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Risk assessment for metazoan parasites of yellowtail kingfish *Seriola lalandi* (Perciformes: Carangidae) in South Australian sea-cage aquaculture

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Abstract

Metazoan parasites can threaten the sustainability and profitability of finfish sea-cage aquaculture. It is critical, therefore, to identify local parasite species and determine which are potentially harmful. Although several studies have documented parasite species on wild and farmed fish from aquaculture sites, few have used qualitative risk analyses to determine the likelihood and consequence of parasite transfer from locally found wild fish to farmed fish. Indeed, most risk assessments for marine fish farming identify hazards from diseases reported in other, often distant, countries. The usefulness of this approach is limited if an endemic parasite with potential to cause serious disease is undetected before the establishment of aquaculture. This study performs a qualitative risk assessment for 57 metazoan parasite species found to infect wild yellowtail kingfish (*Seriola lalandi*) and Samson fish (*S. hippos*) in southern Australia to determine real risks to local sea-cage aquaculture of *S. lalandi* in South Australia and for industry expansion elswhere. Risk was estimated by considering the likelihood and consequence of parasite establishment and proliferation in *S. lalandi* sea-cage farming. *Benedenia seriolae* and *Zeuxapta seriolae* (Monogenea) were considered extremely likely to establish and proliferate. *B. seriolae* is currently recorded as the highest potential negative consequence for cost-effective sea-cage farming of *S. lalandi* in Australia, should the industry expand elsewhere. However, *B. seriolae* infections can be managed by bathing fish in either hydrogen peroxide or fresh water. Absence of potential treatment methods for *Paradeontacylix* spp. (Digenea), *Kudoa* sp. and *Unicapsula seriolae* (Myxozoa) suggests that these species may present the highest negative consequences for *S. lalandi* aquaculture in Australia. However, the presence of myxozoan infection in the flesh of wild South Australian *Seriola* spp. needs confirmation to determine whether these parasite species present an immediate risk to farmed *S. lalandi* in South Australia.

Keywords: Risk assessment; Parasite assemblage; Parasite management; Aquaculture; *Seriola lalandi*; *Seriola hippos*

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1. Introduction

Wild fish are believed to be the primary reservoirs of parasite infection for fish farmed in sea-cages (e.g. McVicar, 1997; Bouloux et al., 1998). Cultured fish may develop higher parasite burdens than those present in wild fish populations because conditions in sea-cage aquaculture may enhance parasite transmission (e.g. Ogawa, 1996). Parasites with single host life-cycles are likely to establish and proliferate in aquaculture because they may reproduce rapidly and can directly reinfect their hosts. Indeed, parasites that are normally considered benign, or for which pathology is unknown or unrecorded in wild host populations, are often associated with diseases of significant economic consequence in aquaculture (Bouloux et al., 1998).

In Australia, yellowtail kingfish (*Seriola lalandi*) fingerlings are grown from fertilised eggs in land-based hatcheries where, through standard biosecurity practices, fish are isolated from infection by metazoan parasites. When fingerlings are moved into sea-cages, wild marine fish species may act as an initial source of parasites for farmed fish. The natural occurrence of *S. lalandi* and *S. hippos* (Samson fish) near locations where *S. lalandi* are farmed in South Australia, provides an opportunity for transfer of parasites from wild to farmed populations. Presently, only two parasite species require management in the South Australian *S. lalandi* industry, the monogeneans *Benedenia seriolae* and *Zeuxapta seriolae*. However, recent research on the parasite assemblages of wild Australian *S. lalandi* indicates that up to 40 other metazoan parasite species can infect wild fish in southern and eastern Australian waters and *S. hippos* is known to share seven of these species (see Hutson et al., 2007). Despite this, the potential risks of metazoan parasite fauna for sea-cage aquaculture of *S. lalandi* in Australia are largely unknown.

There is potential for further development of sea-cage aquaculture of *S. lalandi* throughout Australia. Research is required to identify sources of parasites and to determine which are potentially harmful species. Undeniably, effective control of parasites in sea-cage farms can only be achieved through reliable parasite identification and assessment of the risks they present. According to the Standards Australia/Standards New Zealand (2004) for risk management, risk is 'the chance of something happening that will have an impact on objectives'. For the aquaculture industry, risk generally applies to the potential impact on long-term sustainability (Fletcher et al., 2004). Therefore, a risk assessment that identifies the risk associated with parasite species that may decrease profitability through mortality, morbidity and reduced marketability of stocks is needed.

The aims of this study are: a) to document the parasites of wild and farmed *Seriola* spp. in South Australian waters and b) to assess the risk to sustainability of *S. lalandi* farming posed by documented parasites. This paper specifically considers metazoan parasites recorded from wild and farmed *Seriola* spp. surveyed during this study and from scientific literature. Our risk assessment identifies: 1) the most likely parasite species to establish and proliferate in South Australian *S. lalandi* sea-cage aquaculture, 2) parasite species with potentially negative consequences for *S. lalandi* aquaculture and 3) parasite species which may be difficult to manage, i.e. parasite species of immediate priority for research into potential management strategies.

