

***Paradeontacylix godfreyi* n. sp. (Digenea: Sanguinicolidae) from the heart of wild *Seriola lalandi* (Perciformes: Carangidae) in southern Australia**

KATE S. HUTSON¹ & IAN D. WHITTINGTON^{1,2}

¹Marine Parasitology Laboratory, School of Earth and Environmental Sciences, The University of Adelaide, North Terrace, Adelaide, South Australia 5005, Australia. E-mail: kate.hutson@adelaide.edu.au

²Monogenean Research Laboratory, Parasitology Section, The South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia

Abstract

Paradeontacylix godfreyi n. sp. (Digenea: Sanguinicolidae) is described from the heart of wild yellowtail kingfish, *Seriola lalandi* Valenciennes, 1833, collected near Port Augusta, northern Spencer Gulf, South Australia. One specimen of *P. godfreyi* was also collected from the heart of a single wild specimen of *S. lalandi* captured near Killarney, Victoria. *Paradeontacylix godfreyi* is distinguished from other species in the genus by a combination of morphological characters including the shape and number of posterior tegumental spines, the number of rows of tegumental spines along the ventral body margin, the maximum number of marginal tegumental spines per row, the number of testes and the extent of the testicular field. Comparisons are made with a *Paradeontacylix* sp. collected from the heart of wild Samson fish, *S. hippos* Günther, 1876 from Greenly Island, South Australia and from the heart of wild *S. lalandi* from Killarney, Victoria. We also document a new host record for *P. sanguinicolides* McIntosh, 1934 from the heart of wild *S. hippos* from Greenly Island, South Australia. The importance of determining potential intermediate hosts for *Paradeontacylix* species in relation to South Australian *S. lalandi* aquaculture is discussed.

Key words: Digenea, Sanguinicolidae, *Paradeontacylix godfreyi* n. sp., blood fluke, *Seriola lalandi*, *Seriola hippos*, Carangidae, aquaculture, South Australia, Victoria

Introduction

Sanguinicolids are digenean parasites that inhabit the circulatory system of a broad diversity of fish species worldwide. For *Seriola* species (Carangidae), *Paradeontacylix*

***Paradeontacylix godfreyi* n. sp. (Digenea: Sanguinicolidae) from the heart of wild *Seriola lalandi* (Perciformes: Carangidae) in southern Australia**

KATE S. HUTSON¹ & IAN D. WHITTINGTON^{1,2}

¹Marine Parasitology Laboratory, School of Earth and Environmental Sciences, The University of Adelaide, North Terrace, Adelaide, South Australia 5005, Australia. E-mail: kate.hutson@adelaide.edu.au

²Monogenean Research Laboratory, Parasitology Section, The South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia

Abstract

Paradeontacylix godfreyi n. sp. (Digenea: Sanguinicolidae) is described from the heart of wild yellowtail kingfish, *Seriola lalandi* Valenciennes, 1833, collected near Port Augusta, northern Spencer Gulf, South Australia. One specimen of *P. godfreyi* was also collected from the heart of a single wild specimen of *S. lalandi* captured near Killarney, Victoria. *Paradeontacylix godfreyi* is distinguished from other species in the genus by a combination of morphological characters including the shape and number of posterior tegumental spines, the number of rows of tegumental spines along the ventral body margin, the maximum number of marginal tegumental spines per row, the number of testes and the extent of the testicular field. Comparisons are made with a *Paradeontacylix* sp. collected from the heart of wild Samson fish, *S. hippos* Günther, 1876 from Greenly Island, South Australia and from the heart of wild *S. lalandi* from Killarney, Victoria. We also document a new host record for *P. sanguinicolides* McIntosh, 1934 from the heart of wild *S. hippos* from Greenly Island, South Australia. The importance of determining potential intermediate hosts for *Paradeontacylix* species in relation to South Australian *S. lalandi* aquaculture is discussed.

Key words: Digenea, Sanguinicolidae, *Paradeontacylix godfreyi* n. sp., blood fluke, *Seriola lalandi*, *Seriola hippos*, Carangidae, aquaculture, South Australia, Victoria

Introduction

Sanguinicolids are digenean parasites that inhabit the circulatory system of a broad diversity of fish species worldwide. For *Seriola* species (Carangidae), *Paradeontacylix*

species are serious pathogens of farmed amberjacks, *S. dumerili* (Risso, 1810), and have been associated with mass mortalities in the Spanish Mediterranean (Crespo *et al.* 1992) and Japan (Ogawa & Fukudome 1994). A *Paradeontacylix*-like blood fluke has also been associated with low-level mortalities of farmed yellowtail kingfish, *S. lalandi* Valenciennes, 1833, in New Zealand (Diggles & Hutson 2005). Five *Paradeontacylix* species have been described: *P. sanguinicoloides* McIntosh, 1934 (the type species) from wild *S. lalandi*; *P. odhneri* (Layman, 1930) from purple puffer, *Takifugu porphyreus* (Temminck & Schlegel, 1850) (= *Spheroides borealis*); *P. sinensis* Liu, 1997 from puffer fish, *T. oblongus* (Bloch, 1786) (= *Fugu oblongus*); *P. grandispinus* Ogawa & Egusa, 1986 and *P. kampachi* Ogawa & Egusa, 1986 from farmed *Seriola dumerili* (= *S. purpurascens*).

