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Metazoan parasite assemblages of wild *Seriola lalandi* (Carangidae) from eastern and southern Australia

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Abstract

Yellowtail kingfish, *Seriola lalandi* support significant commercial and recreational fisheries as well as aquaculture operations throughout the world. Metazoan parasite infections of *S. lalandi* are of considerable economic and ecological importance, yet very little is known about wild parasite assemblages. *S. lalandi* were collected from the east coast and south coast of Australia and examined for metazoan parasites. Forty-three parasite taxa were identified, including 26 new host records. Four of the parasite species recovered have been previously associated with disease or mortality in *Seriola* aquaculture. Comparisons are made between ectoparasite and endoparasite prevalence and intensity of *S. lalandi* from New South Wales and Victoria. *S. lalandi* sampled from the east coast of Australia shared ectoparasites previously documented from this species in New Zealand, providing support that *S. lalandi* in the Tasman Sea comprise a single stock. Based on previously used criteria to evaluate the suitability of parasites as biological tags, the monogenean *Paramicrocotyloides reticularis* Rohde and the copepod *Parabrachiella seriolae* Yamaguti and Yamasu may be potentially useful for stock discrimination.

Keywords: *Seriola* species; Parasite survey; Aquaculture; Australia; New Zealand

1. Introduction

Yellowtail kingfish, *Seriola lalandi* Valenciennes are distributed in waters of the Pacific and Indian Oceans off South Africa, Japan, southern Australia, New Zealand, Canada and the United States of America [1]. In Australia, *S. lalandi* is a popular recreational species which inhabits southern coastal waters from Queensland to Western Australia, and northern Tasmania [2]. The primary wild-caught commercial fishery is in New South Wales (NSW) and produces about 200 tonnes per year [3]. This species is also farmed in sea cages in Spencer Gulf, South Australia, and currently produces about 1500 tonnes per annum with production expected to increase to 10,000 tonnes by 2012 [4].

Parasites infecting *Seriola* species are ecologically and economically important. For example, wild *S. lalandi* off the east coast of Australia can be infected with *Kudoa* sp. and *Unicapsula seriolae* Lester, that soften the flesh, making the fish unmarketable [5,6]. Outbreaks of monogeneans have caused significant mortalities in sea cage farming of *Seriola* species in the Mediterranean [7], Japan [8], New Zealand [9] and Australia [10]. Considering the relative importance of *S. lalandi* parasites and the increasing commercial value of the species in Australia, it is surprising that the parasite community of *S. lalandi* has not been studied in detail.

Past research has focused on *S. lalandi* from the east coast of Australia, where few species of monogeneans, crustaceans and helminths have been reported. With the exception of gill monogeneans, parasite prevalence and intensity data are lacking for wild *S. lalandi* populations in Australian waters. From commercial, environmental and scientific view points, it is

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highly preferable that surveys of wild fish occur before fish farming commences to determine the potential for pathogen interactions between wild and farmed fish. The locations chosen for study are completely free of finfish aquaculture, providing an ideal basis for examining levels of infection in the absence of any potential interaction with farming activities.

The aims of this paper are to: a) document the metazoan parasites that infect wild *S. lalandi* off the eastern and southern coasts of Australia; b) record parasite prevalence and intensity; c) compare the metazoan parasite assemblage of *S. lalandi* sampled from two different localities in Australia; d) compare the ectoparasite assemblage of wild *S. lalandi* from Australia with wild *S. lalandi* in New Zealand and; e) identify parasite species that could be used as biological tags.

2. Materials and methods

Commercial fishers caught 25 *S. lalandi* at Sir John Young Banks off Greenwell Point, NSW (34°56′52″S, 150°55′45″E) between June and July 2003. Fish ranged from 760 to 950 mm fork length (FL) (mean=830 mm FL). Recreational fishers caught 25 *S. lalandi* off Killarney, Victoria (38°23′36″S, 142°20′24″E) in January 2004 and January 2005. Fish ranged from 440 to 790 mm FL (mean=539 mm FL).

Live fish were bathed individually in 10–20 L of seawater containing 5 mg/L praziquantel for 10 min to dislodge all gill monogeneans [11]. Fish were then bathed in freshwater for approximately 10 min to remove all *Benedenia seriolae* (Yamaguti) Meserve (see [12]). Fish were euthanised in this treatment with a lethal dose of clove oil (>200 mg/L). If fish specimens were not obtained alive, they were bathed in freshwater after the gills had been removed and fixed in 10% formalin. All parasites were collected from the bath water from both treatments by filtration through a 75 μm sieve and fixed in 10% formalin [12].

The exterior of the fish, including inside the mouth and buccal folds and in the fin sulcus, was examined for ectoparasites. Parasites were preserved in 10% formalin. The gills were removed by dissection and examined for ectoparasites and pathology. The heart was removed, opened and examined for parasites under a dissecting microscope. It was then flushed with saline and the settled contents were examined under a dissecting microscope. Alternatively, the heart was fixed in 10% formalin and examined later. The brain cavity and body cavity were exposed and samples of brain, muscle, spleen, liver, kidney, gall and gonad were removed and fixed in 10% formalin. Tissues were embedded in paraffin wax, sectioned at 5 μm and stained with Mayer's haematoxylin and eosin for routine light microscope examination.

The viscera, swim bladder and muscle were examined for gross pathology. The digestive tract was removed and the stomach, caeca and intestine were opened separately and shaken vigorously in physiological saline. The settled contents were sorted under a dissecting microscope and parasites were aspirated with a pipette. Fresh squashes were made of brain, muscle and bile and examined using a compound microscope. Bile was not examined in NSW. If parasites were detected, they were fixed in 10% formalin. Sub-samples of myxozoans from parasitised bile were frozen in the field, then thawed and measured in the laboratory. Measurements were made using a computerised digitising system similar to that described by Roff and Hopcroft [13].

