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Observations of 'pseudoparasitism' involving snake eels (Teleostei: Ophichthidae) in commercially important Black Jewfish *Protonibea diacanthus* (Sciaenidae) and other teleost species

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ABSTRACT

Snake eels (family Ophichthidae) are a widespread and highly diverse, but poorly understood group of fishes known worldwide in tropical to temperate waters from inshore to at least 1300 m depth. During the dissections of a commercially harvested large marine sciaenid, the Black Jewfish *Protonibea diacanthus* (Lacépède, 1802), collected from coastal waters off northern Australia, ophichthids were found encased in the mesenteries in the body cavity. Subsequently, specimens of ophichthids were also collected from the stomach contents of *P. diacanthus*, suggesting this as the potential source of the ophichthids in the body cavity. Genetic analysis confirmed four species of ophichthids were collected from the body cavity of 19 *P. diacanthus* specimens. Further investigation has revealed the occurrence of at least three additional ophichthid species from the body cavities of ten Australian teleost species classified in eight different families. Teleost species with ophichthid eels present in their guts were medium to large, opportunistic carnivores suggesting that prey items were targeted rather than incidentally ingested. Preliminary identification of the eels suggests that some may be new Australian records, highlighting an important, but little utilised source of ophichthid specimens for scientific studies. This paper presents the first published report of eels in the body cavity of fishes in Australian waters and is a good example of collaboration and co-operation on collections-based research between various stakeholders in the fisheries industry and of citizen science.

❑ *Pisces, Teleostei, Anguilliformes, Ophichthidae, pseudoparasitic, eel, marine biodiversity, northern Australia*

The family Ophichthidae, whose members are commonly known as snake eels or worm eels, is the most diverse of the true eels (Order Anguilliformes) with 351 valid species (Fricke *et al*. 2020). Snake eels are distributed in coastal, midwater and offshore waters of tropical to warm temperate oceans to at least 1300 m depth, although most species occur in less than 200 m (Smith & McCosker 1999; McCosker 2010). Snake eels are separated into two subfamilies: members of Ophichthinae (281 valid species) usually with hardened, finless tail tips and sometimes also hard, pointed snouts for burrowing tail and/or head first; and, members of Myrophinae (70 valid species) differentiated by their soft tail tips and with both dorsal and anal fin continuous with the caudal fin (Smith & McCosker 1999; Fricke *et al*. 2020). Several reports have been published of ophichthids found in the body cavities of a variety of fish species around the world (see Isbert *et al*. 2011). Reports characterised the ophichthids presence in fish body cavities as either accidental or pseudoparasitic incursions (Breder & Nigrelli 1934; Walters 1955; Garratt 1986; Isbert *et al*. 2011). Walters (1955) and Isbert *et al*. (2011) determined however, that the term 'pseudoparasite' was inappropriate and misleading, as this suggested an eel could potentially survive in the body cavity of the "host" fish. Instead, it is most likely that the snake eels were consumed as part of the fish diet, from which a small number are able to survive ingestion and enter the body cavity, where they die and become encased in the mesenteries (Walters 1955; Garratt 1986; Isbert *et al*. 2011).

The Black Jewfish, *Protonibea diacanthus* (Sciaenidae), targeted in commercial and recreational fisheries, occurs throughout tropical Indo-West Pacific marine waters; within Australia, it is found from south of Onslow (ca. 21°45'S) in Western Australia (Bray *et al*. 2012), across northern Australia, south to at least River Heads, Mary River mouth (ca. 25°25'S) on the central coast of Queensland (Barton 2018; JWJ, unpublished data). During a study on the parasites of the Black Jewfish, in northern Australian waters, specimens of snake eels were recovered from the body cavity and, subsequently, the stomach contents. Additional records of ophichthid eels in Australian teleost fishes were opportunistically collected from other sources, including museum records, research surveys and reports from recreational and commercial fishers. This paper presents data on the eels collected and discusses the potential route the eels undertook prior to encasement in the mesenteries.