2. Materials and methods

2.1. Fish and parasite collection

Wild *S. lalandi* ($n=62$) were caught by rod and reel in Spencer Gulf near Port Augusta (32 ° 42′04″S, 137 °46′17″E), Fitzgerald Bay (32 ° 24′14″S, 137 °19′16″E), Arno Bay (33 °55′21″S, 136 °36′14″E) and Boston Bay (34 °44′3″S, 135 °55′46″E) and offshore at Greenly Island (34 °38′29″S, 134 °47′28″E) and Kangaroo Island (35 °34′48″S, 137 °25′35″E), South Australia between May 2003 and May 2005 (Fig. 1). Wild *S. hippos* ($n=6$) were caught at Greenly Island (34 °38′29″S, 134 °47′28″E) and Rocky Island (34 °48′23″S, 134 °42′40″E), South Australia in April 2004 and April 2005 (Fig. 1). Wild *Seriola* spp. ranged between 320 and 1410 mm fork length (FL). Farmed *S. lalandi* ($n=58$) were captured by rod and reel from inside sea-cages in Spencer Gulf, South Australia at Fitzgerald Bay ($n=14$), Arno Bay ($n=26$) and Boston Bay ($n=18$) between May 2003 and May 2005 (Fig. 1). Farmed fish ranged between 282 and 652 mm FL. Methodology for parasite sampling was similar to that described previously (Hutson et al., 2007). Representatives of parasite species are lodged in the South Australian Museum (SAMA), North Terrace, Adelaide, South Australia 5000, Australia. We used FreeCalc (Ausvet Animal Health Services, 2002) to determine the likelihood of not detecting a parasite species in our samples of wild and farmed fish. Assumptions were: 1) if a fish was infected the parasite would have been detected and 2) that fish were sampled from a large population size ($n=999{,}999$).

2.2. Risk assessment

Several risk analyses provide frameworks to identify hazards and quantify the risks posed by metazoan parasites in aquaculture (Diggles, 2003; Fletcher et al.,

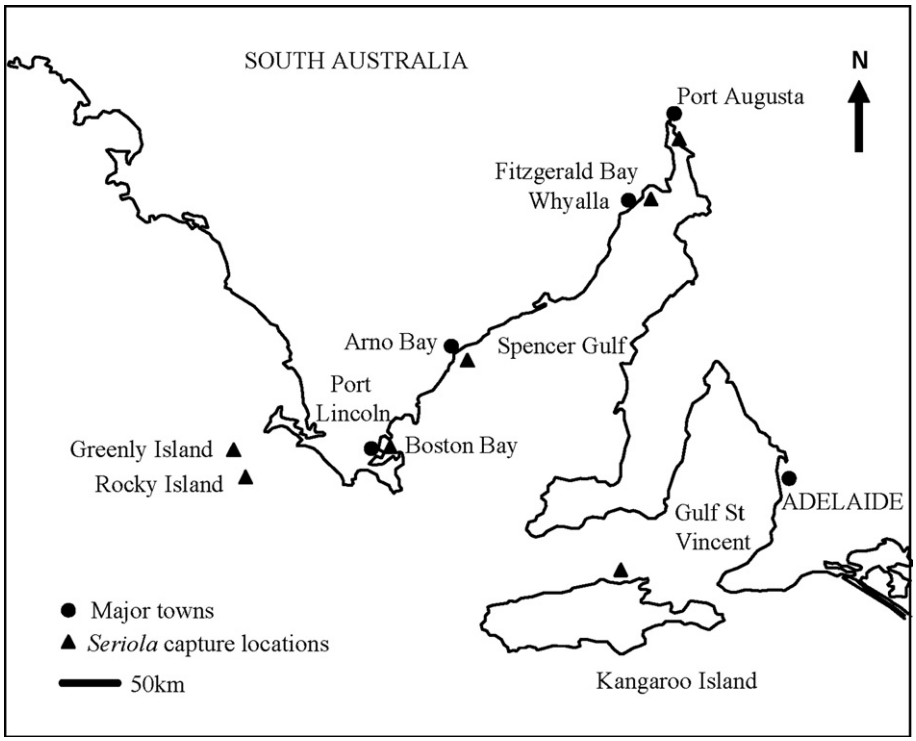

Fig. 1. Wild and farmed *Seriola* capture locations in South Australia, Australia.

2004; Nowak, 2004; Murray and Peeler, 2005). We devised a qualitative five-factor assessment to determine the likelihood of parasite establishment in farmed fish by combining current knowledge on 1) the potential exposure of farmed hosts to parasites on wild hosts and 2) the biological pathway necessary for parasite species to infect the farmed fish species. We also developed a semi-quantitative framework to assess the potential negative consequence of establishment and proliferation of parasite species. This risk assessment estimated two parameters, likelihood and consequence, to be considered independently. Consequence was reviewed in light of possible treatment measures and is herein referred to as 'ability to treat'. Risk was estimated for each parasite species identified from this survey and from previously published records in the scientific literature.

2.2.1. Likelihood

The likelihood of parasite establishment and proliferation in *S. lalandi* sea-cage farming was estimated. This included: 1) an estimate of exposure of farmed fish to wild infected *S. lalandi* and *S. hippos* considering information currently available on host species range and parasite species range and 2) information on the biological pathways necessary for the parasite species to infect the farmed fish species. Parasite host-specificity allows us to predict which species of naturally occurring fish may act as vectors or infection reservoirs for farmed fish. For the purposes of this study, we examined two wild *Seriola* species for metazoan parasites. It is important to keep in mind that parasites of farmed fish which exhibit direct life-cycles are likely to originate from natural populations on wild specimens of the same host species or genera, while parasites with complex life-cycles will involve intermediate host species.