Nematodes were preserved in 70% ethanol. Fixed nematodes were cleared and mounted in lactophenol and examined using a compound microscope. Trematodes and cestodes were killed in near boiling saline then fixed in 10% formalin. Fixed parasites were placed in distilled water before being stained in Mayer's haematoxylin overnight, then destained in 1% HCl in 70% ethanol. The trematodes and cestodes were dehydrated in an ethanol series before being cleared in cedar wood oil and mounted on a slide in Canada balsam. Trematodes and cestodes were examined using a compound microscope.

Additional trematode specimens, collected from the stomach and caeca of *S. lalandi* from Rapid Bay and Cape Noarlunga, South Australia, that had been previously lodged in the Australian Helminth Collection (AHC) at the South Australian Museum (SAMA) by T.H. Johnston in 1945 (unpublished data) (AHC 1126–1128) were also stained, mounted and examined by us. *Caligus spinosus* (SAMA C6310) and *Paramicrocotyloides reticularis* specimens collected by Ben Doolan from the gills of 4 *S. lalandi* captured off Lord Howe Island, NSW (about 700 km off the east coast of Australia) were also examined. Voucher specimens of metazoan parasites lodged by Sharp, Poortenaar, Diggles and Willis [14] sampled from *S. lalandi* in New Zealand were requested from the National Institute of Water and Atmospheric Research (NIWA) Museum, P.O. Box 14-901 Kilbirnie, Wellington, New Zealand but were unable to be located. Some of the parasite species documented from *S. lalandi* in New Zealand by Smith, Diggles, McKenzie, Kim, Maolagain, Notman and Griggs [15] were made available by Dr Peter Smith for study including *C. spinosus* Yamaguti (reported as *C. aesopus*), *Lernanthropus* sp., *Paramicrocotyloides* sp., and an undetermined species of acanthocephalan. We stained and mounted whole specimens of *Paramicrocotyloides* sp. from New Zealand.

Parasite material collected in this study is deposited in the AHC and the Marine Invertebrate Collection (C) at SAMA. Parasite prevalence and intensity are given in whole numbers and follow Bush et al. [16]. We considered examining potential effects of host size on ectoparasite prevalence, but analysis was not possible because equivalent fish size classes were not obtained from the two sampling locations. Consequently, the contributing factors of host size and sample location on parasite prevalence cannot be verified separately.

3. Results

Forty-three metazoan parasite species were identified from *S. lalandi* sampled at Sir John Young Banks, NSW and Killarney, Victoria. Myxozoans were treated as a

Table 1
Prevalence and intensity of parasites from *Seriola lalandi* collected from Sir John Young Banks, New South Wales and Killarney, Victoria