MATERIALS AND METHODS

The Black Jewfish specimens reported in this study are the same as those reported in Taillebois *et al*. (2017) and Barton (2018). Fish were collected from a number of locations across northern Australia (see Taillebois *et al.* (2017) for list of all collection locations; locations where ophichthids were collected from *P. diacanthus* are listed in Table 1), primarily by line fishing by staff of both the Western Australian and Northern Territory Departments of Fisheries and Indigenous Marine Rangers as well as by commercial fishers (collected under Northern Territory Fisheries Permit S17/2737). A single ophichthid eel was also recovered from a Golden Snapper, *Lutjanus johnii* (Bloch 1792), fished from Lucinda, near Townsville, by a commercial fisher as part of the same project for which the Black Jewfish were collected. All fish were euthanased (Charles Darwin University Animal Ethics Approval A13014), placed on ice and transported to the laboratory for processing; some fishes were frozen whole prior to processing. Total length (in mm) and sex was recorded. The collection of data for stomach contents of *P. diacanthus* has been previously described in Barton (2018). Ophichthid eels removed from Crimson Snapper, *Lutjanus erythropterus* Bloch, 1790, were collected during an RV *Investigator* survey to the North-West Shelf, WA (IN2017_V05). Observations of ophichthid eels in the gut cavities of fishes from Queensland were also opportunistically collected by JWJ from a combination of personal observation and communication with recreational and commercial fishers between 1977–2013.

Specimens of eels were carefully dissected from the mesenteries in the body cavity or from the external surfaces of various organs and refrozen; specimens of eels collected from the stomach contents were also refrozen. Examination of the specimens were undertaken at CSIRO Australian National Fish Collection, Hobart. Eel specimens were identified as far as possible, based on overall morphology using Smith & McCosker (1999) with other more recent references for the family (e.g. Hibino *et al*. 2019). At least one specimen of each species retained at CSIRO was x-rayed, except for the eel specimen retrieved from a flathead collected off Newcastle, NSW; this was sent to the authors late in this study. Although the number and placement of head pores are useful taxonomic characterstics for eels, these counts were often impossible due to skin desiccation and/or abrasion from the gut of the 'host' species.

Small tissue samples from these eels were collected for genetic analysis. DNA was extracted using the Wizard® SV Genomic DNA Purification system (Promega, Australia) and as per the extraction method outlined in Nielsen *et al*. (2019). A portion of the cytochrome oxidase subunit I (COI) mitochondrial DNA gene was amplified using the BCL and BCH primers of Baldwin *et al*. (2009). Amplified products were sequenced at the CSIRO marine genetics laboratories on a 16 capillary ABI 3130XL DNA Autosequencer (Applied Biosystems™, USA) (as per amplification and sequencing protocols outlined in Appleyard *et al*. 2018). Consensus sequences were assembled in Geneious vers R8.1.4 (Biomatters Ltd, New Zealand) and compared using the BOLD IDS tool (Ratnasingham & Hebert 2007) and GenBank BLASTn (via an internal application in Geneious) to check the similarity of sample sequences against existing database reference sequences.

Institutional abbreviations follow Fricke and Eschmeyer (2020) and other abbreviations are as follows: FL = Fork Length, TL = Total Length, NSW = New South Wales, NT = Northern Territory, Qld = Queensland, WA = Western Australia. For simplicity and ease of discussion we have used the term 'host' although these eels are not truly parasitic.

RESULTS

Ophichthidae from Black Jewfish

A total of 335 *P. diacanthus* (mean TL 805.3 mm, range 330–1300 mm) collected from 13 locations across northern Australia were examined for this study; a total of 19 fish (5.6%) were found with members of the family Ophichthidae in the body cavity. Table 1 presents data for the five locations with these fish only. Table 2 presents additional data for individual fish where ophichthid incursions were investigated in further detail.

The presence of members of the family Ophichthidae is obvious at the time of dissection (Fig. 1), although the level of encasement by mesentery can differ from almost non-existent to fully encased. The level of deterioration of the specimen, with regards to usable morphological details, seemed to be related to the level of encasement by mesenteries: specimens with low encasement are presumed to have been recently ingested and were usually in much better (i.e. fresher) condition than those with high levels of encasement that are presumed to have been in the body cavity for a longer period. In addition to the presence of members of the family Ophichthidae in the mesenteries, a number of fish (four with eels in the body cavity and five without) also had eels in the stomach contents; these fish were only found in Roebuck Bay, Western Australia.

Taxonomic investigation of the eels from Black Jewfish led to them originally being identified as belonging to four different species of the family Ophichthidae based on a combination of characters including colour pattern, body depth, teeth morphology, and presence or absence of a finless, hardened tail tip. Unfortunately, due to a combination of the degraded state of the specimens and the lack of comprehensive keys to the relevant genera in the family, morphological identification of these specimens was very difficult (Table 2).

