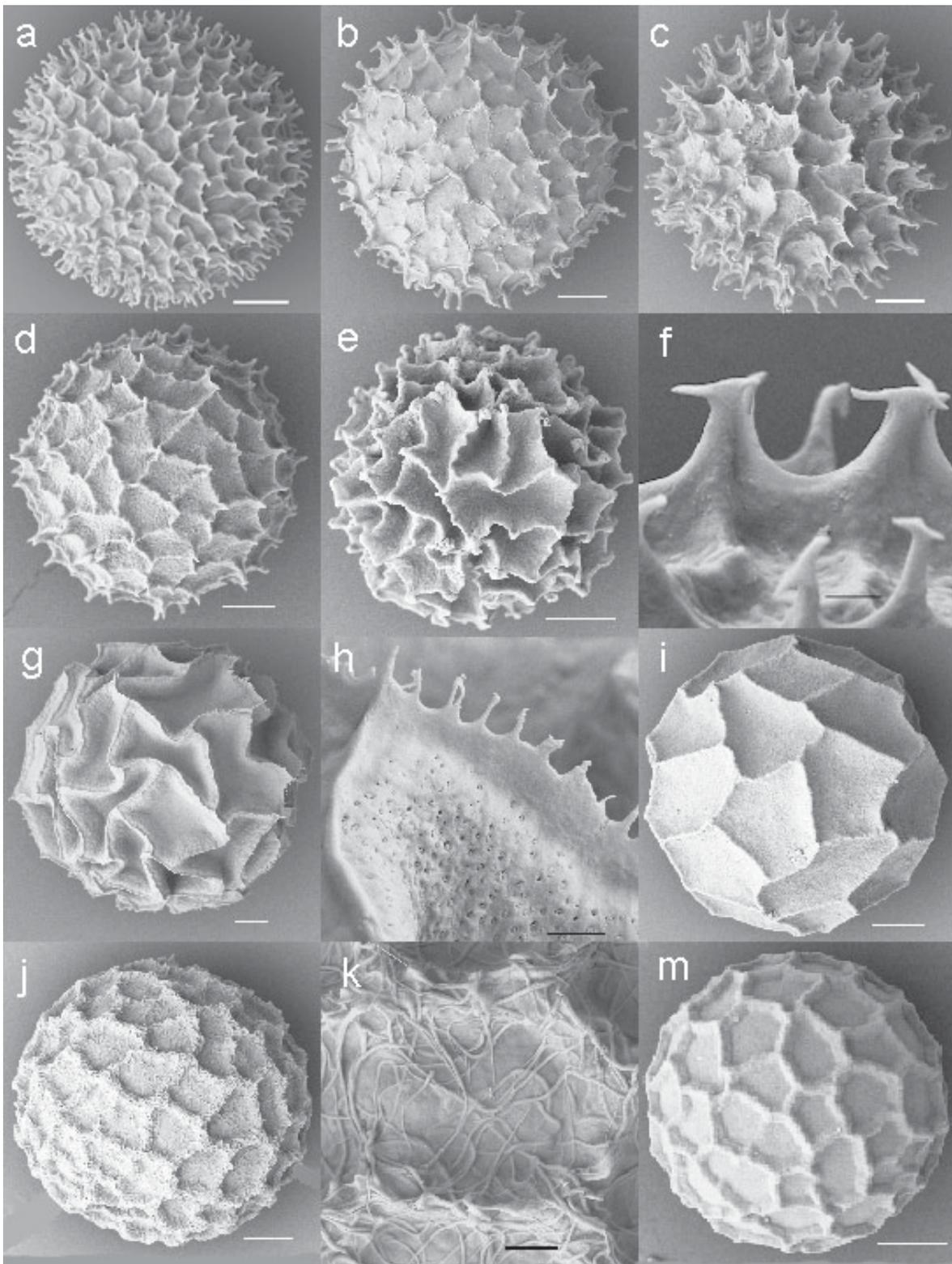Proc. Linn. Soc. N.S.W., 133, 2011

61

Figure 4. **a**, *B. longirostris*, Walga Rock; **b**, *B. longirostris*, Wardagga Rock; **c**, *B. longirostris*, Yorkrakine Rock; **d**, *B. longirostris*, Mt Madden; **e**, *B. longirostris*, Yendang Rock; **f**, *B. longirostris* Walga Rock, details of surface morphology; **g**, *B. occidentalis*, Carnarvon; **h**, *B. occidentalis*, Carnarvon, details of surface morphology; **i**, *B. papillata*, Esperance; **j**, *B. pinderi*, Onslow; **k** *B. pinderi*, Onslow, surface details; **m**. *B. proboscida*, Bloodwood. Scales: white bar 50 ųm, black bar 10 ųm.