Group/family	Taxon	Microhabitat	New South Wales	Victoria
Ectoparasites				
Monogenea				
Capsalidae	*Benedenia seriolae*	Body surface	83 (20, 24); 8 (1–29); 760–950; AHC 29102 & 29103	60 (15, 25) 9 (1–36); 440–790; AHC 29104[b]
Heteraxinidae	*Paramicrocotyloides reticularis*	Gills	38 (9, 24); 2 (1–4); 780–950; AHC 29105 & 29106	NR
	Zeuxapta seriolae	Gills	83 (20, 24); 32 (1–92); 450–950; AHC 29107	38 (8, 21); 6 (1–22); 440–790; AHC 29108[b]
Crustacea				
Bomolochidae	*Naricolax chrysophryenus*	Nasal cavity[c]	4 (1, 24); 1; 850; C6240[a]	NR
Caligidae	*Caligus amblygenitalis*	Surface, cavities	17 (4, 24); 3 (1–7); 780–85; C6311[ab]	NR
	C. lalandei	Body surface[c]	38 (9, 24); 1 (1–2); 770–910; C6229[b]	20 (5, 25); 2 (1–4); 470–790; C6228[b]
	C. spinosus	Gill arches	13 (3, 24); 1 (1–2); 810–920; C6231	4 (1, 25); 1; 540; C6230
	Caligus sp.	ND	8 (2, 24); 2 (1–2); 830–860; C6232[ab]	12 (3, 25); 1 (1); 470–760; C6312[ab]
Dissonidae	*Dissonus hoi*	Nasal cavity	13 (3, 24); 2 (1–2); 850–920; C6235[ab]	NR
Lernanthropidae	*Lernanthropus paenulatus*	Gills	33 (8, 24); 2 (1–8); 780–900; C6239	5 (1, 21); 1; 480; C6309[b]
Laernaeopodidae	*Parabrachiella* sp.	Gills	4 (1, 25); 15; 900; C6238	NR
	Parabrachiella seriolae	Buccal folds	56 (14, 25); 3 (1–9); 770–910; C6237[b]	4 (1, 25); 3; 760; C6236[b]
Pennellidae	*Peniculus* sp.	Body surface	13 (3, 24); 1 (1); 440–870; C6244[ab]	20 (5, 25); 2 (1–5); 470–540; C6233[ab]
Endoparasites				
Myxozoa				
Ceratomyxidae	*Ceratomyxa buri*	Gall bladder	NA	52 (11, 21); NA; 480–760; AHC 34173[ab]
	C. seriolae	Gall bladder	NA	32 (6, 19; NA; 480–760; AHC 34174[ab]
Trematoda				
Acanthocolpidae	*Stephanostomum petimba*	Digestive tract	64 (16, 25); 10 (1–35); 760–950; AHC 29109[ab]	NR
	Tormopsolus orientalis	Stomach, intestine	40 (10, 25); 5 (1–18); 770–990; AHC 29110 & 29111[b]	48 (12, 25); 3 (1–8); 460–590; AHC 29112 & 29113[b]
Bucephalidae	*Bucephalus gorgon*	Digestive tract	64 (16, 25); 16 (1–70); 760–900; AHC 29114 & 29115[b]	68 (17, 25); 15 (1–91); 440–790; AHC 29116[b]
	Rhipidocotyle longicirrus	Intestine	20 (5, 25); 3 (1–5); 770–900; AHC 29118 & 29119[ab]	NR
	Telorhynchus sp.	Digestive tract	NR	12 (3, 25); 3 (2–5); 440–510; AHC 29121 & 29122[ab]
Didymozoidae	Undetermined species	Viscera	12 (3, 25); 1; 770–870; AHC 29123	48 (12, 25); 1 (1–2); 440–660; AHC 34174
Hemiuridae	*Erilepturus hamati*	Stomach	NR	12 (3, 25); 1 (1); 500–520; AHC 29124[b]
	Elytrophalloides oatesi	Stomach	NR	4 (1, 25); 1; 500; AHC 29125[ab]
	Elytrophallus sp.	Stomach	NR	12 (3, 25); 3 (1–6); 480–520; AHC 29126[ab]
	Hirudinella sp.	Stomach	NR	4 (1, 25); 1; 760; AHC 34176[ab]
	Lecithocladium sp.	Stomach	4 (1, 25); 1; 800; AHC 29127[ab]	NR
	Parahemiurus merus	Stomach	NR	32 (8, 25); 3 (1–7); 440–665; AHC 29128[b]
	Plerurus digitatus	Stomach	4 (1, 25); 1; 810; AHC 29129[ab]	NR
Lecithasteridae	*Aponurus laguncula*	Stomach	NR	16 (4, 25); 2 (1–3); 500–520; AHC 29130 & 29131[ab]
Lepocreadidae	*Opechona kahawai*	Stomach	NR	16 (4, 25); 6 (4–7); 450–510; AHC 29132 & 29133[ab]
Sanguinicolidae	*Paradeontacylix godfreyi*	Heart	NR	4 (1, 25); 1; 760; AHC 28904
	P. sanguinicoloides	Heart	4 (1, 25); 1; 770; AHC 28909	NR
	Paradeontacylix sp.	Heart	NR	4 (1, 25); 1; 760; AHC 28911
Cestoda				
Tentacullariidae	*Nybelinia thyrsites*	Intestine	4 (1, 25); 1; 810; AHC 29134[ab]	NR
Tetraphyllidea	Type 1	Stomach	4 (1, 25); 1; 830; AHC 29135[ab]	NR
	Type 4	Digestive tract	4 (1, 25); 1; 810; AHC 29136[ab]	16 (4, 25); 1 (1); 440–520; AHC 29137–29140[ab]
Acanthocephala				
Rhadinorhynchidae	*Rhadinorhynchus* sp. 1	Intestine	4 (1, 25); 1; 790; AHC 29141	NR
	Rhadinorhynchus sp. 2	Intestine	NR	28 (7, 25); 6 (1–16); 460–590; AHC 29142 & 34177
Nematoda				
Anisakidae	*Anisakis* sp.	Stomach, viscera	NR	16 (4, 25); 7 (2–21); 460–790; AHC 34189[b]
	Contracecum sp.	Stomach	4 (1, 25); 1; 920; AHC 34184[ab]	NR
	Hysterothylacium sp.	Stomach, caeca	40 (10, 25); 2 (1–7); 760–950; AHC 34179–34183[ab]	12 (3, 25); 3 (1–6); 440–790; AHC 34190[ab]
	Pseudoterranova sp.	Intestine	4 (1, 25); 1; 780; AHC 34178[ab]	NR
Spiruridae	*Rhabdochona* sp.	Intestine	NR	4 (1, 25); 1; 510; AHC 34191[ab]

Under each locality prevalence is expressed in percent (%) followed in parentheses by the number of fish infected and the total number of fish examined; intensity is followed by the range in parentheses; host size as fork length range is presented in mm; museum accession numbers for the South Australian Museum (SAMA) are indicated. [a]Denotes new host records; [b]denotes new locality records; [c]denotes microhabitats indicated from previous studies that could not be verified in the present survey; NA not applicable; ND not determined; NR not recovered.

Table 2
Previous *Seriola* host and locality records for metazoan ecto- and endoparasite taxa documented in the present study showing parasite synonyms, host species, host origin (wild or farmed), host location and important references