FIG. 1. Unidentified snake eels (Family Ophichthidae) found in the body cavity of *Protonibea diacanthus* in northern Australia. Arrows point to the specimen. Top left, NTM S. 17726-001 from Adelaide River, NT; bottom left and right – from Roebuck Bay, WA.

DNA analysis of eight specimens of snake eel in comparison to sequences on BOLD confirmed the presence of four different species. Despite successful sequencing, none of the specimens collected in this study were an exact (100%) pairwise match to a known species in the BOLD database.

Within the four identified species, three belong to the subfamily Ophichthinae and are most likely members of the genus *Ophichthus* Ahl, 1789; the fourth species is a member of the subfamily Myrophinae and is most likely a member of the genus *Scolecenchelys* Ogilby, 1897.

Ophichthus sp. 1 (Fig. 2A) was collected from three individuals of *P. diacanthus* from Roebuck Bay: one from the stomach (CSIRO H 8472-01) and two from the body cavity (CSIRO H 8473-01 and CSIRO H 8474-01). The three specimens had a COI gene sequence with a 98.4-98.7% match to 10 samples of "*Ophichthus* sp." from Taiwan in the BOLD database – these Taiwan specimens are likely to be *Ophichthus machidai* McCosker, Ide & Endo, 2012 (H-C. Ho, National Museum of Marine Biology & Aquarium, Taiwan, personal communication June 2019). The specimen in best condition (CSIRO H 8473-01) shares morphological similarities with *O. machidai* in having the

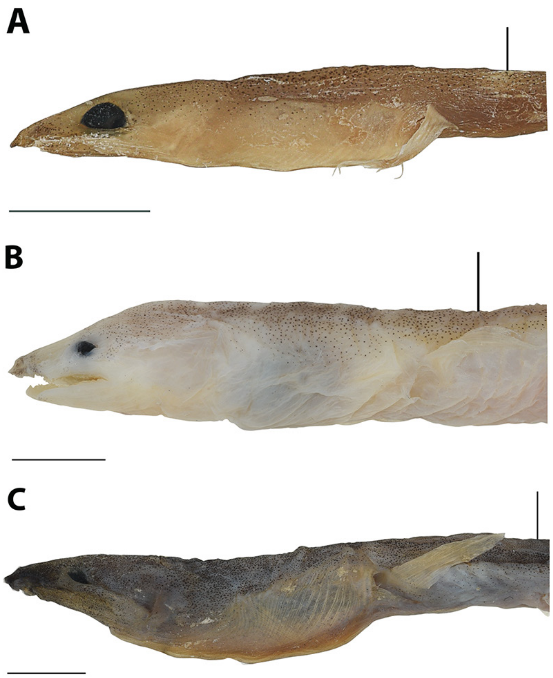

FIG. 2. Preserved lateral head images of Australian pseudoparasitic eels of genus *Ophichthus* removed from Black Jewfish, *Protonibea diacanthus*. **A**, *Ophichthus* cf. *machidai*, CSIRO H 8473-01, 140 mm TL, Roebuck Bay, WA; **B**, *Ophichthus* cf. *sangjuensis*, CSIRO H 8475-02, 198 mm TL, Roebuck Bay, WA; **C**, *Ophichthus* cf. *chilkensis*, CSIRO H 8477-02, 368 mm TL, Wyndham, WA. Vertical bars denote location of dorsal fin origin. Scale bar = 0.5 mm.

dorsal fin origin over the pectoral fin (over or slightly behind in description), elongate pectoral fins, speckled dorsal colouration and pale ventral colouration. Also, the vertebral count data (one of the key diagnostic characters for most eels) of CSIRO H 8473-01 (the only specimen x-rayed) matches the range known for *O. machidai* (i.e. ca. 12/52/150 for predorsal/preanal/total vertebrae in this specimen versus mean vertebral formula of 13/56/154 and total vertebrae 146-161 in McCosker *et al*. 2012; Hibino *et al*. 2019). However, the three Australian specimens are tentatively identified as *Ophichthus* cf. *machidai*, given that they are juveniles (140-281 mm TL versus maximum of 672 mm TL in McCosker *et al*. 2012) and the tooth and head pore morphology is difficult to determine due to either abraded skin, head missing or dehydration caused by the

TABLE 1. Locations in this study where collected *Protonibea diacanthus* included encased eel specimens of family Ophichthidae from along the coastlines of Western Australia and the Northern Territory. Locations are listed in order from west to east; only locations with encased fish are listed.