B. pinnata Geddes 1981 (Fig. 5a,b). Average size 198.8 µm, mean number of depressions 27.7. Depressions bold, polygonal with some constricted and all bordered by wide walls. Walls merge basally into almost flat floors. Floors and walls dimpled and ridge crests with numerous minute grooves (Fig 5b). Depressions moderately deep (wh:dw 0.3 – 0.5).

B. proboscida Henry 1924 (Fig. 4m). Average size 220.0 µm, mean depression numbers 72.7. Depressions regularly polygonal, some pentagonal and a few amalgamations. Walls triangular on a flat, slightly dimpled floor. Depressions shallow (wh:dw <0.2).

B. simplex Linder 1941 (Fig 5c,d). Average size 301.4 µm, mean depression numbers 41.0. Depressions regularly polygonal with some pentagonal. Walls ropey and flat floors with strong dimples (Fig. 5d). Depressions shallow (wh:dw < 0.2).

B. vosperi Timms 2008 (Fig. 5e,f,g). Average size 433.4 µm, mean depression numbers 111.2. Depressions polygonal, various sizes and many amalgamations. Walls thin, vertical and with thin extensions anastomosing and forming free filaments (Fig. 5f,g). Even thinner membrane between some of the anastomosing branches and extending to based of the free filaments. Depressions thus unusually deep (wh:dw > 0.8), floors flat and lacking dimples.

B. wellardi Milner 1929 (Fig. 5h). Average size 181.1 µm, mean depression numbers 47.2. Depressions polygonal, ridges triangular in cross section, floors concave and weakly dimpled. Some elevated flat areas between depressions. Depressions moderately deep (wh:dw 0.3 – 0.5).

Branchinella new species K (Fig.5i). Average size 160.1 µm, mean depression number 41.0. Depressions polygonal with thick walls forming wide rounded ridges. Floors subplanar, except where invaginated, and smooth. Depressions shallow (wh:dw <0.2).

Branchinella new species M (Fig. 5j). Average size 223.7 µm, mean depression number 41.5. Depressions somewhat polygonal, but generally constricted and often linear. Walls thick with ridge crests lumpy facilitated by weak transverse grooves. Floors concave and strongly dimpled. Depressions moderately deep (wh:dw 0.3 -0.5).

Branchinella new species S (Fig. 5k). Average size 169.5 µm, mean depression number 50.4. Depressions polygonal with thick walls forming wide rounded ridges. Floors flat to slightly concave, moderately dimpled. Depressions shallow to moderately deep (wh:dw 0.2 – 0.4).

Branchinella new species Y (Fig. 5m). Average size 174.7 µm, mean depression number 35.3. Depressions irregularly polygonal, many constricted and linear. Walls wide and ridge crests rounded and with minute pores. Floors vary from subplanar in shallow depressions (wh:dw <0.2) to concave in deep depressions (wh:dw >0.5). Floors and ridge walls moderately dimpled.

DISCUSSION

While egg morphology in large branchiopods is not as immutable as it was once thought (Brendonck et al. 1990; Mura & Rossetti, 2010), there is still value in understanding the range of structures seem in the various species. Sometimes morphologies are distinct and invariable enough to be able to construct a key to species (e.g. for *Eulimnadia* of the world, Rabet, 2010, and pers. comm..), but in many genera there are species with unique morphology and other species which are too variable to choose a morphotype as distinctive. This is the case for *Chirocephalus* (Anostraca:Chirocephalidae) in Italy (Mura, 2001; Mura and Rossetti, 2010), *Branchinecta* (Anostraca: Branchinectidae) in North America (Mura, 1991a) and for *Branchinella* in Australia the situation is imtermediate

In understanding egg morphologies it is important to optimise the chances for studying mature unaltered eggs. Only mature females with full ovisacs of mature eggs should be chosen (Mura, 1991b) and the same author liked to obtain eggs from live females by allowing them to drop their eggs isolated in small containers, and hence avoid contamination. In the present study and many others (Brendonck et al. 1990; Thiery & Gasc, 1991) this was not possible and eggs were carefully removed from the brood pouch of a female isolated from others to prevent contamination. Another factor rarely mentioned by other authors is the effect of dehydration (associated with egg age or environment or preservation?) on egg surface morphology. Many eggs, mainly those without strong polygonal morphology, appeared shrivelled, and if they could have been expanded then similarities in structure would have been more apparent. In the case of *Tanymastix stagnalis* (Linneaus) variability in egg shape was shown to be due to variable embryo volumes (Thiéry et al., 2007). In the present study