Parasite taxa	Synonyms	Host species	Origin	Location	References
Ectoparasites					
Monogenea					
Benedenia seriolae	*Epibdella seriolae*	*S. lalandi*	Wild	Australia (NSW)	[52]
				New Zealand	[14]
			Farmed	Australia (SA)	[12]
				New Zealand	[9]
		S. quinqueradiata	Farmed	Japan	[53]
		S. dumerili	Farmed	Japan	[32]
		S. rivoliana	Farmed	Japan	[32]
Paramicrocotyloides reticularis		*S. lalandi*	Wild	Australia (Qld)	[21]
				New Zealand	[9]
Zeuxapta seriolae	*Axine seriolae*	*S. lalandi*	Wild	Australia (Qld)	[20]
	Zeuxapta japonica			New Zealand	[14]
	Zeuxapta zyxivaginata		Farmed	Australia (SA)	[54]
				Japan	Ingo Ernst, unpublished data
		S. hippos	Wild	Australia (NSW)	[55]
		S. dumerili	Wild	Mediterranean, Spain	[7]
			Farmed	Japan	[56]
Crustacea					
Caligus lalandei		*S. lalandi*	Wild	South Africa	[53]
				Chile	[57]
				New Zealand	[58]
				Mexico	[59]
				Korea	[31]
				Japan	[31]
		S. hippos	Wild	New Zealand	[60]
		S. quinqueradiata	Wild	Japan	[31]
Caligus spinosus	*C. aesopus*	*S. lalandi*	Wild	Australia (Qld)	[21]
				New Zealand	[60]
		S. hippos	Wild	New Zealand	[60]
		S. quinqueradiata	Farmed	Japan	[53]
Dissonus hoi		*S. hippos*	Wild	Australia (WA)	[61]
Lernanthropus paenulatus		*S. lalandi*	Wild	Australia (NSW)	[30]
				New Zealand	Present study
				Woods Hole, USA	[22]
Parabrachiella seriolae		*S. quinqueradiata*	Farmed	Japan	[62]
Parabrachiella sp.		*S. lalandi*	Wild	Australia (Qld)	[21]
				New Zealand	[14]
Endoparasites					
Myxozoa					
Ceratomyxa seriolae		*S. quinqueradiata*	Farmed	Japan	[39]
Ceratomyxa buri		*S. quinqueradiata*	Farmed	Japan	[39]
Trematoda					
Bucephalus gorgon	*Gasterostomum gorgon*	*S. lalandi*	Wild	USA	[63]
	Nannoenterum gorgon	*S. dumerili*	Wild	Mediterranean, Corsica	[64]
	Bucephalus introversus				
Rhipidocotyle longicirrus	*Bucephalopsis longicirrus*	*S. dumerili*	Wild	France	[65]
	Bucephaloides longicirrus				
	Bucephalopsis arcuatus				
	Bucephaloides arcuatus				
Stephanostomum petimba		*S. hippos*	Wild	Australia (WA)	[66]
		S. dumerili	Wild	Corsica, France	[67]
Tormopsolus orientalis	*Tormopsolus medius*	*S. lalandi*	Wild	Australia (Qld)	(see [68])
				British West Indies	[69]
				Japan	[79]
		S. dumerili	Wild	Curaçao	[71]
				Mediterranean, Corsica	[70]
				Mediterranean, Spain	[70]
				Hawaii	[63]
				Japan	[63]
		S. quinqueradiata	Wild	Japan	(see[70])

Table 2 (*continued*)

Parasite taxa	Synonyms	Host species	Origin	Location	References
Endoparasites					
Trematoda	*Ectenurus hamati*	*S. lalandi*	Wild	Japan	[70]
		S. quinqueradiata	Wild	Japan	[70]
Parahemiurus merus		*S. dumerili*	Wild	Jamaica	[72]
		S. quinqueradiata	Wild	Japan	[72]
Paradeontacylix godfreyi		*S. lalandi*	Wild	Australia (SA)	[41]
P. sanguinicoloides		*S. lalandi*	Wild	Atlantic coast, USA	[73]
		S. hippos	Wild	Australia (SA)	[41]
Paradeontacylix sp.		*S. hippos*	Wild	Australia (SA)	[41]
		S. dumerili	Wild	Mediterranean, Spain	[23]
Acanthocephala					
Gorgorhynchoides elongatus		*S. dumerili*	Wild	Atlantic Ocean	[74]
		S. rivoliana	Wild	Atlantic Ocean	
Gorgorhynchoides lintoni		*S. lalandi*	Wild	Atlantic Ocean	[75]
Rhadinorhynchus seriolae		*S. quinqueradiata*	Wild	Japan	[76]
Nematoda					
Anisakis sp.		*S. lalandi*	Wild	Australia (SA)	SAMA AHC 1186 and 1187[a]
				New Zealand	[15]
Contracecum sp.		*S. lalandi*	Wild	New Zealand	[60]
Hysterothylacium sp.		*S. lalandi*	Wild	New Zealand	[77]

[a]Unpublished data, specimens collected by T. H. Johnston, held in the South Australian Museum Helminth Collection.
Where parasites have been previously recorded from Australia, the state is indicated as follows: Queensland (Qld), New South Wales (NSW), South Australia (SA) and Western Australia (WA).

phylum in the Metazoa following Lom and Dyková [17]. Table 1 lists the species found, associated microhabitat and prevalence and intensity. We have also indicated whether the parasite is a new host or locality record. We considered a new locality record if the parasite had not been previously recorded from the Australian state of sampling. Where parasites were found in the stomach, caeca and intestine, their microhabitat is noted as the digestive tract. *Caligus amblygenitalis* Pillai, *C. lalandei* Barnard, *Caligus* sp., *Dissonus hoi* and *Naricolax chrysophryenus* (Roubal, Armitage and Rohde) Lin and Ho were collected from the filtered freshwater bath and prohibited accurate identification of their microhabitat. However, *C. amblygenitalis* has been recorded previously from the body surface, oral cavity and gill cavity of its hosts [18], *C. lalandei* has been recorded previously from the body surface of *S. lalandi* (see [14]) and *N. chrysophryenus* is known to infect the nasal cavity of snapper, *Pagrus auratus* [19].

Several parasite taxa recovered from *S. lalandi* could not be identified to species (Table 1). This is the result of several factors including the limited number of specimens recovered, the discovery of only an immature stage, and lack of useful taxonomic information available for some groups (e.g. Didymozoidae). It is also likely that we have collected previously undescribed species. In particular, the hemiurids, lecithasterids and lepocreadids were difficult to identify, as