Location	No. fish	Mean mm TL (Range)	Number of fish encased (%)	Mean intensity of fish encasement (%)
Western Australia				
Roebuck Bay	36	1018.5 (720-1199)	13 (36.1)	1.54 (1-3)
Kimberley	20	646.7 (520-920)	2 (10)	1
Wyndham	34	1067.1 (804-1300)	2 (5.9)	1.5 (1-2)
Northern Territory				
Cape Hotham	10	990 (430-1230)	1 (10)	1
Maningrida	29	730.9 (420-1210)	1 (3.4)	1
TOTAL	129	906.8 (420-1300)	19 (14.7)	1.4 (1-3)

Eel taxon	Museum Reg. No.	Size (mm TL)	BOLD No.	Host family	Host species	Host size (mm TL)	Host organ	Host collection locality	Approximate position	Date host collected
Ophichthus cf. *machidai*	CSIRO H 8472-01	281	BW-A13816	Sciaenidae	*P. diacanthus*	1012 mm	stomach	WA, Roebuck Bay	18°04′S, 122°15′E	7/08/2015
Ophichthus cf. *machidai*	CSIRO H 8473-01	140	BW-A13817	Sciaenidae	*P. diacanthus*	980 mm	mesenteries	WA, Roebuck Bay	18°04′S, 122°15′E	31/07/2015
Ophichthus cf. *machidai*	CSIRO H 8474-01	>172	BW-A13818*	Sciaenidae	*P. diacanthus*	1010 mm	mesenteries	WA, Roebuck Bay	18°04′S, 122°15′E	1/08/2014
Ophichthus cf. *machidai*	CSIRO H 8474-01	212	BW-A13819	Sciaenidae	*P. diacanthus*	1010 mm	mesenteries	WA, Roebuck Bay	18°04′S, 122°15′E	1/08/2014
Ophichthus cf. *sangjuensis*	CSIRO H 8475-01	213	BW-A13821	Sciaenidae	*P. diacanthus*	1100 mm	stomach	WA, Roebuck Bay	18°04′S, 122°15′E	21/06/2015
Ophichthus cf. *sangjuensis*	CSIRO H 8475-02	198	BW-A13822	Sciaenidae	*P. diacanthus*	1100 mm	stomach	WA, Roebuck Bay	18°04′S, 122°15′E	21/06/2015
Ophichthus cf. *chilkensis*	CSIRO H 8477-01	>260	BW-A13823	Sciaenidae	*P. diacanthus*	822 mm	mesenteries	WA, Cambridge Gulf	15°28′S, 128°06′E	1/05/2015
Ophichthus cf. *chilkensis*	CSIRO H 8477-02	368	BW-A13824	Sciaenidae	*P. diacanthus*	822 mm	mesenteries	WA, Cambridge Gulf	15°28′S, 128°06′E	1/05/2015
Scolecenchelys sp.	CSIRO H 8476-01	>150	BW-A13815	Sciaenidae	*P. diacanthus*	870 mm	stomach	WA, Roebuck Bay	18°04′S, 122°15′E	14/08/2015
Ophichthinae	NTM S.17726-001	205	BW-A12762*	Sciaenidae	*P. diacanthus*	1230 mm	swimbladder	NT, the Narrows	12°14′S, 131°16′E	25/04/2014
Ophichthinae	NTM S.17727-001	2:72-160	No DNA	Sciaenidae	*P. diacanthus*	649 mm	swimbladder	WA, Three Ways Creek	16°12′S, 124°33′E	4/10/2014
Ophichthinae	NTM S.16084-001	245	No DNA	Sciaenidae	*P. diacanthus*	not recorded	body cavity	NT, Chambers Bay	12°13′S, 131°35′E	15/06/2005
Ophichthinae	NTM S.18451-001	ca. 177	No DNA	Sciaenidae	*P. diacanthus*	not recorded	body cavity	NT, Off Bynoe Harbour	12°23′S, 130°18′E	15/08/2005
Ophichthinae	NTM S.16558-001	124	No DNA	Sciaenidae	*P. diacanthus*	not recorded	body cavity	NT, Chambers Bay	12°13′S, 131°35′E	May 2007
Ophichthinae	NTM S.16503-001	158	No DNA	Sciaenidae	*P. diacanthus*	not recorded	body cavity	NT, Charles Pt	12°19′S, 130°39′E	June 2007
Yirrkala cf. *chaselingi*	CSIRO H 8292-27	355	BW-A15141	Lutjanidae	*Lutjanus erythropterus*	ca. 500-590	mesenteries	WA, north of Cape Lambert	20°12′S, 117°22′E	20/10/2017
Ophichthinae	CSIRO unregistered	145	No DNA	Lutjanidae	*Lutjanus johnii*	785	mesenteries	Qld, Lucinda	18°32′S, 146°20′E	25/05/2014
Malvoliophis pinguis	not retained	unknown	No DNA	Pomatomidae	*Pomatomus saltatrix*	not recorded	body cavity	Qld, Scarborough	27°11′S, 153°07′E	May 1977
Leiuranus semicinctus	not retained	ca. 285	No DNA	Scombridae	*Acanthocybium solandri*	1475 mm FL, 22.3 kg	body cavity	Qld, off Cairns	17°15′S, 147°30′E	30/09/2011
Ophichthinae	not retained	?	No DNA	Serranidae	*Hyporthodus ergastularius*	not recorded	body cavity	Qld, Fraser I to Gold coast	ca. 24°S - 28°S	26/11/2013
Ophichthinae	not retained	?	No DNA	Serranidae	*Hyporthodus octofasciatus*	not recorded	body cavity	Qld, Fraser I to Gold coast	ca. 24°S - 28°S	26/11/2013
Ophichthinae	not retained	?	No DNA	Polyprionidae	*Polyprion oxygeneios*	not recorded	body cavity	Qld, Fraser I to Gold coast	ca. 24°S - 28°S	26/11/2013
Ophichthinae	not retained	?	No DNA	Centrolophidae	*Hyperoglyphe antarctica*	not recorded	body cavity	Qld, Fraser I to Gold coast	ca. 24°S - 28°S	26/11/2013
Ophichthinae	CSIRO unregistered	ca. 120	Not yet sampled	Platycephalidae	*Platycephalus richardsoni*	not recorded	body cavity	NSW, Newcastle region	32°56′S, 151°47′E	2019