Five likelihood criteria were used to estimate farmed fish exposure to the parasite species and five likelihood criteria were used to estimate the likelihood of parasite establishment through the necessary biological pathway. Using a likelihood matrix following the Australian Quarantine and Inspection Service (AQIS, 1999), these two factors were combined to determine the likelihood of parasite establishment and proliferation in *S. lalandi* farming in South Australia. Likelihood definitions ranged from negligible to extreme (based on Fletcher et al., 2004).

2.2.1.1. Estimate of exposure of farmed fish to wild parasitised Seriola species. To estimate exposure, we considered the likelihood of a parasite occurring in areas of *S. lalandi* farming (Table 1). Wild *S. lalandi* and *S. hippos* are migratory species capable of moving long

Table 1
Metazoan parasites of wild and farmed *Seriola* spp. in Australia

Group	Taxon	Microhabitat	Host	Locality	Wild	Farmed	Reference/accession no.
Acanthocephala							
	Australorhynchus tetramorphacanthus	Intestine	*lalandi*	EC, SA	Yes	No	Lebedev (1967)
	Rhadinorhynchus sp. 1	Intestine	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Rhadinorhynchus sp. 2	Intestine	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
Cestoda							
	Callitetrarhynchus gracilis	Body cavity	*lalandi*	SG	Yes	Cyst: W, PL	AHC 29179
	Nybelinia thyrsites	Intestine	*lalandi*	EC	Yes	No	Hutson et al. (2007)
Tetraphyllidea	Type 1	Stomach	*lalandi*	EC, SG	Yes	No	AHC 29161
	Type 4	Digestive tract	*lalandi*	EC, Vic, SG	Yes	PL	AHC 29162–29165
Copepoda							
	Caligus amblygenitalis	Cavities*	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	C. epidemicus	Body surface*	*lalandi*	EC, SG	Yes	No	C6313
	C. lalandei	Body surface*	*lalandi*	EC, Vic	Yes	No	Hutson et al. (2007)
		Body surface	*hippos*	SA	Yes	No	C6314
	C. spinosus	Gill arch	*lalandi*	EC, Vic	Yes	No	Hutson et al. (2007)
	Caligus sp. 1	Not determined	*lalandi*	EC, Vic, SA, SG	Yes	W, AB, PL	C6232 and C6312
		Not determined	*hippos*	SA	Yes	NA	C6315
	Caligus sp. 2	Gill arches	*hippos*	SA	Yes	NA	C6316
	Dissonus hoi	Nasal cavity	*lalandi*	EC, SG	Yes	W	C6317
		Nasal cavity	*hippos*	WC	Yes	No	Tang and Kalman (2005)
	Lepeophtheirus sp.	Not determined	*hippos*	SA	Yes	No	C6318
	Lernanthropus paenulatus	Gills	*lalandi*	EC, Vic, SG	Yes	No	C6239 and C6309
		Gills	*hippos*	SA	Yes	No	C6319
	Naricolax chrysophryenus	Nasal cavity*	*lalandi*	EC, SG	Yes	AB, PL	C6284–C6298
	Parapetalus spinosus	Gills	*hippos*	SA, WC	Yes	NA	C6320
	Parabrachiella seriolae	Buccal folds	*lalandi*	EC, Vic, SG	Yes	No	C6321
		Buccal and fin sulcus	*hippos*	SA	Yes	NA	C6322
	Parabrachiella sp.	Gills	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Peniculus sp.	Body surface	*lalandi*	EC, Vic	Yes	No	Hutson et al. (2007)
Monogenea							
	Benedenia seriolae	Skin	*lalandi*	EC, Vic, SG	Yes	W, AB, PL	AHC 29180
		Skin	*hippos*	SA	Yes	NA	AHC 29181
	Zeuxapta seriolae	Gills	*lalandi*	EC, Vic, SG	Yes	W, AB, PL	AHC 29182
		Gills	*hippos*	EC	Yes	NA	Rohde (1981)
	Paramicrocotyloides reticularis	Gills	*lalandi*	EC	Yes	No	Rohde (1978), Hutson et al. (2007)
Myxozoa							
	Ceratomyxa seriolae	Gall-bladder	*lalandi*	Vic, SG	Yes	W, AB, PL	AHC 34259
	C. buri	Gall-bladder	*lalandi*	Vic, SG	Yes	W, AB, PL	AHC 34260
	Kudoa sp.	Muscle	*lalandi*	EC	Yes	No	Rohde (1976)
	Unicapsula seriolae	Muscle	*lalandi*	EC	Yes	No	Lester (1982)
Nematoda (larva)							
	Anisakis sp.	Stomach, caeca	*lalandi*	SG	Yes	No	AHC 34261
		Stomach	*hippos*	SA	Yes	NA	AHC 34262
	Contracaecum sp.	Caeca	*lalandi*	EC	Yes	No	Hutson et al. (2007)
		Stomach	*hippos*	SA	Yes	NA	AHC 34263
	Hysterothylacium sp.	Stomach, caeca	*lalandi*	EC, SG	Yes	No	AHC 34264
		Stomach	*hippos*	SA	Yes	NA	AHC 34265
	Pseudoterranova sp.	Intestine	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Rhabdochona sp.	Stomach	*lalandi*	Vic	Yes	No	Hutson et al. (2007)