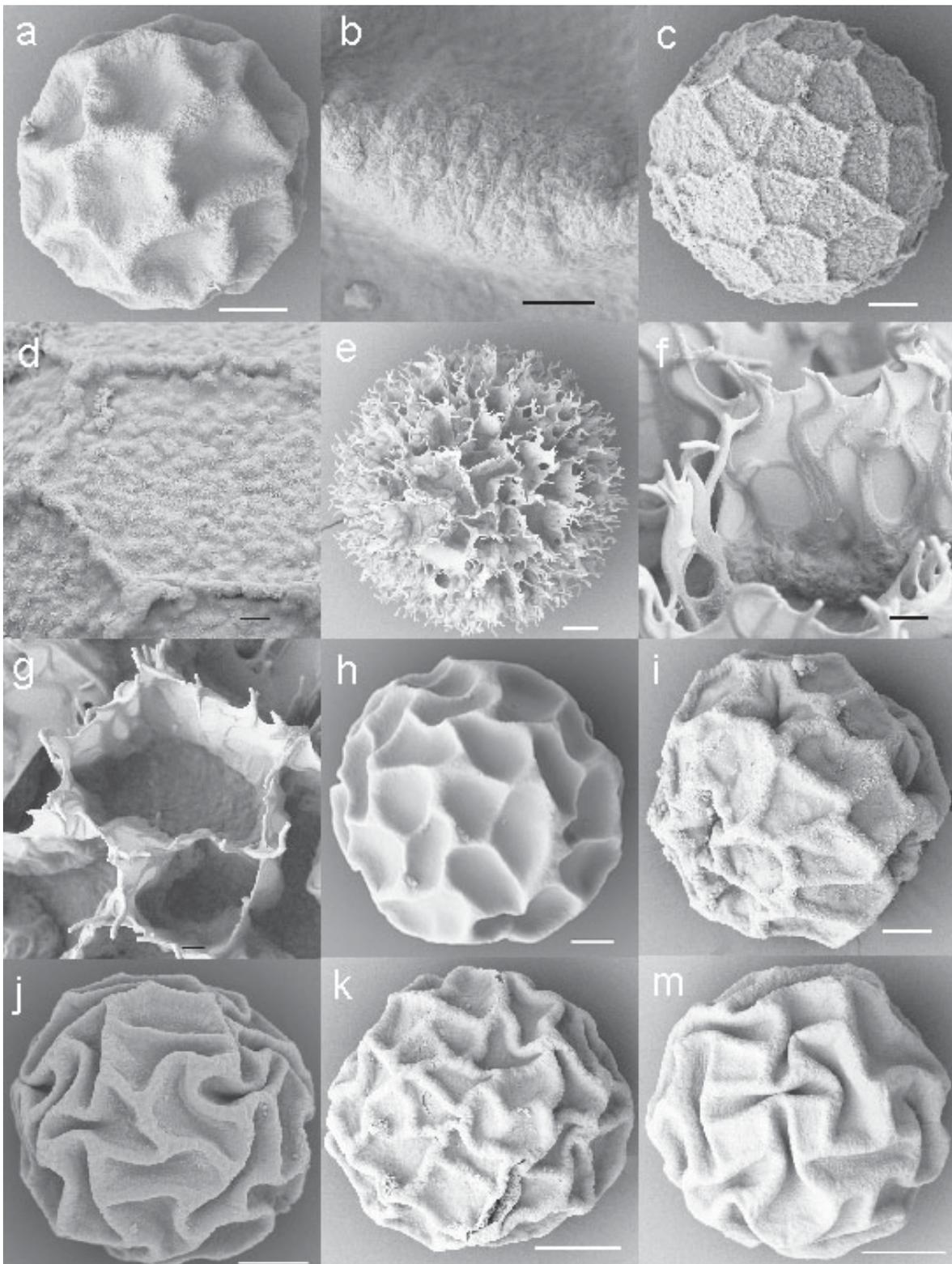Proc. Linn. Soc. N.S.W., 133, 2011

63

Figure 5. **a**, *B. pinnata*, Bloodwood; **b**, *B. pinnata*, Bloodwood, details of surface morphology; **c**, *B. simplex*, Lake Carey; **d**, *B. simplex*, Lake Carey, details of surface morphology; **e**, *B. vosperi*, Esperance; **f,** *B. vosperi*, Esperance, details of surface morphology; **g**, *B. vosperi*, Esperance, details of surface morphology; **h**, *B. wellardi*, Bloodwood; **i,** *Branchinella* n. sp. K, Birdsville Track; **j**, *Branchinella* n. sp. M, Moora; **k**, *Branchinella* n. sp S, Sumana; **m**, *Branchinella* n. sp. Y, Yarromere. Scales: white bar 50 ɥm, black bar 10 ɥm.