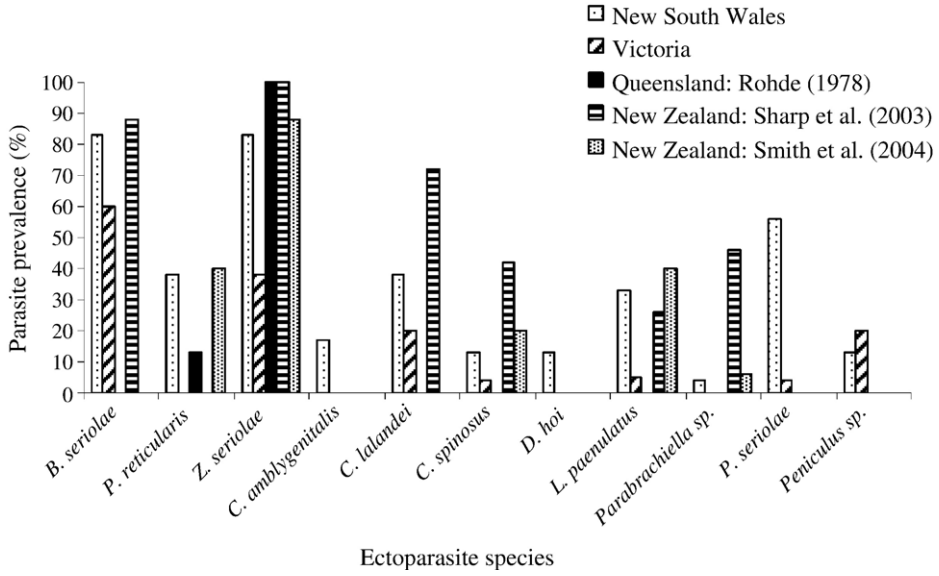

Fig. 1. *Seriola lalandi* ectoparasite prevalence in New South Wales, Victoria and Queensland, Australia, and New Zealand.

most specimens recovered were immature. We have proposed identifications for some of these species, but it is impossible to be certain due to their immaturity. Tetraphyllideans were identified as Type 1 and Type 4 following the descriptions by Chambers, Cribb and Jones [20]. We noted evidence of granuloma formation associated with larval nematodes in wild *S. lalandi* from Victoria and found one empty cyst that resembled a cestode blastocyst in the viscera of *S. lalandi* in Victoria. There was no evidence of metazoan parasite infection in histological sections of internal organs. Representatives of all metazoan parasite species collected in this study are lodged at SAMA (Table 1). Previous *Seriola* host and locality records for parasite species recovered here are shown in Table 2.

Trematode specimens lodged by Johnston in 1945 are poor, but after mounting by us were identified as *Bucephalus gorgon* (Linton) Eckmann and *Rhipidocotyle longicirrus* (Nagaty) Bartoli and Bray (Table 2). This mounted material is available from SAMA with the following accession numbers (*B. gorgon* AHC 29117; *R. longicirrus* AHC 29120. Using material provided by Dr Peter Smith, NIWA, Private Bag 14 901, Wellington, New Zealand, we confirmed the identification of parasite species made by Smith et al. [15] from *S. lalandi* in New Zealand. We agree with identifications of *C. spinosus* (reported as *C. aesopus*). We stained and mounted specimens of *Paramicrocotyloides* sp., which matched the description of *P. reticularis* Rohde following Rohde [21]. *Lernanthropus* sp. matched the description of *Lernanthropus paenulatus* Wilson following Wilson [22]. We were unable to provide further insight into an undetermined species of acanthocephalan, which Smith et al. [15] suspected may be a *Longicollum* sp. Prevalence of *S. lalandi* ectoparasites from New Zealand and Australia are shown in Fig. 1.

4. Discussion

A diverse community of metazoan parasites infect wild *S. lalandi* in southern and eastern Australia. This study documents 43 metazoan parasite taxa (Table 1) including 26 new host records. Only 8 of the species we detected have previously been reported from *S. lalandi* in Australian waters (Table 2). Identifying 43 parasite species is most likely a consequence of parasitological effort, and increases the number of documented metazoan parasite taxa infecting wild *S. lalandi* in Australia to 50. This is the second parasite survey of its kind on a wild carangid species following that of Grau et al. [23] who documented the metazoan parasite community of wild amberjack, *Seriola dumerili* (Risso) from the western Mediterranean Sea.

4.1. Parasites not detected

Despite a thorough sampling method involving fresh and histologically sectioned material, we found no evidence of seven parasite species documented previously from wild *S. lalandi* in Australia. Six of these species have been reported from fish captured further north along the east coast in Queensland, including *Kudoa* sp. (see [5]), *Unicapsula seriolae* [6], *Tetrarhynchus* sp. (see [24]), *Dinurus longisinus* Looss, *Ectenurus trachuri* (Yamaguti) Yamaguti (see [25]) and *Lecithaster stellatus* Looss (see [26]), while *Australorhynchus tetramorphacanthus* [27], was described from *S. lalandi* from the Great Australian Bight and the Tasman Sea.

Despite *Kudoa* sp. and *U. seriolae* exhibiting high prevalences in *S. lalandi* in Queensland [24], the softened flesh condition associated with these parasite infections is relatively rare in *S. lalandi* in NSW [28]. Similarly, we did not detect any sign of myxozoan infection in the muscle of *S. lalandi* from NSW or Victoria. *Tetrarhynchus* sp. was also recorded from *S. lalandi* in Queensland, and while it was not found in the present study, one empty cyst, suspected of being a cestode blastocyst was found in the viscera of a *S. lalandi* from Victoria. Blastocysts of similar colour and size containing a larval cestode, *Callitetrarhynchus gracilis* Rudolphi, occur in viscera of wild *S. lalandi* caught in South Australia (KSH, unpublished data).

One possible explanation for us not detecting the previously documented hemiurids *D. longisinus, E. trachuri* and *L. stellatus*, from *S. lalandi*, is the more southerly location of our survey. Hemiurid infections are acquired when predatory fish eat infected intermediate hosts and these parasite species may only infect intermediate fish host species that are found in warmer, tropical waters. To our knowledge, the acanthocephalan *A. tetramorphacanthus* has not been reported from *S. lalandi* since its original description.

4.2. Ectoparasite infection patterns

Monogeneans are important pathogens of farmed *Seriola* sp. and have been associated with considerable losses in aquaculture in Australia [10,29], New Zealand [9] and Japan [8]. We detected *B. seriolae* (Yamaguti) Meserve on the body surface and *P. reticularis* Rohde and *Zeuxapta seriolae* (Meserve) Price on the gills (Table 1). *B. seriolae* and *Z. seriolae* have been responsible for considerable losses of farmed *Seriola* sp. in Japan (Table 2), and infect *S. lalandi* farmed in sea cages in Spencer Gulf, South Australia (Chambers and Ernst, 2005).