Table 1 (*continued*)

Group	Taxon	Microhabitat	Host	Locality	Wild	Farmed	Reference/accession no.
(adult)	*Hysterothylacium* sp.	Stomach	*lalandi*	SG	Yes	No	AHC34266
Trematoda							
Acanthocolpidae	*Tormopsolus orientalis*	Stomach, intestine	*lalandi*	EC, Vic, SG	Yes	PL	AHC 29143 and 29144
	T. attenuatus	Caeca	*hippos*	SA	Yes	No	AHC 29145
	Stephanostomum petimba	Digestive tract	*lalandi*	EC, SC, SG	Yes	No	AHC 29146
		Caeca	*hippos*	SA	Yes	NA	AHC 29147
Bucephalidae	*Bucephalus gorgon*	Digestive tract	*lalandi*	EC, SC, SG	Yes	W	AHC 29148
		Caeca	*hippos*	SA	Yes	NA	AHC 29149
	Rhipidocotyle longicirrus	Digestive tract	*lalandi*	EC, SG	Yes	PL	AHC 29150 and 29151
	Telorhynchus sp.	Digestive tract	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
Didymozoidae	Undetermined species	Viscera	*lalandi*	EC, Vic	Yes	No	Hutson et al. (2007)
Hemiuridae	*Dinurus longisinus*	Stomach	*lalandi*	EC	Yes	No	Bray et al. (1993a)
	Ectenurus trachuri	Stomach	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Erilepturus hamati	Stomach	*hippos*	SA	Yes	No	AHC 29152
	Elytrophallus sp.	Stomach	*lalandi*	EC, Vic, SG	Yes	No	AHC 29153
		Stomach	*hippos*	SA	Yes	NA	AHC 29154
	Elytrophalloides oatesi	Stomach	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
	E. humerus	Stomach	*lalandi*	SG	Yes	AB	AHC 29155
	Hirudinella sp.	Stomach	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
Lecithasteridae	*Lecithocladium* sp.	Stomach	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Lecithaster stellatus	Stomach	*lalandi*	EC	Yes	No	Bray et al. (1993b)
	Parahemiurus merus	Stomach	*lalandi*	Vic, SG	Yes	PL	AHC 29156–29159
		Stomach	*hippos*	SA	Yes	NA	AHC 29160
Lepocreadidae	*Plerurus digitatus*	Stomach	*lalandi*	EC	Yes	No	Hutson et al. (2007)
	Aponurus laguncula	Stomach	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
	Opechona kahawai	Stomach	*lalandi*	Vic	Yes	No	Hutson et al. (2007)
Sanguinicolidae	*Paradeontacylix godfreyi*	Heart	*lalandi*	SG, Vic	Yes	No	AHC 28904–28908
	P. sanguinicoloides	Heart	*lalandi*	EC	Yes	No	Hutson and Whittington (2006)
		Heart	*hippos*	SA	Yes	No	AHC 28910
	Paradeontacylix sp.	Heart	*lalandi*	Vic	Yes	No	Hutson and Whittington (2006)
		Heart	*hippos*	SA	Yes	No	AHC 28912

Parasites identified in the present study and documented previously from wild and farmed *S. lalandi* and wild *S. hippos* from the east coast of Australia (EC), Victoria (Vic), west coast of Australia (WC), South Australian waters other than Spencer Gulf (SA) and Spencer Gulf, South Australia (SG) are included. It is indicated where a parasite species has been detected on farmed *S. lalandi* in Fitzgerald Bay, Whyalla (W), Arno Bay (AB) or Boston Bay, Port Lincoln (PL). Accession numbers are given for parasites in the Australian Helminth Collection (AHC) and Marine Invertebrate Collection (C) at the South Australian Museum. * Denotes microhabitats indicated from previous studies that were undetermined in this survey; NA not applicable.

distances. Studies on movements of *S. lalandi* using conventional tags show that some fish from the east coast of Australia migrate between Australia and New Zealand (Gillanders et al., 2001). It is not known, however, whether *S. lalandi* migrate from waters of Victoria, New South Wales, Queensland or Western Australia into South Australian waters. *S. lalandi* tagged in NSW have been recaptured in Victoria and Western Australia, suggesting long migrations do occur (Woodrick, K., NSW Department of Primary Industries, unpublished data). For the purposes of this risk assessment, parasite species only documented from the east coast of Australia were considered to present a negligible risk of exposure, while those only from the southern coast (i.e. Victoria), nearer to farming operations in Spencer Gulf, South Australia, were considered to present a low risk of exposure to farmed *S. lalandi*.

Seriola hippos is also a highly mobile species; tagging data show that fish from Perth, Western Australia, can move up to 2400 km along the south coast of Australia into South Australian waters (Rowland, A., Murdoch University, unpublished data). *S. hippos* are not known to enter Spencer Gulf where *S. lalandi* are farmed, but are captured near the gulf entrance. For the purpose of this risk assessment, parasite species of *S. hippos* were also considered to pose a low risk of exposure to farmed *S. lalandi*.