We provide a description of a new species of *Paradeontacylix* from the heart of wild *S. lalandi* near Port Augusta, northern Spencer Gulf, South Australia and Killarney, Victoria. Comparisons are made with an unknown *Paradeontacylix* species from the heart of wild Samson fish, *S. hippos* Günther, 1876 in South Australia and from wild *S. lalandi* from Victoria and with other species in the genus.

Material and methods

Eight parasite specimens were collected from the heart of several *S. lalandi* captured near Port Augusta in northern Spencer Gulf, South Australia between September 2004 and October 2005. An additional 2 parasite specimens were collected from a single specimen of *S. lalandi* near Killarney, Victoria in January 2005. Two parasite specimens were also collected from the heart of a single specimen of *S. hippos* captured near Greenly Island, offshore from Port Lincoln, South Australia in April 2005.

The heart was removed from fish recently killed by an overdose of clove oil (> 200 mg/L), opened and examined for parasites using a dissecting microscope. Following visual inspection, the heart was flushed with saline and the settled contents examined under a dissecting microscope. Parasite specimens were aspirated with a pipette and killed in almost boiling saline before fixation in 10% formalin. Fixed parasites were placed in distilled water before being stained in Mayer's haematoxylin, then destained in 1% HCl in 70% ethanol. The parasites were dehydrated in an ethanol series, cleared in cedar wood oil and mounted on slides in Canada balsam.

Mounted parasites were studied using a compound microscope and drawings were made with the aid of a drawing tube. Parasite prevalence and mean intensity follows Bush *et al.* (1997). The fork length range of parasitised hosts is presented in millimetres (mm), followed in parentheses by the fork length range of all fish examined and the total number of hosts studied. Measurements of parasite specimens were made using a computerised digitising system similar to that described by Roff & Hopcroft (1986). All measurements are given in micrometres (μm) as the mean followed in parentheses by the range and number of structures measured.

Type-material of known *Paradeontacylix* species was examined for comparative purposes. *Paradeontacylix grandispinus* and *P. kampachi* were obtained from the Meguro Parasitological Museum (MPM), Tokyo, Japan (MPM 19415 and 19416, respectively). Three additional *P. kampachi* specimens were kindly loaned from the Cavanilles Institute of Biodiversity and Evolutionary Biology parasitological collection, collected and provided by Dr Francisco Montero (Marine Zoology Unit, Cavanilles Institute of Biodiversity and Evolutionary Biology, The University of Valencia, Valencia, Spain). The United States National Parasite Collection (USNPC) made high quality digital images of the single type-specimen of *P. sanguinicoloides* available (USNPC 34329). A single specimen of *P. sanguinicoloides* collected previously by the senior author from wild *S. lalandi* in New South Wales (see Diggle & Hutson 2005) was also used for comparative purposes and is lodged in the South Australian Museum (SAMA; accession details: SAMA AHC 28909). Type-material of the new species is deposited in SAMA, North Terrace, Adelaide, South Australia 5000, Australia and the USNPC, Beltsville, MD 20705, USA.

Results

Sanguinicolidae von Graff, 1907

Paradeontacylix McIntosh, 1934

Paradeontacylix godfreyi n. sp. (Figs 1, 2A)

Type-host: *Seriola lalandi* Valenciennes, 1833 (Carangidae).

Type-locality: Port Augusta, northern Spencer Gulf, South Australia (32° 42'04''S, 137°46'17''E).

Other locality: Killarney, Victoria (38°23'36''S, 142°20'24''E).

Site: Heart.

Infection details: Port Augusta: number of infected fish = 4; prevalence 12.5%; mean intensity 2 (1–5); host sizes 1410–1500 FL (350–1500 FL, n = 32). Victoria: number of infected fish = 1; prevalence 4%; intensity 1; host sizes 760 FL (460–790 FL, n = 25). The single infected specimen of *S. lalandi* from Victoria was also parasitised by a specimen of *Paradeontacylix* sp. (see below). Nodules, resulting from parasite eggs, were observed in the inner muscle layers of the heart in the ventricle and atrium.

Etymology: The species is named after Mr Reggie Godfrey, who has studied the behavioural patterns of yellowtail kingfish at Port Augusta for over 50 years. His knowledge and skill greatly assisted host and parasite collections at Port Augusta.

Material deposited: Holotype SAMA AHC 28903, 5 paratypes SAMA AHC 28904–28908; 2 paratypes USNPC No. 097276.