Prevalence of *B. seriolae* in NSW (83%) was similar to New Zealand (88%) [14], and slightly lower in Victoria (60%) (Table 1, Fig. 1). The intensity of *B. seriolae* was similar in NSW and Victoria (8 and 9 parasites, respectively) but higher in New Zealand (29) [14]. There are no previous published records of prevalence and intensity for *B. seriolae* of wild *S. lalandi* in Australia.

P. reticularis was recovered from wild *S. lalandi* at Sir John Young Banks, NSW and Lord Howe Island, but not in Victoria (Table 1). This species is not known to infect farmed or wild *S. lalandi* in South Australia [9]. In New Zealand, *P. reticularis* is known to infect *S. lalandi* brood-stock [9], but to date has not been recorded from farmed *S. lalandi*. We found that *P. reticularis* was more prevalent in NSW (38%) compared to Rohde (1978), who reported 13% prevalence in Queensland (Fig. 1). In NSW, *P. reticularis* infected at a lower intensity than *Z. seriolae*, with an intensity of 2 individuals. Our results follow Smith et al. (2004) who found that the prevalence of *P. reticularis* (as *Paramicrocotyloides* sp.) ranged between

27–40% across three sites in New Zealand with an intensity of 2 individuals.

Rohde (1978) and Sharp et al. [14] found *Z. seriolae* on all wild *S. lalandi* sampled in Queensland and New Zealand respectively. While we did not detect *Z. seriolae* on all individuals, prevalence was high in NSW (83%) compared to Victoria (38%). Our results from NSW are consistent with Rohde et al. [30] and Smith et al. [15] who found *Z. seriolae* prevalence was 95% in NSW and ranged between 83–88% across three sites in New Zealand, respectively (Fig. 1). Smith et al. [15] suggested that Sharp et al. [14] may have misidentified *P. reticularis* as *Z. seriolae*, which would lead to the prior study reporting a higher prevalence of *Z. seriolae*. Intensities of *Z. seriolae* in NSW (32; Table 1) and New Zealand (44) [14] were higher compared to Victoria (6; Table 1). Smith et al. (2004) detected the same intensity of *Z. seriolae* in New Zealand (6) to that observed in Victoria.

Ten parasitic copepod species were detected, with all 10 species found in NSW and six species detected in Victoria (Table 1). Four species are caligids, including *Caligus amblygenitalis* Pillai, *C. lalandei* Barnard, *C. spinosus* Yamaguti and an undetermined *Caligus* species. *C. lalandei* is well known from farmed *Seriola* species in Japan and Korea (Table 2) but has not been associated with disease problems [31]. In contrast, *C. spinosus* has been associated with gill disease in farmed *S. quinqueradiata* (Temminck and Schlegel) in Japan [32]. We found lower parasite prevalence for *C. lalandei* (20% Victoria, 38% NSW) in Australia compared to wild *S. lalandi* sampled across three sites in New Zealand (72%) (Fig. 1) [14]. *C. spinosus* prevalence was also lower in Australia (4% Victoria, 13% NSW) compared to New Zealand studies (42% and 20%) (Fig. 1) ([14,15], respectively). *C. amblygenitalis* has not been documented previously from carangid hosts.

Parasites that infect the nasal cavity, *Naricolax chrysophryenus* (Roubal, Armitage and Rohde, 1983) and *D. hoi* Tang and Kalman 2005, were rare and were only found on *S. lalandi* in NSW (Table 1). *N. chrysophryenus* has been previously reported from snapper, *P. auratus*, and has not been reported previously from carangid hosts, while *D. hoi* was recently described from *S. hippos* Günther in Western Australia (Table 2). There are no previous records of *Peniculus* sp. from *Seriola* sp., although they are known from other pelagic fishes in Australia [33]. *L. paenulatus* Wilson from NSW exhibited similar prevalence (33%) to those determined in New Zealand (26% and 40%) ([14,15], respectively) but was only detected on one *S. lalandi* sampled in Victoria. *Parabrachiella seriolae* Yamaguti and Yamasu, which has not been previously documented from New Zealand, was the most prevalent copepod in NSW (58%) but was only observed on one host specimen in Victoria (Table 1). Prevalence of *Parabrachiella* sp. varied considerably between two New Zealand studies (46% and 6%) ([14,15], respectively). We found low prevalence of *Parabrachiella* sp. in NSW (4%), which is consistent with Smith et al. [15] who found 6% of fish were infected. However, we recorded higher parasite intensity in NSW (15) compared to New Zealand (2).

Ectoparasitic copepods can have a considerable impact on wild and farmed fish [34]. In the northern hemisphere, fish farms have been implicated in the spread of salmon lice to wild fish and the subsequent decline of wild salmon populations [35,36], while others argue that over-fishing, habitat loss and climate change are primarily responsible for stock declines [37]. In view of the intense debate surrounding the issue of parasite transfer between farmed and wild fish, it is important that the levels of parasitic infection are determined in the absence of farming activities. Here, we have provided sound baseline data of the prevalence and intensity of ectoparasitic crustaceans on wild fish hosts that will be useful for comparative purposes in the event of future aquaculture development of *S. lalandi* in NSW and Victoria.

Clearly, the prevalence and intensity of *S. lalandi* ectoparasites is variable between locations studied. The ectoparasites sampled from NSW exhibited patterns of infection similar to previous findings in New Zealand, while prevalence and intensity were generally lower in Victorian hosts. Ectoparasite patterns of infection may be driven by numerous factors including season, host size, parasite life cycle, host-specificity and infection dynamics. Tingley, Ives and Russell [38] found evidence of seasonal variation for the ectoparasitic copepods *Lepeoptheirus salmonis* and *Caligus elongatus* on *Salmo trutta*. They suggest that differences in parasite species' developmental rates and host-specificity may also be driving factors in patterns of infection. Parasite establishment may also be directly related to variations in individual host immunity.