In South Australia, *S. lalandi* is believed to spawn at the top of Spencer Gulf near Port Augusta (Fig. 1), where they are frequently captured (Fowler et al., 2003). Given

Table 2
Consequence of parasite establishment and proliferation in *Seriola lalandi* sea-cage aquaculture

Parasite taxa	Potential mass mortality	Pathology	Marketability	Consumer health	Consequence
Acanthocephala					
Australorhynchus tetramorphacanthus	–	–	–	–	Negligible
Rhadinorhynchus spp.	–	–	–	–	Negligible
Cestoda					
Callitetrarhynchus gracilis	–	–	−*	–	Negligible
Nybelinia thyrsites	–	Unknown	–	–	Negligible
Tetraphyllideans Type 1	–	Unknown	–	–	Negligible
Type 4	–	Unknown	–	–	Negligible
Copepoda					
Caligus amblygenitalis	–	X	–	–	Low
C. epidemicus	–	X	–	–	Low
C. lalandei	–	X	–	–	Low
C. spinosus	–	X	–	–	Low
Caligus sp. 1	–	X	–	–	Low
Caligus sp. 2	–	X	–	–	Low
Dissonus hoi	–	Unknown	–	–	Negligible
Lepeophtheirus sp.	–	X	–	–	Low
Lernanthropus paenulatus	–	X	–	–	Low
Naricolax chrysophryenus	–	Unknown	–	–	Negligible
Parapetalus spinosus	–	Unknown	–	–	Negligible
Peniculus sp.	–	Unknown	–	–	Negligible
Parabrachiella seriolae	–	Unknown	–	–	Negligible
Parabrachiella sp.	–	Unknown	–	–	Negligible
Monogenea					
Benedenia seriolae	X	X	X	–	High
Paramicrocotyloides reticularis	–	X*	–	–	Low
Zeuxapta seriolae	X	X	–	–	Moderate
Myxozoa					
Ceratomyxa seriolae	–	Unknown	–	–	Negligible
C. buri	–	Unknown	–	–	Negligible
Kudoa sp.	–	–	X	–	Low
Unicapsula seriolae	–	–	X	–	Low
Nematoda					
Anisakis sp. (larvae)	–	X	–	–	Low
Contracaecum sp. (larvae)	–	X	–	–	Low
Hysterothylacium sp. (larvae and adult)	–	X	–	–	Low
Pseudoterranova sp. (larvae)	–	X	–	–	Low
Rhabdochona sp. (adult)	–	X	–	–	Low
Trematoda					
Aponurus laguncula	–	Unknown	–	–	Negligible
Bucephalus gorgon	–	Unknown	–	–	Negligible
Dinurus longisinus	–	Unknown	–	–	Negligible
Didymozoid	–	Unknown	–	–	Negligible
Ectenurus trachuri	–	Unknown	–	–	Negligible
Elytrophalloides oatesi	–	Unknown	–	–	Negligible
E. humerus	–	Unknown	–	–	Negligible
Elytrophallus sp.	–	Unknown	–	–	Negligible
Erilepturus hamati	–	Unknown	–	–	Negligible
Hirudinella sp.	–	Unknown	–	–	Negligible
Lecithocladium sp.	–	X	–	–	Low
Lecithaster stellatus	–	Unknown	–	–	Negligible
Opechona kahawai	–	Unknown	–	–	Negligible

Table 2 (*continued*)

Parasite taxa	Potential mass mortality	Pathology	Marketability	Consumer health	Consequence
Trematoda					
Paradeontacylix godfreyi	X	X	–	–	Moderate
P. sanguinicoloides	X	X	–	–	Moderate
Paradeontacylix sp.	X	X	–	–	Moderate
Parahemiurus merus	–	Unknown	–	–	Negligible
Plerurus digitatus	–	Unknown	–	–	Negligible
Rhipidocotyle longicirrus	–	Unknown	–	–	Negligible
Stephanostomum petimba	–	X	–	–	Low
Telorhynchus sp.	–	Unknown	–	–	Negligible
Tormopsolus attenuatus	–	Unknown	–	–	Negligible
T. orientalis	–	Unknown	–	–	Negligible

Parasites are scored for four criteria, (denoted with an X) including: 1) previous mass mortalities in *Seriola* aquaculture, 2) potential parasite pathology, 3) potential negative impact on marketability and 4) potential negative impact on consumer health. *See Discussion for comment.

the long-range movements of large, wild *S. lalandi* (see Gillanders et al., 2001), it is likely fish migrate north into Spencer Gulf and pass *S. lalandi* farms to spawn at the top of the gulf. For the purposes of this risk assessment, parasites found on wild *S. lalandi* in South Australian waters outside Spencer Gulf were considered to present a moderate risk of exposure to farmed kingfish. A high risk was assigned to parasites found to be infecting *S. lalandi* in Spencer Gulf, while an extreme risk was assigned to parasites found on farmed *S. lalandi* in Spencer Gulf.

2.2.1.2. Biological pathway necessary for parasite species to infect farmed fish species. We estimated the likelihood of parasite transfer from wild to farmed fish considering the biological pathway or route of infection. Parasites known only to infect *S. hippos* or other fish species and not *S. lalandi* may be host-specific (i.e. may only infect one host species). These parasites may present minimal risk to *S. lalandi* and were considered to pose a negligible risk of establishment. Parasites with complex, indirect life-cycles that require two or more specific host species for development may be limited in their ability to establish and proliferate in farmed fish because of restricted interactions between required host species, e.g. these parasite species may require an infected intermediate host to be consumed by the definitive host. In a sea-cage, there are limited opportunities for farmed fish to eat infected wild species unless smaller, parasitised fish or crustaceans move into the sea-cage through the netting. Parasites with two or more host species in the life-cycle, that require the definitive host to consume an infected intermediate host, were considered to pose a low risk of establishment and proliferation.