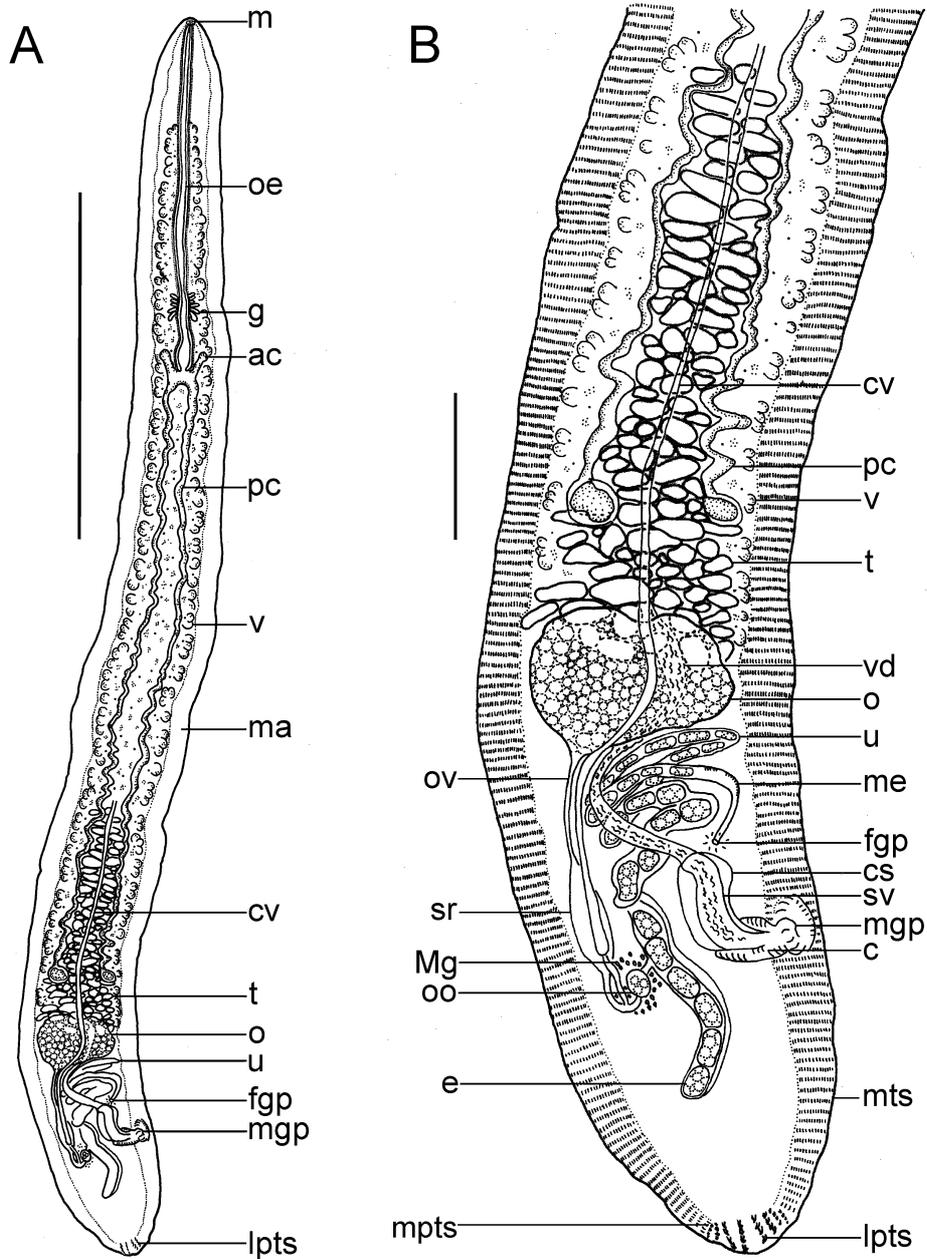


FIGURE 1. *Paradeontacylix godfreyi* n. sp. A. Whole adult parasite, holotype, ventral view. B. Posterior portion, holotype, ventral view, showing testicular field and post-ovarian region. Abbreviations: ac, anterior caecum; c, cirrus; cs, cirrus sac; cv, common vitelline duct; e, egg; fgp, female genital pore; g, gland cells; lpts, large posterior tegumental spines; m, mouth; ma, margin; me, metraterm; Mg, Mehlis' gland; mgp, male genital pore; mpts, medium posterior tegumental spines; mts, marginal tegumental spines; o, ovary; oe, oesophagus; oo, oötype; ov, oviduct; pc, posterior caecum; sr, seminal receptacle; sv, seminal vesicle; t, testis; u, uterus; v, vitellarium; vd, vas deferens. Scale bars: A = 1,000 μ m; B = 250 μ m.