TABLE 2. Records of pseudoparasitic eels referred to in this study (> denotes damaged due to head missing; * denotes sequencing attempted, but unsuccessful). Ophichthinae refers to specimens that are currently unresolved beyond subfamily level due to dessication and/or damage.

gut cavity. As *O. machidai* has not yet been confirmed from Australia (McCosker *et al.* 2018; previously only documented from Japan and Taiwan by Hibino *et al.* 2019), we defer conclusive identification of these specimens until material in better condition becomes available. Kimura *et al*. (2018) also noted two un-named *Ophichthus* species from Vietnam which share similar features with this unknown species from northern Australia.

Ophichthus sp. 2 (Fig. 2B) was collected from the stomach of a single, large *P. diacanthus* female at Roebuck Bay; two specimens (CSIRO H 8475-01 and CSIRO H 8475-02) were examined in detail and subsampled for genetics. When compared with other sequences in the BOLD database, *Ophichthus* sp. 2 showed 94.3–94.5% similarity to two specimens of *Ophichthus brevicaudatus* Chu, Wu & Jin 1981 from China. Slightly more divergent (93.5–94.0% similarity) to these sequences was a sequence from another undetermined species of *Ophichthus* or *Pisodonophis* Kaup, 1856 from Indonesia, Philippines and Taiwan. *Ophichthus* sp. 2 has minute melanophore-sized spots dorsally and is pale ventrally with the dorsal fin origin above the anterior to middle of pectoral fin and with three to five premaxillary teeth visible when mouth closed. Vertebral count data collected from one of the two specimens was 12/48/143, which is close to *Ophichthus sangjuensis* (Ji & Kim 2011) with MVF 14/50/147 and total vertebrae range 143–153 (Hibino *et al*. 2019). Again, as this species has not been recorded from Australia, we tentatively identified it as *Ophichthus* cf. *sangjuensis*, pending confirmation of its existence in Australia from specimens in better condition and larger size (these two Australian specimens are 198–213 mm TL, but it is documented to 627 mm TL by Ji & Kim 2011).