4.3. Endoparasite infection patterns

Of the 31 endoparasite species detected in this survey, 26 species were recovered from various regions of the digestive tract of *S. lalandi* (Table 1). Parasites of the digestive tract normally infect via the oral route. For wild piscivorous fish like *S. lalandi*, prevalence and intensity of intestinal parasites may be driven by seasonality of available prey species, which serve as intermediate hosts. In aquaculture, these parasite species may be effectively controlled by feeding fish manufactured (i.e. pellet) diets, although they cannot be completely excluded because farmed fish may eat wild fish that could stray into sea cages.

Myxozoans *Ceratomyxa seriolae* Yokoyama and Fukuda and *C. buri* Yokoyama and Fukuda were recovered from the gall bladder (Table 1). These species are known from the gall bladder of farmed *S. quinqueradiata* in Japan (Table 2) [39]. There has been no apparent associated illness or mortality with myxozoan infections of the gall bladder in *Seriola* species in aquaculture [40]. *Myxobolus spirosulcatus* Maeno, Sorimachi, Ogawa and Kearn was described from *S. quinqueradiata* in Japan, but was not recovered from *S. lalandi* in this study. Grau et al. [23] also recovered *Myxobolus* sp. from the brain of wild *S. dumerili*, however we found no evidence of myxozoan infection in fresh preparations or histological sections of the brain of *S. lalandi*.

We recovered 18 trematode species representing acanthocolpids, bucephalids, didymozoids, hemiurids, lecithasterids,

lepocreadids and sanguinicolids (Table 1). Grau et al. [23] recovered 10 trematode species from wild *S. dumerili* representing all of these families, except for Lepocreadidae. The acanthocolpids *Stephanostomum petimba* Yamaguti and *Tormopsolus orientalis* Yamaguti were prevalent in NSW, while only *T. orientalis* was found in Victoria (Table 1). These acanthocolpid species are well known from *Seriola* spp. around the world (Table 2). Of the bucephalids, *Bucephalus gorgon* (Linton) Eckmann was the most commonly encountered trematode in NSW and Victoria (Table 1) and was also identified from previously unidentified trematode collections made by T.H. Johnston in South Australia in 1945. Identifying *Rhipidocotyle longicirrus* (Nagaty) Bartoli and Bray from NSW and from T.H. Johnston's unpublished trematode collections in South Australia, provides a new host and locality record for the species (Table 1). *Telorhynchus* sp. are well-known parasites of Australian salmon, *Arripis trutta* (Forster). We found an undetermined *Telorhynchus* sp. in the digestive tract of *S. lalandi* from Victoria (Table 1). *S. lalandi* from Victoria hosted the lepocreadid species *Opechona kahawai* Bray and Cribb and the lecithasterid species *Aponurus laguncula* Looss, along with the majority of hemiurid species, including *Erilepturus hamati* (Yamaguti) Manter, *Elytrophallus* sp., *Elytrophalloides oatesi* Leiper and Atkinson, *Parahemiurus merus* Linton and *Hirudinella* sp. *Lecithocladium* sp. and *Plerurus digitatus* Looss infected *S. lalandi* in NSW. No single species of hemiurid was recovered from NSW and Victoria (Table 1).

Didymozoid trematodes have been documented previously from wild and farmed *Seriola* species. We detected an undetermined species of didymozoid in the digestive tracts and viscera of *S. lalandi* from NSW and Vic, respectively. Grau *et al.* [23] found two species of didymozoid infecting *S. dumerili* including *Nematobothrium scombri* (Taschenberg) Ishi in the gills, abdominal cavity and liver and *Wedlia bipartite* (Wedl) Cobbold, in the gills.

Three species of blood fluke, *Paradeontacylix godfreyi* Hutson and Whittington, *P. sanguinicoloides* McIntosh and *Paradeontacylix* sp., infected *S. lalandi* at low intensities (Table 1). Detecting *Paradeontacylix* sp. in these regions is an important finding with regard to potential development of aquaculture in Australia [41]. Species of *Paradeontacylix* have been associated with mass mortalities of farmed *S. dumerili* in the Spanish Mediterranean [42] and Japan [43]. They are also of concern to *S. lalandi* farming in New Zealand where *Paradeontacylix*-like blood flukes have been detected in histological sections of the heart, brain and internal organs and have been associated with low level mortalities [9]. It has been suggested that blood fluke infestation in farmed *S. quinqueradiata* in Japan may also promote mortality of fish with bacterial infections [44].

Cestode species *Nybelinia thyrsites* Korotaeva and tetraphyllidean metacestodes Types 1 and 4 following Chambers et al. [20] were recovered from the digestive tract from *S. lalandi* in NSW (Table 1). Only tetraphyllidean Type 4 was recovered from Victoria. To our knowledge there are no previous records of the trypanorhynch *N. thyrsites* and larval tetraphyllidean metacestodes Type 1 and Type 4 from carangid hosts.

Acanthocephalans in *Rhadinorhynchus* were rare in NSW (4%) compared to Victoria (28%) (Table 1). *Rhadinorhynchus* sp. 1 from NSW is similar to *R. japonicus* Fujita known from *Scomber japonicus* Houttuyn in Japan. *Rhadinorhynchus* sp. 2 is similar to the description of *R. seriolae* (Yamaguti) Golvan and *R. trachuri* Harada which have been recorded previously from Japan from *S. quinqueradiata* [45] and *Trachurus japonicus* Temminck and Schlegel, respectively. Further taxonomic discrimination of *Rhadinorhynchus* sp. from *S. lalandi* is warranted, but was beyond the scope of this study. Interestingly, *Australorhynchus tetramorphacanthus* Lebedev in the same acanthocephalan family, Rhadinorhynchidae, is known from *S. lalandi* in the Great Australian Bight and the Tasman Sea [27] while a suspected *Longicollum* sp. (Pomphorhynchidae) was recovered from *S. lalandi* in New Zealand [15].