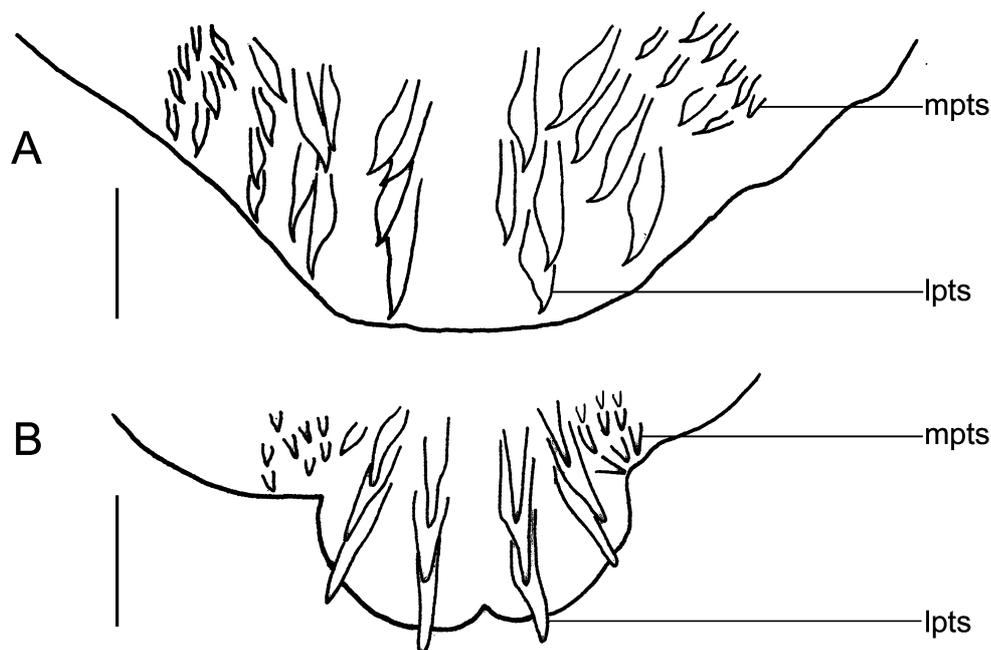


FIGURE 2. Large posterior tegumental spines (lpts) and medium posterior tegumental spines (mpts), ventral view of Australian *Paradeontacylix* species. A. *Paradeontacylix godfreyi* n. sp. holotype, showing claw-like large posterior tegumental spines arranged in 4 longitudinal rows each comprising 4 spines and medium posterior tegumental spines arranged in 2 to 3 longitudinal rows each comprising 4 spines on either side of large posterior tegumental spines. B. *Paradeontacylix* sp. (SAMA AHC 28912) showing pointed, slightly curved large posterior tegumental spines arranged in 4 longitudinal rows each comprising 3 spines and medium posterior tegumental spines arranged in 3 longitudinal rows each comprising 3 spines on either side of large posterior tegumental spines. Scale bars = 30 μ m.

Description

Paradeontacylix sensu Smith (2002). Description and measurements based on 8 mature adult specimens. Body slender, dorsoventrally flattened, 4,080 (3,739–4,215, n = 6) long by 428 (357–566, n = 8) wide; approximately 10 times longer than wide, width consistent throughout most of specimen only narrowing at anterior and posterior extremities (Fig. 1A). Lateral body margins slender, skirt-like (Fig. 1A), bearing numerous transverse rows of marginal tegumental spines spanning entire length of parasite except for anterior extremity. Marginal tegumental spines ventrolateral, arranged in numerous transverse rows, 816 (690–890, n = 6) (Table 1) on both sides of body, rows regularly spaced (Fig. 1B); number of spines per row increasing from 4 posteriorly to 22 at mid-body region. Posteriorly, 16 large tegumental spines, 33 (22–40, n = 16) long by 4 (2–6, n = 16) wide at base; conspicuous, claw-like distally, arranged in 4 longitudinal rows each comprising 4 spines (Fig. 2A). Additionally, 2–4 rows of medium-sized spines 19 (11–23, n = 8) long by 3 (2–5, n = 8) wide at base, arranged on either side of large spines (Fig. 2A).

Mouth subterminal. Oesophagus narrow anteriorly, widening posteriorly, 1,171 (928–1,572, n = 6) long, ~30% of total body length, surrounded by gland cells along entire length, larger gland cells forming compact mass in posterior portion (Fig. 1A). Short anterior and elongate posterior intestinal caeca forming H-shape; anterior caeca 74 (68–85, n = 4) long extending anterolaterally from midline; posterior caeca often highly sinuous, 2,237 (2,050–2,703, n = 7) long, ~56% of body length, approximately 34 times longer than anterior caeca, terminating blindly among testicular field, anterior to ovary (Figs 1A, B).

Testes 99 (n = 1), mostly transversely elongate, some rounded, stacked irregularly mostly between posterior extremities of caeca. Testicular field 852 (642–1,112, n = 4) long representing 21 (18–25)% of total body length; posteriorly, overlapping anterior third of ovary (Fig. 1A). Vas deferens descending at mid-line from posterior region of testicular field, passing dorsal to ovary, following curved path to form seminal vesicle filling entire cirrus sac. Cirrus cylindrical, 60 (47–75, n = 4) long. Male genital pore dorsal, near left body margin, 461 (343–569, n = 7) from posterior end of body (Fig. 1B).

Ovary heart-shaped, overlapped anteriorly by testes, 196 (149–279, n = 8) long and ~4% of body length, 330 (222–443, n = 8) wide or 76% of body width, located 696 (438–959, n = 7) or ~17% of body length from posterior end of body (Fig. 1B). Oviduct originating from right side of ovary, passing posteriorly, dilating to form seminal receptacle, 199 (139–261, n = 6) long, 38 (17–53, n = 7) wide. Posteriorly, seminal receptacle narrows, receives common vitelline duct, turns left to join oötype 55 (41–64, n = 7) long by 49 (36–56, n = 7) wide, ovoid, near level of cirrus sac, surrounded by Mehlis' glands (Fig. 1B). Uterus descending 137 (92–202, n = 7) posterior to oötype, then ascending through several coils filling space immediately posterior to ovary, finally descending to form slender metraterm. Female genital pore opening dorsally, anterior to male pore, at level of junction of vas deferens with seminal vesicle (Fig. 1B). Distance between male and female pores 152 (84–206, n = 4). Eggs ovoid 38 (36–41, n = 4) long, 30 (29–34, n = 4) wide, measured *in utero*. Vitellarium follicular, follicles extending from level one-third along length of oesophagus posteriorly to anterior margin of ovary (Fig. 1A). Common vitelline duct first observed medianly, just anterior to testicular field, passing posteriorly ventral to testes and ovary, terminating at level of oötype. Excretory vesicle and pore not observed.