Two specimens of *Ophichthus* sp. 3 (CSIRO H 8477-01; H 8477-02, Fig. 2C) were collected from the mesenteries of a single *P. diacanthus* from Wyndham. The sequences from both specimens were grouped together (although there is a base pair variation between the two COI sequences) and showed 87.9-89.1% similarity with *Pisodonophis boro* (Hamilton 1822), from India (type locality), Bangladesh and China, and 86.2–86.8% similarity to an unresolved taxon, *Pisodonophis* sp. (NTM S.17851-011) from Joseph Bonaparte Gulf, WA. The genera *Pisodonophis* and *Ophichthus* are currently inadequately defined (Hibino *et al*. 2019), so both genera are relevant to the identification of this unknown species. The two specimens are very elongate and bicolored, darker dorsally than ventrally. Only one (CSIRO H 8477-02) of the two specimens is completely intact (CSIRO H 8477-01 is missing the head, presumably damaged when extracted), so taxonomic characters discussed are limited to CSIRO H 8477-02. Both jaws have irregularly biserial (mostly recurved) teeth, the vomerine teeth are biserial for most of their length (longer anteriorly), 7 premaxillary teeth are present, the anterior nostrils are tubular and located on the upper lip, and a small barbel is present between the anterior and posterior nostrils. The eyes are very small, head length is 16.8 times in TL (approx. 6% TL), tail length 66.2% TL, head length 5.6 times in Trunk Length. The dorsal fin origin is just behind the rear tip of the pectoral fin (by about half length of pectoral fin) and the pectoral fin base is restricted to the dorsal half of the gill opening. The vertebral count of 13/65/209 is at the upper limits for most ophichthid species but most closely matches *Ophichthus chilkensis* Chaudhuri, 1916, currently known only from India (Mishra *et al*. 2019). Given that the generic limits for *Ophichthus* and *Pisodonophis* are uncertain, and the large range extension that this would be, it is tentatively identified as *Ophichthus* cf. *chilkensis* until further specimens from Australia or matching genetic sequences from India can be confirmed.

A single specimen of subfamily Myrophinae (CSIRO H 8476-01, not figured) was collected from the stomach of a *P. diacanthus* from Roebuck Bay. The COI sequence from this specimen showed a 93.9–94.0 % similarity with a sequence from *Scolecenchelys macroptera* (Bleeker, 1857) collected from China. The single specimen was unfortunately missing its head so limited morphological data could be collected. Although an unknown number of anterior vertebrae are missing, it is clear that the dorsal fin origin is nine vertebrae in advance of the anal fin origin, the total vertebrae less pre-anal vertebrae count is 88 and the total vertebrae less pre-dorsal vertebrae count is 97. Although it is difficult to assign this species to a taxon with the limited data available, we tentatively refer it to *Scolecenchelys* sp., although it is perhaps possible that it could also belong to genus *Muraenichthys* Bleeker, 1853 or another Myrophine genus if the *S. macroptera* sequence in BOLD has been misidentified.

Some previous 'pseudoparasitic' eel samples collected from the body cavity of *P. diacanthus* by NT Fisheries and commercial fishers and lodged with NTM are also included in Table 1. These specimens were in relatively poor condition without DNA samples, so identifications are lacking at this stage.

Eels from other teleost fishes

Ophichthidae from Golden Snapper. A single ophichthid specimen was collected from the mesenteries of a Golden Snapper, *Lutjanus johnii*, sampled at Lucinda, north Qld. The specimen was very degraded / digested and morphological examination could not identify it further than to the family. Molecular analysis was not attempted.

Ophichthidae from Crimson Snapper. In November 2017, during an RV *Investigator* voyage off the North West Shelf of WA, three specimens of ophichthid eels were removed from the mesenteries of a Crimson Snapper, *Lutjanus erythropterus* (Chris Dowling, Fisheries WA, personal communication July 2019). The specimens were relatively intact, and a COI sequence was obtained for the specimen in best condition (CSIRO H 8292-27, Fig. 3). This sequence shared 91.0 % similarity with *Callechelys catostoma* (Schneider, 1801) from French Polynesia and 90.1-90.2 % similarity with *Yirrkala tenuis* (Günther, 1870) from the Seychelles. The vertebral count of the three specimens (ca. 7-8 predorsal, ca. 79-81 preanal and ca. 149-153 total) and the absence of pectoral fins is a close match to two species of *Yirrkala* known from northern Australia, namely *Yirrkala chaselingi* Whitley, 1940 with ca. 150-155 vertebrae, and *Yirrkala calyptra* McCosker, 2011 with 7-9/73-75/143-147 vertebrae (McCosker, 2011). The overlapping distribution of *Y. chaselingi* (the other two Australian *Yirrkala* species are currently only known from Qld; see McCosker *et al*. 2018) points to it being the most likely candidate, but comparative pre-dorsal and pre-anal vertebral counts and certainty over the true number of supraorbital pores is lacking (McCosker 2011 noted 'appears to have three rather than four supraorbital pores', but the best specimen we examined has four). *Yirrkala ori* McCosker, 2011, known from South Africa, also has 4 supraorbital pores and a similar vertebral count, i.e. 6-7/71-76/149-152 (McCosker, 2011). We tentatively identify this specimen as *Yirrkala* cf. *chaselingi* until a more definitive description of the species is provided.