Parasite species that require only two host species to complete their life-cycle are more likely to be present in farmed fish, particularly when intermediate host species are in close proximity to sea-cages (e.g. Aiken et al., 2006). The likelihood of infection would also increase for parasites with a direct infective stage to locate the definitive host (i.e. sanguinicolids and myxozoans). Parasites requiring a two-host life-cycle with direct infection of the definitive host were considered to pose a moderate risk for farmed fish. Parasites with direct life-cycles are usually found in sea-cage aquaculture as they only require a single host species and may be able to reproduce rapidly. These parasites were considered to pose a high risk of establishment. Parasites that have previously established on sea-caged *S. lalandi* in South Australia were considered to pose an extreme risk of establishment and proliferation.

2.2.2. Consequence

Information was gathered from scientific literature on parasites (species or genus, if available) to indicate any potential negative consequence of establishment and proliferation with regard to sustainable aquaculture in Australia. Data was sought that directly related to host pathology, previous parasite records in *Seriola* spp. aquaculture and potential impacts on marketability and consumer health. Using this information, we determined the consequence of parasite establishment and proliferation as adapted from risk criteria by Fletcher et al., 2004.

The consequence of potential parasite establishment and proliferation was reviewed with regard to four risk criteria including: 1) potential to cause mass host mortality, 2) parasite pathology, 3) potential impact on marketability and 4) potential impact on consumer health (Table 2). Parasites were scored for each of these four criteria. Parasites that met all four criteria were assigned an extreme consequence, parasites that met three criteria were assigned a high consequence, parasites that met two criteria were assigned a moderate consequence, parasites

Table 3
Parasite risk analysis for *Seriola lalandi* sea-cage aquaculture in Spencer Gulf, South Australia

Parasite taxa	1) Exposure	2) Pathway	Likelihood	Consequence	Ability to treat
Acanthocephala					
Australorhynchus tetramorphacanthus	Low	Low	Negligible	Negligible	Yes
Rhadinorhynchus sp. 1	Negligible	Low	Negligible	Negligible	Yes
Rhadinorhynchus sp. 2	Low	Low	Negligible	Negligible	Yes
Cestoda*					
Callitetrarhynchus gracilis	Extreme	Low	Low	Low	Yes
Nybelinia thyrsites	Negligible	Low	Negligible	Negligible	Yes
Tetraphyllideans Type 1	High	Low	Low	Negligible	Yes
Type 4	Extreme	Low	Low	Negligible	Yes
Copepoda*					
Caligus amblygenitalis	Negligible	High	Negligible	Low	Yes
C. epidemicus	High	High	High	Low	Yes
C. lalandei	Low	High	Low	Low	Yes
C. spinosus	Low	High	Low	Low	Yes
Caligus sp. 1	Extreme	High	High	Low	Yes
Caligus sp. 2	Low	Negligible	Negligible	Low	Yes
Dissonus hoi	Extreme	High	High	Negligible	Yes
Lepeophtheirus sp.	Low	Negligible	Negligible	Low	Yes
Lernanthropus paenulatus	High	High	High	Low	Yes
Parapetalus spinosus	Low	Negligible	Negligible	Negligible	Yes
Peniculus sp.	Low	High	Low	Negligible	Yes
Parabrachiella seriolae	High	High	High	Negligible	Yes
Parabrachiella sp.	Negligible	High	Negligible	Negligible	Yes
Naricolax chrysophryenus	High	High	High	Negligible	Yes
Monogenea					
Benedenia seriolae	Extreme	Extreme	Extreme	High	Yes
Paramicrocotyloides reticularis	Negligible	High	Negligible	Low	Yes
Zeuxapta seriolae	Extreme	Extreme	Extreme	Moderate	Yes
Myxozoa					
Ceratomyxa seriolae	Extreme	Moderate	Moderate	Negligible	No
C. buri	Extreme	Moderate	Moderate	Negligible	No
Kudoa sp.	Negligible*	Moderate	Negligible*	Low	No
Unicapsula seriolae	Negligible*	Moderate	Negligible*	Low	No
Nematoda					
Anisakis sp.	High	Low	Low	Low	Yes
Contracaecum sp.	Low	Low	Negligible	Low	Yes
Hysterothylacium sp. (larvae and adult)	High	Low	Low	Low	Yes
Pseudoterranova sp.	Negligible	Low	Negligible	Low	Yes
Rhabdochona sp.	Low	Low	Negligible	Low	Yes
Trematoda					
Aponurus laguncula	Low	Low	Negligible	Negligible	Yes
Bucephalus gorgon	Extreme	Low	Low	Negligible	Yes
Dinurus longisinus	Negligible	Low	Negligible	Negligible	Yes
Didymozoid	Low	Low	Negligible	Negligible	Yes
Ectenurus trachuri	Negligible	Low	Negligible	Negligible	Yes
Ellytrophalloides humerus	Extreme	Low	Low	Negligible	Yes
E. oatesi	Low	Low	Negligible	Negligible	Yes
Ellytrophallus sp.	High	Low	Low	Negligible	Yes
Erilepturus hamati	Low	Low	Negligible	Negligible	Yes
Hirudinella sp.	Low	Low	Negligible	Negligible	Yes
Lecithocladium sp.	Negligible	Low	Negligible	Negligible	Yes
Lecithaster stellatus	Negligible	Low	Negligible	Negligible	Yes