the simple explanation of variable dehydration associated with preservation is more likely. This shrivelling would have been another factor affecting egg size so that standard deviations for egg size need to be interpreted with care. Presumedly dehydration also occurs in nature, so that eggs in sediments could change shape and size as they age, but this has not been investigated.

All species in which more than one population was studied exhibited variation in egg morphology (Table 2), though usually within acceptable limits. For the widespread *B. australiensis* at least three morphotypes were observed (Fig. 1,Table 2) I Bloodwood, II The Gums, L Goran, Laverton, Snowleigh and III Poodina). For *B. longirostris* isolated on numerous inselbergs in Western Australia, at least six morphotypes were evident (Fig. 4, I = Andersons, Elachbutting, Walga; II = Madden; III =McDermid; IV = Yorkrakine; V = Wardagga; VI = Yendang). In the case of *B. longirostris* where morphologies of adult males are known (Zofkova and Timms, 2009), there is no relationship between egg type and adult features, as is also the case for *Chirocephalus* (Mura and Rossetti, 2010). For *B. affinis*, shrivelling associated with dehydration would explain most of the differences observed between populations (Fig. 1), though in *B. halsei*, the L Cronin and Ilparpa populations could represent different morphotypes (Fig. 3). In *B. compacta* there are either two morphotypes (Fig.2, I = L Avon; II = Little Unicup, Marchagee) or perhaps the difference between east and west Australia suggest the two groups may be separate species. In this case the two groups exhibit adult morphological differences, to be examined elsewhere. Though only one morphotype was noted in the present study for *B. occidentalis*, two apparently different ones were recorded by Timms et al. (2004). This situation has not been resolved, and indeed all the morphotypes mentioned above are enigmatic, much like the situation in *Chirocephalus ruffoi* (Mura & Rossetti, 2010).

Egg sizes vary markedly within and between species, not only in this study but for many species shared between Timms et al. (2004) and this study (Table 1). Three of the seven species where multiple populations were studied had egg sizes varying more than 65% (Table 2) and five of the 22 species common to Timms et al. (2004) and this study had sizes varying in excess of 45% (Table 1). Of the many factors affecting egg size (Mura, 1991b) altitude of collecting site and water chemistry are hardly important in this study, but female size could be. Although many studies have shown no such relationship (e.g. Mura, 1991b, Belk, 1977) , for the

species studied here (ranging from 8 to 33 mm) there is a positive relationship between female length and the size of eggs (y = 9.485x +100.0; r²= 0.54, P >0.05%, where y is egg size and x is female length when preserved. It is conceivable that as females grow the eggs they produce in each batch could increase in size and so result in a range of sizes for a species. Species with particularly large eggs (> 300 ųm) include, in order from the largest, *B. occidentalis, B. vosperi, B. compacta, B. australiensis and B. simplex*. At the other extreme, small eggs (< 200 ųm) are typical in *B. clandestina*, *Branchinella* new species K, S and Y, *B. denticulata* and *B. mcraeae.*

The number of depressions on the egg surface is also variable within species. Across all species the mean number of depressions is 69 and median 39. Species with numerous depressions include (from most numerous), *B. lyrifera, B. complexidigitata, B. kadjikadji, B. vosperi* and *B. pinderi* (all > 95) Likewise species with unusually low numbers of depressions include *B. compacta, B. arborea, B. budjiti* and *B. australiensis* (all between 20.6 and 21.2). The number of depressions is unrelated to egg size and can vary between populations (Table 1 and 2). This is seen in *B. affinis, B. australiensis, B. compacta, B. halsei, B. longirostris* and *B. occidentalis* where standard deviations increased markedly when multiple populations were studied (Table 1).

Other morphometric features separating species include the presence of pores, particularly on wall crests, spines and/or transverse ridges on wall crests, the degree of dimple development, on the floors of the depressions, and most importantly the nature of superficial adnornments in the form of membranes and spines on the ridges. The adaptive value of these features is unknown, though for *B. longirostris* the hooked spines may be a deterrent for egg predators such as planarians known to be common in their habitat (Dumont, et al., 2002; Jocqué et al., 2007).