Remarks

Smith (2002) provided a key to the genera of the Sanguinicolidae and revised the generic diagnosis for *Paradeontacylix*. According to the revision, *Paradeontacylix* species possess 19 to 71 testes. However, the new species described here has up to 99 testes. The number of testes in most specimens we collected was difficult to determine with accuracy, except in the holotype. While the greater number of testes is noteworthy, we have not revised the generic diagnosis here based on this single character. Testes number can be

highly variable in some species, and degeneration of the testes has been observed in adult specimens of *Aporocotyle simplex* and *Cruoricola lates* (see Thulin 1980, Herbert *et al.* 1994). A revision may be necessary when more material of *P. godfreyi* becomes available. Table 1 presents a comparison of the important morphological characters of *Paradeontacylix* species reported from *Seriola* species.

***Paradeontacylix sanguinicoloides* McIntosh, 1934**

Host species: *Seriola hippos* Günther, 1876 (Carangidae).

Locality: Greenly Island, offshore from Port Lincoln, South Australia (34°38'29''S, 134°47'28''E).

Site: Heart.

Infection details: number of infected fish = 1; prevalence 25%; intensity 1; host sizes 1160 FL (1120–1160 FL, n = 4). This Samson fish was also parasitised by a *Paradeontacylix* sp. (see below).

Material deposited: 1 voucher specimen SAMA AHC 28910.

Previous records: *S. lalandi*: blood vessels of the gills, Atlantic Ocean, off Miami, Florida, USA (holotype: USNPC 34329, McIntosh 1934); heart, Sir John Young Banks, New South Wales, Australia (34°56'52''S, 150°55'45''E) (voucher: SAMA AHC 28909, Diggles & Hutson 2005).

Remarks

The single specimen of *P. sanguinicoloides* from *S. hippos* in South Australia and a single specimen recovered previously from *S. lalandi* in New South Wales (see Diggles & Hutson 2005) were identified following McIntosh (1934) and from digital images of the holotype provided by the USNPC. The specimen of *P. sanguinicoloides* from *S. hippos* in South Australia shared characters with the holotype including 4 posterior longitudinal rows of large tegumental spines each comprising 3 rose-thorn-shaped spines, a maximum number of 14 marginal tegumental spines per row and a large testicular field relative to total body length. An accurate count of testes could not be determined for this specimen. Shared characters between the holotype and the specimen of *P. sanguinicoloides* from *S. lalandi* in New South Wales included a maximum number of 14 marginal tegumental spines per row, a large testicular field relative to total body length and 60 testes. In contrast to the type specimen and the specimen of *P. sanguinicoloides* from *S. hippos*, the specimen of *P. sanguinicoloides* from *S. lalandi* had an extra posterior spine in each row i.e. 4 posterior longitudinal rows of large tegumental spines each comprising 4 rose-thorn-shaped spines. Table 1 presents a comparison of important morphological characters between the original report of *P. sanguinicoloides* by McIntosh (1934) and the specimens reported here.

TABLE 1. Distinguishing morphological characters of *Paradeontacylix* species from Victoria (Vic), South Australia (SA) and New South Wales (NSW), Australia, and previously described *Paradeontacylix* species from *Seriola* species. Details include host species, locality, the shape of the large posterior tegumental spines, the number of large posterior tegumental spines (longitudinal rows x number of spines per row), the number of rows of transverse marginal tegumental spines the maximum number of marginal tegumental spines per row, the number of testes and the extent of the testicular field expressed as a % relative to total body length. *Denotes counts made in the current study. NA, not applicable; ND, not determined.

Parasite species	<i>P. godfreyi</i> n. sp. Present study	<i>P. sanguinicolooides</i> Present study	<i>P. sanguinicolooides</i> McIntosh (1934)	<i>Paradeontacylix</i> sp. Present study	<i>P. kampachi</i> Montero <i>et al.</i> (2003)	<i>P. kampachi</i> Ogawa & Egusa (1986)	<i>P. grandispinus</i> Ogawa & Egusa (1986)
Host species	<i>Seriola lalandi</i>	<i>Seriola hippos</i> <i>Seriola lalandi</i>	<i>Seriola lalandi</i>	<i>Seriola lalandi</i> <i>Seriola hippos</i>	<i>Seriola dumerili</i>	<i>Seriola dumerili</i>	<i>Seriola dumerili</i>
Locality	Vic/SA, Australia	SA/NSW, Australia	United States	Vic/SA, Australia	Spain	Japan	Japan
Shape of large posterior tegumental spines	Claw-like	Rose-thorn	Rose-thorn	Pointed, slight curve	No large spines	No large spines	Claw-like
No. of large posterior tegumental spines	4 x 4	4 x 3-4	4 x 3	4 x 3	NA	NA	3-4 x 2-4
No. of rows of transverse marginal tegumental spines	816 (690-890)	580-654	~500	579 (563-603)	513 (510-515)*	510-590	410-470
Max no. of marginal tegumental spines per row	22	14	14	14-15	8-11*	7-10	10-13
No. of testes	99	60 (NSW only)	60	ND	~70*	50-71	19-32
Extent of testicular field	21% (18-25%)	37% (35-39%)	41%	~34%	19%*	19-34%	27-38%

***Paradeontacylix* sp. (Fig. 2B)**

Material studied: single specimen from the heart of *S. lalandi* (Carangidae) from Killarney, Victoria (38°23'36''S, 142°20'24''E) and a single specimen from the heart of *S. hippos* (Carangidae) from Greenly Island, offshore from Port Lincoln, South Australia (34°38'29''S, 134°47'28''E).