Table 3 (*continued*)

Parasite taxa	1) Exposure	2) Pathway	Likelihood	Consequence	Ability to treat
Trematoda					
Opechona kahawai	Low	Low	Negligible	Negligible	Yes
Paradeontacylix godfreyi	High	Moderate	Moderate	Moderate	No
P. sanguinicoloides	Low	Moderate	Negligible	Moderate	No
Paradeontacylix sp.	Low	Moderate	Negligible	Moderate	No
Parahemiurus merus	Extreme	Low	Low	Negligible	Yes
Plerurus digitatus	Negligible	Low	Negligible	Negligible	Yes
Rhipidocotyle longicirrus	High	Low	Low	Negligible	Yes
Stephanostomum petimba	High	Low	Low	Low	Yes
Telorhynchus sp.	Low	Low	Negligible	Negligible	Yes
Tormopsolus attenuatus	Low	Negligible	Negligible	Negligible	Yes
T. orientalis	High	Low	Low	Negligible	Yes

Likelihood of parasite establishment and proliferation including 1) estimate of exposure of farmed fish to parasitised *Seriola* species and 2) biological pathway necessary for parasite species to infect the farmed fish species. Consequence of parasite establishment and proliferation, potential mitigation procedures and mitigated consequence shown.
*See Discussion for comment.

that met one criterion were assigned a low consequence and parasites that met no criteria were assigned a negligible consequence (Table 2). Consequence is reviewed in the Discussion considering current management procedures or treatments available that could potentially mitigate parasite infestations in the event of an outbreak on a farm. We note where there is current ability to treat for parasite groups or species (Table 3).

3. Results

3.1. Species identified in this study

Parasites detected on wild and farmed *S. lalandi* and wild *S. hippos* during this survey and from previous published records in Australia are shown in Table 1. The microhabitat of the parasites is also indicated. Where a parasite species was found in all three regions of the digestive tract (i.e. stomach, caeca and intestine), their microhabitat is noted as 'digestive tract'. Some parasites could not be identified to species, a result of a combination of factors including limited number of parasite specimens, potentially undescribed parasite species and inability to identify larval parasite life stages definitively. Empty cysts, suspected of being cestode blastocysts, were observed in the viscera of farmed *S. lalandi* from Fitzgerald Bay and Botany Bay and in the viscera of wild *S. hippos* from Greenly Island. Blastocysts of similar colour and size containing a larval cestode, *Callitetrarhynchus gracilis*, occurred in the viscera of wild *S. lalandi*. Using FreeCalc, samples of wild ($n=62$) and farmed ($n=58$) *S. lalandi* gave close to 95% confidence of detecting parasite species at 10% prevalence. The sample of wild *S. hippos* ($n=6$) provided a 95% chance of detecting a parasite at 40% prevalence.

3.2. Risk assessment

Parasites were ranked as posing a negligible to extreme likelihood of establishment and proliferation from wild *Seriola* spp. to farmed *S. lalandi* in Spencer Gulf, South Australia (Table 3). The monogeneans *B. seriolae* and *Z. seriolae* presented an extreme likelihood of establishment and proliferation (Table 2). Six copepod species presented a high likelihood of establishment and proliferation (Table 2). The consequence of parasite establishment and proliferation for these copepoda ranged from negligible to high (Table 2). Consequence was high for *B. seriolae* and moderate for *Z. seriolae* and three *Paradeontacylix* spp. We determined that *Kudoa* sp., *Unicapsula seriolae* and *Paradeontacylix* spp., for which there are no current treatments available, pose the greatest risk to *S. lalandi* aquaculture in Australia (Table 3).

We identified routes of parasite transfer to determine the likelihood of parasite establishment and proliferation for this risk assessment. In the Discussion, we examine each parasite group separately, beginning with parasite groups that have direct life-cycles. We identify routes of transfer that were considered when assessing the likelihood of parasite establishment and justify the consequence category assigned to each parasite group or species (Table 2). We also discuss current and potential parasite treatments and management practices in *S. lalandi* sea-cage aquaculture. When considering this risk assessment, it is important to note that the likelihood of parasite establishment is dependent upon current information available on parasite presence and distribution. Despite a thorough parasite sampling technique, it is possible that some parasite species may not have been detected, especially if they occur seasonally or exist at low (<10%) prevalence in wild or farmed *Seriola* populations.

4. Discussion

This parasite risk assessment has used qualitative risk analyses to determine the potential likelihood and consequence of local metazoan parasite establishment and proliferation in *S. lalandi* sea-cage aquaculture. The methodology used in this risk assessment is directly applicable to farmed aquatic species worldwide, particularly where there is potential for parasite establishment from wild to farmed organisms. A parasite survey and qualitative risk assessment has also been made for farmed southern bluefin tuna *Thunnus maccoyii* in South Australia (Nowak, 2004; Deveney et al., 2005), however, unlike *S. lalandi*, *T. maccoyii* is stocked from the wild and may already harbour a variety of parasite disease agents.

The likelihood of parasite establishment and proliferation is dependent upon current information available on parasite presence and distribution. As new information on parasite distributions in wild fish populations becomes available, assessments of the likelihood of parasite establishment and proliferation in sea-cage aquaculture may change.