By a combination of all these features the following species have distinctive eggs (with reasons in parenthesis): *B. occidentalis* (egg size, complex pores, secondary frill on ridge crests), *B. longirostris* (numerous hooked spines, numerous depressions), *B. vosperi* (secondary membranes between support struts, numerous depressions, large egg), *B. lyrifera* (extremely numerous depressions, depression walls in form of mounds covered with hairs) *B. pinderi* (depression walls and adjacent floor covered with hairs), *B. kadjikadji* and *B. complexidigitata* (numerous depressions, crests with membranes between spines), *B. hattahensis* (few hooked spines and crest with incomplete membranes and few spines, strong dimpling of depression floors), *B.*

simplex (strong dimpling of depression floors, ropey depression walls, shallow depressions), *B. australiensis, B. compacta*, and *B. arborea* (all with few deprssions, many tending towards pentagonal, shallow depressions) and *B. budjiti* (few depressions, many tending towards pentagonal, transverse ridges on walls, depression floors strongly dimpled). Species with minute pores in compartment walls and crests include *B. basispina, B. halsei* (not all populations), *B. mcraeae, B. occidentalis* (complex pores) and *B. pinnata*. Only *B. australiensis* (most populations) have numerous small spines (spikes) on elevated areas.

Because many species have similar eggs, or eggs which vary so that some populations have eggs similar to those of other species, it is difficult to establish a dichotomous key to delineate eggs. Eggs in sediments may also be dehydrated, although probably similarly to those preserved in alcohol. The key provided below does not identify all species, only those with distinctive characters. In the couplets only characters visible at up to 100x magnification are used and care has been exercised in its preparation to allow for greater variation (20%) than that generally observed in this study. By using greater magnification and referring to the descriptions above and Figs. 1-5 and Table 1 and 2, it may be possible to separate species among the groups in some couplets. Generic differentiation is certainly possible (Timms et al., 2004) and with this key many species of *Branchinella* can now be identified.

It remains to consider if there are any phylogenetic relationships between the egg types and the three systematic groups thought significant by Geddes (1981). While there are four pairs with considerable similarity — *B. australiensis* and *B. compacta* in Geddes' Group 1, *B. affinis* and *B. denticulata* in his Group II and *B. basispina* and *B. frondosa*, also *B. dubia* and *B. arborea* in Group III — there are far more dissimilarities than these few similarities (for example *B. occidentalis* is unique in Group I, *B. longirostris* is unique in Group II, and *B. wellardi* is unique in Group III. If species described since 1981 are added to the groups (Timms, 2002, 2005, 2009), then possible interrelationships become even more blurred. Overall though, resting eggs of *Branchinella* (subgenus *Branchinella*), which is endemic to Australia (Rogers, 2006) are characterised by having polygonal depressions and few spines. The only species in the subgenus *Branchinellites* studied (*B. kugenumaensis* and *B. madurai,* Brendonck and Belk, 1997) also have polygonal depressions, but the former has smooth ridges and the later dense spinulae, like those in *B. australiensis*.

KEY TO EGGS OF SOME SPECIES OF
BRANCHNELLA
[Use carefully. In couplets relying solely on in differences in size and number of depressions, it is possible not enough leeway has been given to possible variation in known values. So check the result against the descriptions and figures. The most reliable delinations are among those species with adornments (couplets 3 to 9).]

1a. Eggs with grooved surface depressionss (i.e. long deep furrows on surface), either dominating or sometimes secondary to elongated polygonal compartments…..…...2
1b. Eggs with most surface depressions polygonal with subequal axes, but perhaps with a few as elongated polygons; no grooved depressions……...................3

2 The following species are hard to separate, largely because their depression characteristics depend largely on the state of hydration. If the eggs are larger than 235 ųm they are likely to be *B. basispina* and if smaller than 180 ųm they could be *B. clandestina, B. denticulata* or *Branchinella* n. sp. Y. Other species with grooved surface depressions include *B. affinis*, most populations of *B. halsei* and *Branchinella* n .sp. M.