Infection details: number of infected *S. lalandi* (at Killarney) = 1; prevalence 4%; intensity 1; host sizes 760 FL (460–790 FL, n = 25). This kingfish was also parasitised by a specimen of *P. godfreyi* n. sp. (see above). Number of infected *S. hippos* (at Greenly Island) = 1; prevalence 25%; intensity 1; host sizes 1160 FL (1120–1160 FL, n = 4). This Samson fish was also parasitised by a specimen of *P. sanguinicoloides* (see above).

Material deposited: 1 voucher specimen from *S. lalandi* from Killarney, Victoria (SAMA AHC 28911) and 1 voucher specimen from *S. hippos* from Greenly Island, South Australia (SAMA AHC 28912).

Remarks

Parasite specimens collected from the heart of *S. lalandi* at Killarney, Victoria and *S. hippos* at Greenly Island, South Australia were identified as an undetermined *Paradeontacylix* species. Further identification or formal description was precluded because of the limited number (n = 2) and quality of the specimens recovered. The single specimen from *S. hippos* is in good condition and the testicular field can be distinguished, but it is difficult to count the testes. Although the large posterior and transverse marginal tegumental spines are well preserved in the single specimen from *S. lalandi*, the internal features are difficult to distinguish. Both specimens possess large, pointed, slightly curved posterior tegumental spines 24 (11–39, n = 24) long arranged in 4 longitudinal rows each comprising 3 spines (Fig. 2B, Table 1) and have a maximum number of 14–15 marginal tegumental spines in each transverse row (Table 1). Because of these similarities, we consider that these 2 specimens from different *Seriola* species belong to the same species, which may represent an undescribed *Paradeontacylix* species.

***Paradeontacylix kampachi* of Montero *et al.* (2003)**

Material studied: 3 specimens of *P. kampachi* from *S. dumerili* (Carangidae) collected off Puerto de Mazarrón, Spain, generously provided by Dr Francisco Montero from the parasitological collection of the Cavanilles Institute of Biodiversity and Evolutionary Biology. Specimens supplied on glass microscope slides (mounted dorsally) were measured and structures counted by us.

Infection details: see Montero *et al.* (1999, 2003).

Remarks

We agree with Montero *et al.* (2003) that these parasite specimens are representatives of *P. kampachi*. One specimen is in good condition allowing discrimination of the testicular field and an approximate count of the testes (Table 1). The internal features of the remaining 2 specimens are difficult to distinguish. Two specimens possess pointed, tegumental spines 9 (6–10, n = 8) long in the region where the large posterior tegumental spines are found in other *Paradeontacylix* species, but they were not easily distinguishable from the marginal tegumental spines. The other specimen possessed smaller pointed, triangular tegumental spines only 3 (3–6, n = 8) long in the posterior region.

Discussion

Paradeontacylix godfreyi n. sp. differs from the 5 previously described nominal species in the genus and from the *Paradeontacylix* sp. reported here, by a combination of characters. The new species has distinctively shaped posterior tegumental spines, more posterior tegumental spines in longitudinal rows than most other described species, many more rows of transverse marginal tegumental spines and a greater maximum number of marginal tegumental spines per row, more testes and a shorter testicular field than any previously described species (Table 1).

Paradeontacylix godfreyi appears most similar to *P. grandispinus* in general morphology as both species possess up to 16 claw-like posterior spines (Table 1), have rounded or elongated testes and a similar distribution of vitelline follicles (Ogawa & Egusa 1986). However, the new species differs from *P. grandispinus* in having more rows of transverse marginal tegumental spines with more spines per row, a slightly less extensive testicular field relative to total body length and many more testes (Table 1). Although *P. godfreyi* and *P. sanguinicoloides* share the same host species, the new species can be distinguished by its claw-like posterior tegumental spines, numerous transverse rows of marginal tegumental spines, more marginal tegumental spines per row and more testes occupying a shorter testicular field relative to total body length (McIntosh 1934, Table 1). *Paradeontacylix godfreyi* can also be separated from *Paradeontacylix* sp. reported here by its claw-like posterior spines, numerous rows of transverse marginal tegumental spines, greater number of marginal tegumental spines per row and a shorter testicular field relative to total body length (Table 1).

The new species is similar to specimens of *P. kampachi* from Japan and Spain (see Ogawa & Egusa 1986 and Montero *et al.* 2003, respectively), as both possess a short testicular field relative to total body length. However, *P. godfreyi* can be discriminated from this species by the presence of large posterior tegumental spines, numerous marginal tegumental spines in rows and a greater number of testes (Table 1). The new species also differs from *P. odhneri* and *P. sinensis* reported from puffer fish (Tetraodontidae) off Japan and China, respectively (Layman 1930, Liu 1997). Unlike *P. godfreyi*, *P. sinensis* lacks

posterior tegumental spines and has fewer testes (29–32 arranged in pairs of bilateral lobes) that occupy a greater proportion of the total body length (~69%) (Liu 1997). *Paradeontacylix odhneri* differs from *P. godfreyi* as the vitellarium extends posterior to the ovary and the testicular field terminates anterior to the ovary (Layman 1930). The original description of *P. odhneri* does not include detailed information on the marginal tegumental transverse spines, posterior tegumental spines or the number of testes (Layman 1930), so these features could not be compared with *P. godfreyi*.