Apart from some specimens of *Anisakis* sp. that were encysted in the viscera, all nematodes including *Anisakis* sp., *Contracecum* sp., *Hysterothylacium* sp., *Pseudoterranova* sp. and *Rhabdochona* sp. occupied various regions of the digestive tract (Table 1). *Hysterothylacium* was the most dominant nematode in NSW while *Hysterothylacium* and *Anisakis* were common in Victoria (Table 1). *Anisakis, Contracecum* and *Hysterothylacium*, have been reported previously from *S. lalandi* in New Zealand (Table 2).

4.4. Parasite assemblages from different regions

S. lalandi sampled in NSW hosted more ectoparasitic species than those sampled in Victoria. The differences observed in ectoparasitic fauna may be a consequence of a combination of factors including host range, size and mobility as well as parasite seasonality, range and prevalence. For example, tagging studies in Australia suggest that *S. lalandi* <60 cm are generally sedentary (recaptured within 50 km of where they were tagged), whereas fish between 60 and 90 cm may move distances >50 km [46]. *S. lalandi* in Victoria were a smaller size class (average 54 cm FL), while fish from NSW were typically larger (average 83 cm FL) which suggests that larger, mobile fish sampled from NSW, which were parasitised by a greater number of ectoparasitic species (Table 1), may have had more encounters with infective parasite larval stages. Ectoparasite species that were not recorded in Victoria were detected at very low prevalence and intensities in NSW (Table 1). It is possible that these species occur on Victorian *S. lalandi*, perhaps in such a low prevalence that they were undetected here, or perhaps they only occur on larger fish. Alternatively, they may not occur in this location.

Patterns of endoparasitism were variable between locations. Differences in the parasite fauna detected in the digestive tract of *S. lalandi* from NSW and Victoria could be attributed to differing host diet. Fish from NSW may have been feeding on pelagic species, as they were captured in deep water ~14 km off the coast, compared to Victorian fish that were captured in shallow water close to the coastline. These differences, therefore, may relate to differences in the consumption of intermediate host species. In addition, differences in the

presence or absence of parasite species could be because *S. lalandi* were sampled during different seasons at the two locations. Although sampling in the same season is desirable, the unreliable presence and temperamental feeding behaviour of these wild fish made regular collection at both locations impossible.

S. lalandi sampled from the east coast of Australia shared a similar ectoparasite fauna to wild *S. lalandi* in New Zealand. Fish from NSW hosted all the currently known ectoparasites of *S. lalandi* in New Zealand including *Benedenia seriolae*, *Zeuxapta seriolae*, *Paramicrocotyloides reticularis*, *C. spinosus*, *C. lalandei*, *L. paenulatus* and *Parabrachiella* sp. (see [14,15]). This is not surprising considering that Nugroho et al. [47] found there was no significant genetic divergence between fish sampled from the east coast of Australia and New Zealand. Furthermore, studies on the movement of *S. lalandi* using conventional tags showed that *S. lalandi* from Australia's eastern coast can migrate to Lord Howe Island and New Zealand [46]. *S. lalandi* from NSW hosted additional external parasites (*C. amblygenitalis*, *Caligus* sp., *D. hoi*, *Naricolax* sp. and *P. seriolae*) that have not previously been detected in New Zealand, but this may be because the microhabitats of some of these parasites (e.g. oral cavity, nasal cavity, buccal folds) may not have been examined in New Zealand studies.

4.5. Potential stock discriminators

Parasites have been used on many occasions to determine the probable degree of movement of individual fish e.g. Mackenzie [48] and thus provide clues about population homogeneity and the degree of mixing of different populations [49]. Mackenzie [48] suggests that comparison of entire parasite communities may be an efficient approach for distinguishing populations of large pelagic fish species. More recently, parasite genotypes have been used to identify source populations of migratory fish [50]. It is possible that differences observed in parasite fauna between NSW and Victoria could be because there is limited interaction between *S. lalandi* populations from these two areas. Indeed, *S. lalandi* movement from the east coast into southern coastal waters is rare [46]. A single tag return, however, shows that *S. lalandi* is capable of moving from southern NSW to Port Phillip Bay in Victoria (Smith et al. 1991). In addition, an individual *S. lalandi* tagged in NSW and recaptured in WA suggests that long-range movements from the east coast across the south coast of Australia are not inconceivable (Woodrick, K., NSW Department of Primary Industries; unpublished data).

Parasites may be used as biological tags for stock discrimination of fish populations. The ideal parasite tag will meet key selection criteria (according to [51]). In brief, it is preferred that the parasite has: (1) a long life span, (2) a direct life cycle, (3) a constant level of infection, (4) can be easily detected and identified and (5) is not considered to be a serious pathogen. We identified the monogenean *P. reticularis* and the copepod *P. seriolae* as the two most likely parasite tag candidates for population discrimination of *S. lalandi*. Both parasite species have direct life cycles, can be easily detected and identified and are not considered to be serious pathogens. *P. reticularis* has a reliable prevalence in Queensland (13%, Rohde 1978), NSW (38%, present study) and New Zealand (27–40%, Smith et al. 2004). *P. seriolae* may also be a suitable candidate as it had a reliable presence on fish in NSW (56%) and cannot be lost during handling as it firmly anchors itself in tissue under the buccal folds of its host. These parasites could be useful in determining whether there is exchange between *S. lalandi* populations from the east and south coast of Australia.

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