3a (1b). Depression wall crests with adornments adding to their height; adornments aligned along crests………………………………………..…..........4
3b (1b). Depression wall crests smooth or lumpy or even slightly ridged, but without protruding spines, hooks or membranes (*B. australiensis* may have very short spines on the crests, but they are unaligned)...9

4a (3a). Crest adornments string-like applied to surface………..………….............................….............5
4b (3a). Crest adornments in the form of protruding spines or membranes………..……........................6

5a (4a). Depressions indistinct, but moundlike horns at junctions; strings concentrated on these mounds; eggs with > 250 depressions…....................*B. lyrifera*
5b (4a). Depressions distinctly polygonal; strings on walls and floor of depressions; eggs with < 120 depressions………………...……...............*B. pinderi*

6a (4b). Eggs without spines but with adornment membranes stretched between digitiform struts on crests; eggs > 400 µm.…………………... *B. vosperi*
6b (4b). Eggs with membranes stretched between spines; eggs < 375 µm.…………...............…........7

66

Proc. Linn. Soc. N.S.W., 133, 2011

7a (6b). Spines simple……………………………..
…........................ *B.complexidigitata, B. kadjikadji*
7b (6b). Spines with 1-3 recurved apices, so they look like ship's anchors…..........……....................……8

8a (7b). Eggs with <60 depressions; depression walls inverted U-shaped; membrane between anchor-like spines with supporting struts; eggs from inland eastern Australia ………........................……....*B. hattahensis*
8b (7b). Eggs with >75, often >125 depressions; depression walls thin sheets or rarely lacking; often with a short membrane between spines and never with supporting struts; eggs from pan gnammas of WA……………………………........…..*B. longirostris*

9a (3b). Eggs with short spines on crests of depressions; eggs with flat elevated areas between depressions; usually <34 depressions………...... *B. australiensis*
9b (3b). Eggs without short spines on depression crests; eggs usually without flat elevated areas between depressions (of present, then >35 depressions)……………..……10

10a (9b). Eggs large > 450 μm diameter; depression wall crest ridged and frilled, this being of similar material to that of crest and not a white adornment……
……….. *B. occidentalis*
10b (9b). Eggs smaller < 400 μm diameter, often much smaller; depression wall smooth or wrinked transversely……………....………...........................11

11a (10b) Fewer than 25 depressions........*B. arborea, B, australiensis, B. budjiti, B. compacta*
11b (10b) More than 26 depressions....…………....12

12a (11b) More than 60 depressions....*B. proboscida*
12b (11b) Fewer than 50 depressions ...…………13

13a (12b) Egg size > 275 ųm……………......….......14
13b (12b) Egg size < 270 ųm……………….......….16

14a (13a) Depressions very shallow, depth/width ratio <0.10; compartment floors with large tumidities; compartment walls very uneven (lumpy)..*B. simplex*
14b (13a) Not as above…………………………….......15

15a (14b) Fewer than 30 depressions, relatively deep (depth/width ratio >0.4).....................*B. australiensis*
15b (14b) More than 31depressions , moderately deep (depth/width ratio 0.2-0.4)...*B. nichollsi, B. papillata*

16a (13b) Walls of depressions wide and rounded (i.e. inverted U-shaped), so crest is rounded…………17

16b (13b) Walls of depressions triangular in cross section so crests sharpish…………........................18

17a (16a) Depressions relatively shallow, depth/width ratio > 0.25; number of depressions >75 …….….…… …………………….................…*B. halsei*, Alice Springs
17b (16a) Depressions deep, depth/width ratio > 0.3; number of depressions < 60 …………...*B. campbelli, B. frondosa, Branchinella* n. sp. K, n. sp. S

18a (16b) Egg size > 210 ųm..........*B. buchanensis, B. dubia*
18b (16b) Egg size < 200 ųm……………............19

19a (18b) Floor of depressions smooth.....*B. wellardi*
19b (20b) Floor of depressions with tumidities……
…………........................…*B. lamellata, B. mcraeae*

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Appendix 1. Localities for the species studied