Ophichthidae from other Australian teleosts in Queensland

Since 1977, JWJ has collated records of instances in Qld where ophichthid eels were discovered in the body cavities of another five teleost fishes in four different families collected by recreational and commercial fishers. The first was a live Halfband Snake Eel, *Malvoliophis pinguis* (Günther 1872), inside the body cavity of a Tailor, *Pomatomus saltatrix* (Linnaeus 1766) (Pomatomidae) from Moreton Bay (JWJ, unpublished data, specimen not retained or photographed). The second was an encased Saddled Snake Eel, *Leiuranus semicinctus* (Lay & Bennett 1839), inside a Wahoo, *Acanthocybium solandri* (Cuvier 1832) (Scombridae) collected by longline off Cairns (M. Zischke, personal communication to JWJ, Fig. 4, specimen not retained), the eel identification evident from the 25 broad dark saddles (narrowest across head) interspersed by narrow white bars (see Randall 2005). Lastly, unidentified ophichthid species (specimens photographed but not retained) were collected from depths of 300-500 m by a commercial fisher around seamounts in south-east Qld between Fraser Island and the Gold Coast from four different

FIG. 3. Preserved lateral head image of *Yirrkala* cf. *chaselingi* (CSIRO H 8292-27, 355 mm TL, North of Cape Lambert, WA) removed from Crimson Snapper, *Lutjanus erythropterus*. Vertical bar denotes location of dorsal fin origin. Scale bar = 0.5 mm.

teleost species in three different families (J. Rowley, personal communication to JWJ). These additional teleosts include what was previously and colloquially known as 'bar cod' (now known to consist of Banded Rockcod *Hyporthodus ergastularius* (Whitley 1930) and Eightbar Grouper, *Hyporthodus octofasciatus* (Griffin 1926), family Serranidae), Hapuku (*Polyprion oxygeneios* (Schneider & Forster 1801), family Polyprionidae) and Blue-eye Trevalla (*Hyperoglyphe antarctica* (Carmichael 1819), family Centrolophidae).

Ophichthidae from NSW Tiger Flathead. Lastly, in late 2019 just prior to the submission of this manuscript, a specimen of unidentified Ophichthidae was extracted from the body cavity of a Tiger Flathead (*Platycephalus richardsoni* Castelnau 1872, family Platycephalidae). The specimen was originally caught by a commercial fisher off Newcastle, NSW and purchased from the Sydney Fish Markets. It is small (ca. 120 mm TL) and the tail tip is damaged, making genus identification difficult, but dorsal and anal fins are present and pectoral fins appear to be absent. Extraction of DNA has not yet been attempted.

DISCUSSION

This study represents the first report of the presence of encased snake eels in a number of fishes in Australian waters. Within the family Ophichthidae, members of the genera *Ophichthus*, *Myrichthys* Girard, 1859 and *Apterichtus* Duméril, 1805 have been reported from the body cavities of various fish species, ranging from the Bahamas, Florida, the north-west Atlantic to the Mediterranean Sea (Isbert *et al*. 2011); members of the genera *Callechelys* Kaup, 1856 and *Caecula* Vahl, 1794 were also found in a variety of fishes from South Africa (Garratt 1986). All the "host" fish reported were predatory, and most had a benthic habitat preference (see Waters 1955); three of the fish reported belonged to the family Serranidae (see Isbert *et al*. 2011) which have a similar ecology to the family Sciaenidae, to which *P. diacanthus* belongs. Interestingly,

FIG. 4. Fresh dorsal image of *Leiuranus semicinctus* from Wahoo, *Acanthocybium solandri*. Specimen not retained, ca. 285 mm TL, east of Cairns, Qld. Image by M. Zischke. Scale bar = 1 cm.

coincident with the study on *P. diacanthus*, a similar study was undertaken on a number of other fish species (families Lutjanidae and Lethrinidae) from the same collection locations; only one *Lutjanus johnii* out of 1200 specimens of mixed species examined, all predatory, but not specifically benthic, were found to have encased eels (Barton, unpub. data), although the eel genus could not be identified. A second benthic snapper species, *Lutjanus erythropterus,* was recently found with an encased eel, genus *Yirrkala* from the North West Shelf, WA. Other host families encountered during this study (Platycephalidae, Polyprionidae, Serranidae) are primarily benthic to benthopelagic in nature, although some (e.g. Centrolophidae, Scombridae) can also be associated with seamounts and drop-offs and have pelagic aspects to their behaviour, likely driven by diurnal and /or nocturnal vertical migrations for feeding. It is difficult to know if all the eels were taken near the benthos as there are also some pelagic members of the Ophichthidae, including *Neenchelys* Bamber, 1915 (Ho *et al*. 2015), but some eels were unidentifiable either due to poor condition or not being retained.