The *Paradeontacylix* sp. found in *Seriola hippos* in South Australia and *S. lalandi* in Victoria is most similar to *P. grandispinus* (Table 1). Both species possess large posterior tegumental spines, have a similar maximum number of marginal tegumental spines per row and possess a testicular field that occupies most of the intercaecal field. However, *Paradeontacylix* sp. has more rows of transverse marginal tegumental spines along the margin (Table 1) and the posterior tegumental spines are blunter with shallower curves compared to those in *P. grandispinus*. The specimens of *P. kampachi* from *S. dumerili* reported by Montero *et al.* (2003) off Spain could not be distinguished from specimens of *P. kampachi* from the same host species in Japan (Ogawa & Egusa 1986). Material from both localities possesses small marginal tegumental spines, a similar number of rows of marginal tegumental spines and maximum number of marginal tegumental spines per row, a short testicular field relative to total body length and have a similar number of testes (Table 1).

It is evident from collections in the present study that adult *Paradeontacylix* species may not exhibit a high degree of host-specificity. For example, we found *P. sanguinicoloides* in *S. hippos*, but this parasite species has been documented previously only from *S. lalandi* off the Atlantic coast of the USA (McIntosh 1934) and off New South Wales, Australia (Diggles & Hutson 2005). Furthermore, the *Paradeontacylix* sp. reported here infected *S. hippos* in South Australia and *S. lalandi* in Victoria. Although *P. godfreyi* was not recovered from *S. hippos*, this may be due to the limited number of host and parasite specimens obtained. We also observed that individual fish can host multiple species of *Paradeontacylix*, with one *S. hippos* specimen host to *Paradeontacylix* sp. and *P. sanguinicoloides* and one specimen of *S. lalandi* was parasitised by *Paradeontacylix* sp. and *P. godfreyi*.

With low host-specificity and the possibility of multiple species infections, *Paradeontacylix* species may be of potential concern for Australian *S. lalandi* aquaculture. However, to date, *Paradeontacylix* species have not been detected in farmed *S. lalandi* in Australia. Unlike Japan where farmed *S. dumerili* are stocked from the wild and may already harbour adult specimens of *Paradeontacylix* species, juvenile *S. lalandi* in Australia are spawned from wild caught brood stock and reared in land-based hatcheries. Consequently, juvenile fish are unlikely to be exposed to infective cercariae of sanguinicolid until they are stocked into sea cages where wild intermediate molluscan or annelid hosts may reside nearby. Indeed, *Paradeontacylix*-like blood flukes have been

detected in histological sections of the heart, brain and internal organs from farmed *S. lalandi* in New Zealand, despite juveniles being reared in a hatchery (Diggles & Hutson 2005). One explanation for the apparent absence of *Paradeontacylix* species in Australian *S. lalandi* aquaculture may be the lack of availability, abundance and proximity of appropriate wild invertebrate intermediate hosts near sea cages. However, the intermediate host species for *Paradeontacylix* species are currently unknown.

It is essential to identify potential intermediate host species for *Paradeontacylix* species so that sea cages containing *Seriola* species can be positioned to keep definitive fish hosts and invertebrate hosts spatially segregated. Bullard & Overstreet (2002) suggest that control of blood fluke infections may only be achieved by separating intermediate and final hosts, as elimination of susceptible intermediate hosts is impractical and cost-prohibitive. It appears that an appropriate intermediate host is absent for *P. godfreyi* in kingfish farming areas in Spencer Gulf, South Australia because adult parasites have not been detected in farmed fish. However, this is not the case for the blood fluke *Cardicola forsteri* Cribb, Daintith & Munday, 2000, infecting southern bluefin tuna, *Thunnus maccoyii* (Castelnau, 1872) in Spencer Gulf. Within 2 months of the capture of wild tuna and their transfer into sea cages, *C. forsteri* intensity increased from a single specimen found in 10 wild tuna sampled to 100% prevalence and an average intensity of 27 specimens per caged tuna (n = 30) (Aiken *et al.* in press). They suggest that the intermediate host, which is currently unknown, must be in close proximity to the caged tuna for so many to become infected in such a short period.

Surveys of potential intermediate hosts for *P. godfreyi* around *S. lalandi* cages in Spencer Gulf, South Australia may prove futile as no blood flukes have yet been reported from farmed kingfish. However, identifying the species of blood fluke infecting farmed *S. lalandi* in New Zealand and further examination of potential intermediate hosts near kingfish sea cages in New Zealand may allow us to draw comparisons or assess potential intermediate host species for *Paradeontacylix* in Australia. Identification of the intermediate host(s) would help to determine suitable sea cage sites for *S. lalandi* away from potential infection sources as the industry expands.

The description of *P. godfreyi* and documentation of *Paradeontacylix* sp. increases the number of sanguinicolid species infecting wild *S. lalandi* in Australian waters to 3, together with *P. sanguinicoloides* from *S. lalandi* in New South Wales (Diggles & Hutson 2005). Before this investigation, no sanguinicolids were reported from *S. hippos* but we have documented a new host record for *P. sanguinicoloides* from *S. hippos* and provide information on an unidentified *Paradeontacylix* sp. from *S. hippos* in South Australia and *S. lalandi* in Victoria.