Species	Locality	Coordinates	Date	Collector*
B. affinis	Turkey Pan, Bloodwood Station, 130 km NW of Bourke, NSW	29° 33' 23"S; 144° 50' 15"E	31-iii-1999	BVT
B. affinis	a rock pool near Emu Rock, 51 km E of Hyden, WA	32° 26' 54S; 119° 24' 34'E	21-ix-2004	BVT
B. affinis	unnamed lake on Guest Rd, Grass Patch, WA	33° 07' 56"S; 121° 48' 10"E	19-i-2007	BVT
B. arborea	roadside pool, N Yantabulla, 125 km NW of Bourke, NSW	29° 19' 5"S; 144° 00' 32"E	18-ii-2010	BVT
B. australiensis	L. Hutchinson, 39 km E of Thargomindah, Qld	27° 55' 32"S; 144° 12' 47"E	9-vi-1998	BVT
B. australiensis	a gilgai 22 km W of The Gums, Qld	27° 23' 20"S; 149° 58' 7"E	9-vi-2008	BVT
B. australiensis	Lake Goran, 20 km S of Curlewis, NSW	31° 17' 15"S; 150° 11' 28"E	8-iv-1996	BVT
B. australiensis	East Snowleigh Lake, Bungarby, 51 km S of Cooma, NSW	36° 40' 51"S; 148° 59' 59"E	13-iii-2010	BVT
B. australiensis	Lake Poodina, Gawler Ranges, SA	31° 55' 30"S; 135° 13' 10"E	30-i-2007	PH & GT
B. australiensis	pool on Mt Nev Track, 56 km NW of Esperance, WA	33° 28' 26S; 122° 21' 25"E	30-i-2007	BVT
B. australiensis	pool 20 km W of Laverton, WA	28° 35' 39"S; 122° 13' 3"E	22-i-2007	BVT
B. basispina	Balladonia Rock, 200 km E of Norseman, WA	32° 27' 40"S; 123° 51' 30"E	18-i-2007	BVT
B. buchananensis	Gidgee Lake, Bloodwood Station, 130 km NW of Bourke, NSW	29° 32' 50"S; 144° 50' 6"E	20-ii-2010	BVT
B. budjiti	clay pan on Rockwell Station, 180 km SW of Cunnamulla, Qld	28° 54' 4"S; 144° 57' 12"E	9-vi-2007	BVT
B. compacta	Avon Lake, 45 km S of Cooma, NSW	36° 37' 04"S; 149° 02' 58"E	14-iii-2010	BVT
B. compacta	Little Unicup Lake, 13 km NNE of L. Muir, WA	34° 19' 54"S; 116° 42' 43'E	18-viii-2009	BVT
B. compacta	Coomberdale West Rd, 20 km N of Moora, WA	30° 28' 03"S; 115° 59' 21"E	6-ix-2009	BVT
B. campbelli	Muella Lake, Bloodwood Station, 130 km NW of Bourke, NSW	29° 30' 26"S; 144° 53' 9"E	1-v-1998	BVT
B. clandestina	swamp at Yantabulla, 125 km NW of Bourke, NSW	29° 19' 36"S; 145° 00' 14"E	20-i-2010	BVT
B. complexidigitata	pool near Lake Logue, 13 km SW of Eneabba, WA	29° 59' 0"S; 115° 07' 43"E	17-ix-2009	BVT
B. denticulata	unnamed canegrass pan, Carnarvon area, WA	24° 47'S; 114° 09'E	unknown	SH
B. dubia	pool, 89 km E of Derby on Gibb R Rd, WA	17° 26'S; 124° 26'E	31-i-1985	MT
B. frondosa	pool on Clifton Downs Station, 135 km NW of Bourke, NSW	29° 19' 53"S; 144° 29' 26"E	8-vi-2007	BVT
B. halsei	L. Hutchinson, 39 km E of Thargomindah, Qld	27° 55' 32"S; 144° 12' 47"E	17-i-2007	BVT
B. halsei	Crescent Pool, Bloodwood Station, 130 km NW of Bourke, NSW	29° 32' 34"S; 144° 51' 33"E	18-x-2006	BVT
B. halsei	Ilparpa claypan, Alice Springs, NT	23° 45' 14"S; 133° 45' 52"E	13-i-2010	JR
B. halsei	Lake Cronin, 82 km E of Hyden, WA	32° 23' 5"S; 119° 45' 53'E	16-x-2008	BVT
B. halsei	Yarraloola claypan, Mundabullengana Station, Pilbara, WA	21° 25' 12"S; 145° 41' 0"E	18-viii-2005	JM & AP
B. hattahensis	Mid Kaponyee Lake, Currawinya Nat. Pk., via Hungerford, Qld	28° 50' 9"S; 144° 20' 1"E	7-xii-1999	BVT