It is most likely that snake eels form a small part of the diet of these opportunistic predators, from which a small number are able to survive the ingestion and are then able to enter the body cavity in which they die and become encased in the mesenteries (Walters 1955; Garratt 1986; Isbert *et al*. 2011). This is supported by the collection of a number of eels collected from stomach contents of *P. diacanthus* in this study (see Barton 2018). Further, the fact that there was 100% COI genetic similarity between *Ophichthus* cf. *machidai* collected from the stomach (CSIRO H 8472-01) and from the mesenteries (CSIRO H 8473-01) of an individual *P. diacanthus*, confirms the relationship. During dissections of *P. diacanthus*, occasional wounds were found in the stomach wall, presumed to have been caused by the spines of teleosts such as fork-tailed catfishes (family Ariidae, which were common dietary items in specimens from Wyndham), but possibly also stingrays (family Dasyatidae), or fish hooks; representatives of all three were found in the body cavity of *P. diacanthus* during the study. Snake eels normally exist in burrows in the sand and routinely reverse or dive into soft substrate using their hard, pointed head or tail tip. If snake eels were ingested by a jewfish with a wounded stomach wall, they could potentially burrow out of the stomach via the wound into the body cavity, whereby they die and become encased in the mesenteries. However, the pointed head and /or tail tip of snake eels likely facilitates ease of burrowing through the soft stomach lining, even in the absence of damage to the stomach lining. Fishes that burrow into sediments (infaunal) are presumably tolerant of low oxygen environments and could feasibly stay alive for longer inside the gut cavities of species that predate upon them, once ingested.

Although not a parasite, the presence of these eels in the jewfish were sufficient to be utilised as a biological tag in Taillebois *et al*. (2017). Presence of these eels was high in comparison to previous reports, although it should be noted that very few studies have previously documented their frequency. Isbert *et al*. (2011) found snake eel specimens entangled in the mesenteries of 1 out of 45 pandoras (*Pagellus erythrinus* (Linnaeus, 1758); Sparidae) in the Mediterranean Sea, with a further 2 pandoras having eels in the stomachs. Garratt (1986) examined over 9000 sparids and serranids and found 11 individuals with an encased eel in the body cavity; only one eel was found per fish.

Larson *et al*. (2013) reported 18 species of Ophichthidae from waters of the Northern Territory, Australia. A number of these species were reported to also occur in Asia and other waters off the coast of northern Australia. Of the species that were close to the "species" identified in this study *S. macroptera* and *Pisodonophis boro* also occurred in Australian waters. However, several species listed by Larson *et al*. (2013) are not represented by a COI sequence in the BOLD database, so whether the eels found in the stomachs and body cavities of *P. diacanthus* in this study belong to these species remains unknown. There are several shallow-water northern Australian ophichthids that are yet to be conclusively identified (J. McCosker personal communication March 2013 in Larson *et al*. 2013). Further collections of eels from the body cavities of fishes in Australian waters needs to be undertaken with specimens utilised for genetic and morphological analysis. Unfortunately, the biodiversity of snake eels in northern Australia is inadequately documented and as discussed it is possible that some of these specimens represent new Australian records or are undescribed species.

This study has built upon previously published reports and highlights that at least seven species of pseudoparasitic ophichthid eels in five genera are recorded from ten different species of Australian teleost fishes in eight families, namely Centrolophidae, Lutjanidae, Platycephalidae, Polyprionidae, Pomatomidae, Serranidae, Sciaenidae and Scombridae. The broad depth range of the host species (inshore to around 500 m) suggests that numerous more species of ophichthid eels could be recorded in this fashion, so it is clear that the diversity of both the pseudoparasitic eels and their hosts will expand as researchers become more aware of this little-known phenomenon. This study also highlights a positive outcome from collaboration and co-operation on collections-based research between various stakeholders in the fisheries industry and of citizen science.

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