Acknowledgements

We are indebted to Bradley Smith and Reggie Godfrey, who demonstrated unmatched

commitment and drive to provide us with kingfish and sanguinicolids. We are extremely grateful to Scott Gray for coordinating host collections in Victoria. Thank you to Darren Godfrey, Jack Laidlaw, Michael McMahon and Shane Mensforth for providing host specimens from South Australia. Thanks are due to Dr Matthew Nolan (The University of Queensland) for discussion and assistance in the laboratory, Dr Pat Pilitt (USNPC) for providing us with detailed digital images of the holotype of *P. sanguinicoloides*, Dr Jun Araki (MPM) and Dr Francisco Montero (University of Valencia) for the loan of specimens for study and Hao Min for interpretation of Chinese literature. This research was made possible through an Australian Postgraduate Award scholarship awarded to KSH and was partially funded by Primary Industries and Resources, South Australia and the Fisheries Research and Development Corporation grant no. 2003/220 awarded to Dr Colin Johnston, Dr Ingo Ernst, IDW, Dr Bronwyn Gillanders, KSH and Dr Clinton Chambers.

References

- Aiken, H.M., Hayward, C.J. & Nowak, B.F. (in press) An epizootic and its decline of a blood fluke, *Cardicola forsteri*, in farmed southern bluefin tuna, *Thunnus maccoyii*. *Aquaculture*.
- Bullard, S.A. & Overstreet, R.M. (2002) Potential pathological effects of blood flukes (Digenea: Sanguinicolidae) on pen-reared marine fishes. *Proceedings of the Gulf and Caribbean Fisheries Institute*, 53, 10–25.
- Bush, A.O., Lafferty, K.D., Lotz, J.M. & Shostak, A.W. (1997) Parasitology meets ecology on its own terms: Margolis *et al.* revisited. *Journal of Parasitology*, 83, 575–583.
- Crespo, S., Grau, A. & Padrós, F. (1992) Sanguinicoliiasis in the cultured amberjack *Seriola dumerili* Risso, from the Spanish Mediterranean area. *Bulletin of the European Association of Fish Pathologists*, 12, 157–159.
- Diggles, B. & Hutson, K.S. (2005) Diseases of kingfish (*Seriola lalandi*) in Australasia. *Aquaculture Health International*, 3, 12–14.
- Herbert, B.W., Shaharom-Harrison, F.M. & Overstreet, R.M. (1994) Description of a new blood fluke, *Cruoricola lates* n. g., n. sp. (Digenea: Sanguinicolidae), from sea-bass *Lates calcarifer* (Bloch, 1790) (Centropomidae). *Systematic Parasitology*, 29, 51–60.
- Layman, E.M. (1930) Parasitic worms from the fishes of Peter the Great Bay. *Izvestiya Tikookeanskoj Nauchno-Promyslovoi Stantsii, Vladivostok*, 3, 1–120.
- Liu, S. (1997) Two new species of trematode of fishes from Fujian, China. *Acta Zootaxonomica Sinica*, 22, 118–124.
- McIntosh, A. (1934) A new blood trematode, *Paradeontacylix sanguinicoloides* n. g., n. sp., from *Seriola lalandi* with a key to the species of the family Aporocotylidae. *Parasitology*, 26, 463–467.
- Montero, F.E., Aznar, F.J., Fernández, M. & Raga, J.A. (2003) Girdles as the main infection site for *Paradeontacylix kampachi* (Sanguinicolidae) in the greater amberjack *Seriola dumerili*. *Diseases of Aquatic Organisms*, 53, 271–272.
- Montero, F.E., García, A. & Raga, J.A. (1999) First record of *Paradeontacylix* McIntosh, 1934 species (Digenea: Sanguinicolidae) in Mediterranean amberjack, *Seriola dumerili* (Risso, 1810), culture. *Bulletin of the European Association of Fish Pathologists*, 19, 107–109.
- Ogawa, K. & Egusa, S. (1986) Two new species of *Paradeontacylix* McIntosh, 1934 (Trematoda:

- Sanguinicolidae) from the vascular system of cultured marine fish, *Seriola purpurascens*. *Fish Pathology*, 21, 15–19.
- Ogawa, K. & Fukudome, M. (1994) Mass mortality caused by blood fluke (*Paradeontacylix*) among amberjack (*Seriola dumerili*) imported to Japan. *Fish Pathology*, 29, 265–269.
- Roff, J.C. & Hopcroft, R.R. (1986) High precision microcomputer based measuring system for ecological research. *Canadian Journal of Fisheries and Aquatic Sciences*, 43, 2044–2048.
- Smith, J.W. (2002) Family Sanguinicolidae von Graff, 1907. In: Gibson, D.I., Jones, A. & Bray, R.A.(Eds.), *Keys to the Trematoda Volume 1*. CABI Publishing, London, 433–452.
- Thulin, J. (1980) A redescription of the fish blood-fluke *Aporocotyle simplex* Odhner, 1900 (Digenea, Sanguinicolidae) with comments on its biology. *Sarsia*, 65, 35–48.