Proc. Linn. Soc. N.S.W., 133, 2011

69

Appendix 1 continued

Species	Location	Coordinates	Date	Collector
B. kadjikadji	claypan near Cowcowing Lakes, Wyalkatchem, WA	30° 57' 52"S; 117° 27' 37"E	28-viii-2004	BVT
B. lamellata	claypan, Bindegolly Nat. Pk., 41 km E of Thargomindah, Qld	28° 00' 0"S; 144° 14' 12"E	1-x-2001	BVT
B. longirostris	Walga Rock, 48 km E of Cue, WA	27° 24' 10"S; 117° 27' 52"E	26-viii-2001	BVT
B. longirostris	Wardagga Rocks, 24 km SW of Paynes Find, WA	29° 23' 21"S; 117° 30' 1."E	25-viii-2001	BVT
B. longirostris	Yorkrakine Rock, 25 km N of Tammin, WA	31° 25' 15"S; 117° 30' 53"E	2-viii-2003	BVT
B. longirostris	Elachbutting Rock, 53 km NE of Mukinbudin, WA	30° 35' 30"S; 118° 36' 43"E	2-viii-2003	BVT
B. longirostris	Anderson Rock, 32 km N of Hyden, WA	32° 10' 5"S; 118° 51' 23"E	28-viii-2001	BVT
B. longirostris	Mt Madden, 42 km N of Ravensthorpe, WA	33° 14' 23"S; 119° 50' 32"E	5-ix-2010	BVT
B. longirostris	McDermid Rock, 180 km E of Hyden, WA	32° 01' 16"S; 120° 44' 13"E	19-i-2009	BVT
B. longirostris	Yendang Rk 155 km W of Menzies, WA	29° 18' 29"S; 120° 18' 16"E	1-ix-2004	BVT
B. lyrifera	Bokeen claypan, Currawinya Nat. Pk. Via Hungerford, Qld	28° 49' 50"S; 144° 20' 57"E	26-vi-2000	BVT
B. lyrifera	Plover claypan, Bloodwood Station, 130 km NW of Bourke, NSW	29° 31' 1S; 144° 49' 39"E	7-viii-1998	BVT
B. mcraeae	a claypan near Onslow, WA	21° 47' 36"S; 115° 06' 1"E	15-ii-2009	BVT
B. nichollsi	swamp on Yarri Rd, 19 km NE of Kalgoorlie, WA	30° 37' 3"S; 121° 36' 0"E	24-i-2007	BVT
B. occidentalis	N Bulla claypan, Rockwell Station, 180 km SW of Cunnamulla, Qld	28° 53' 2"S; 144° 56' 1"E	9-vi-2007	BVT
B. occidentalis	a claypan inland of Carnarvon, WA	unknown	23-viii-1994	SH
B. papillata	pool near Kau Rock, 59 km NE of Esperance, WA	33° 24' 32"S; 122° 19' 47"E	29-i-2007	BVT
B. pinderi	a claypan near Onslow, WA	21° 48' 13"S; 115° 06' 1"E	15-ii-2009	BVT
B. pinnata	pool near Lake Dunn, 68 km NE of Aramac, Qld	22° 39' 00"S; 145° 43' 01"E	12-ii-2010	BVT
B. pinnata	Crescent Pool, Bloodwood Station, 130 km NW of Bourke, NSW	29° 32' 34"S; 144° 51' 33"E	19-i-2010	BVT
B. proboscida	Dead Ram Pan, Bloodwood Station, 130 km NW of Bourke. NSW	29° 31' 46"S; 144° 52' 2"E	2-vi-2001	BVT
B. simplex	Standpipe Ck, Lake Carey, 30 km S of Laverton, WA	28° 56' 49"S; 122° 23' 32"E	24-iv-2004	BD
B. vosperi	pool on Mt Nev Track, 56 km NW of Esperance, WA	33° 28' 29"S; 122° 21' 24"E	30-i-2007	BVT
B. wellardi	Marsilea Pond, Bloodwood Station, 130 km NW of Bourke, NSW	29° 32' 13"S; 144° 52' 26"E	7-vi-2007	BVT
Branchinella n. sp. K	dam on Kulamurina Station 205 km N of Marree, SA	unknown	15 -vi-2000	unknown
Branchinella n. sp. M	pool on Coorow-Green Head Rd, 20 km SW of Coorow, WA	29° 57' 58"S; 115° 55' 1"E	5-ix-2009	BVT
Branchinella n. sp. S	claypan on Sumana Station, 100 km N of Aramac, Qld	22° 18' 38"S; 145° 52' 57"E	2-iv-2009	BVT
Branchinella n. sp. Y	pool on nw beach of Lake Buchanan, Yarromere Station, Qld	21° 32' 14"S; 145° 48' 51"E	26-ii-2008	BVT

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  JR = Jochem van der Reijden; BVT = Brian Timms; MT = Mike Tyler.

Issue XXIX December 2011
CONTENTS