4.1. Copepods

Caligid copepods have direct life-cycles consisting of free-living, free-swimming and attached parasitic stages. Severe ectoparasitic copepod infestations in aquaculture have been associated with mortalities through host osmoregulatory failure, anaemia, ulcerations or through facilitating secondary infections (Finstad et al., 2000).

Caligus spinosus, which we detected on wild and farmed *S. lalandi* (Table 1), has been associated with gill disease in farmed *S. quinqueradiata* in Japan, where serious infestations result in anaemia (Egusa, 1983). Affected fish may also become emaciated due to appetite depression, rub against the sea-cage and develop ulcerations around the mouth (Egusa, 1983; Ho et al., 2001). *C. epidemicus*, which was detected on wild *S. lalandi* in Spencer Gulf (Table 1), is known to parasitise a number of wild and farmed marine fish species in Australia and Asia (Ho et al., 2004; Johnson et al., 2004). Ho et al. (2004) suggest this species presents a threat to aquaculture because of its low host-specificity. Considering the known pathology of *C. spinosus* and *C. epidemicus* in aquaculture, we determined that they have a low consequence for *S. lalandi* aquaculture in Australia (Table 2).

C. lalandei, well known from farmed *Seriola* species in Japan (Ho et al., 2001) and New Zealand (Diggles and Hutson, 2005), was not recovered from wild or farmed *S. lalandi* in the present study, despite being found on wild *S. hippos* (Table 1). This species has been reported previously from *S. lalandi* in Victoria and on the east coast of Australia (Hutson et al., 2007) (Table 1). Interestingly, *C. lalandei* has not been associated with disease in aquaculture, although Ho et al. (2001) suggest it may cause a serious problem in the event of an outbreak because of its large size. However, considering that there is known pathology associated with *Caligus* spp. infections, we determined that *C. lalandei* has a low consequence for *S. lalandi* aquaculture in Australia (Table 2). We also found an undetermined *Caligus* sp. 1 on wild *S. hippos* and wild and farmed *S. lalandi* (Table 1). *Caligus* sp. 2 was recovered from wild *S. hippos*, but was not detected on *S. lalandi*. It is evident that host-specificity of *Caligus* spp. is not fully understood and although all Caligid species were determined to pose a low risk of establishment and a low consequence, this genus should be treated with caution.

We detected *Lepeoptheirus* sp. on *S. hippos* and *Lernanthropus paenulatus* on wild *S. lalandi* and *S. hippos*, although these species are not known to be pathogenic in *Seriola* spp. aquaculture. However, lacerated tissue, erosion, desquamation and necrosis of secondary gill lamellae have been noticed near the site of attachment of *L. kroyeri* to sea bass, *Dicentrarchus labrax*, farmed in sea-cages in Greece (Manera and Dezfuli, 2003). Loss of *D. labrax* condition was associated with *L. kroyeri* infection. Similarly, *Lepeoptheirus salmonis* has been associated with salmon mortalities throughout the northern hemisphere (Costello, 1993). Considering the pathology of species in these two genera in aquaculture elsewhere, we determined that they have a low consequence for *S. lalandi* aquaculture (Table 2). Although *Lepeoptheirus* sp. is only known from *S. hippos* (Table 1), resulting in a negligible likelihood of this species establishing in *S. lalandi* farms (Table 3), it is important to keep in mind that information on host-specificity is changing rapidly. For example, parasites previously considered host-specific have been found to attach to a wide range of hosts under experimental conditions (Bricknell et al., 2006). Therefore, there may be some risk of transfer if wild *S. hippos* ever came in close proximity to farmed *S. lalandi* hosts.

Crustaceans can be treated with approved, prescribed veterinary medications and by fallowing farm sites. In Japan, eradication of *C. spinosus* has been achieved by immersing *S. quinqueradiata* in seawater containing Trichlorfon (Fujita et al., 1968). Bron et al. (1993) showed that fallowing between harvesting and restocking led to lower numbers of *Lepeophtheirus salmonis* on newly introduced fish compared to fish in non-fallowed sites. Although there are no registered chemotherapeutants in Australia, crustacean species could be managed in the event of an outbreak using prescription or permit medication.

4.2. Monogeneans

The capsalid *B. seriolae* and the heteraxinid *Z. seriolae* are common pathogens of farmed *Seriola* spp. and have been associated with considerable losses in *Seriola* aquaculture in Japan (Ogawa, 1996), Australia (Whittington et al., 2001; Ernst et al., 2002) and New Zealand (Diggles and Hutson, 2005). These species occur on wild and farmed *S. lalandi* and wild *S. hippos* in Australia (Table 1). We did not detect the microcotylid *Paramicrocotyloides reticularis* on farmed or wild *S. lalandi* in South Australia, but it has been documented from wild *S. lalandi* in New Zealand (Diggles and Hutson, 2005) and on the east coast of Australia (Rohde, 1978; Hutson et al., 2007) (Table 1).

Hydrogen peroxide has been used effectively in the treatment of monogeneans (Rach et al., 2000) and is the South Australian *S. lalandi* industry's current treatment of choice to control *Z. seriolae* and *B. seriolae* (see Mansell et al., 2005) (Table 3). Cycles of reinfection can also be prevented if treatments are coordinated strategically to break the life-cycle (Ernst et al., 2005). However, treating fish for monogenean infections is labour intensive and costly (Ernst et al., 2002). If left untreated, high numbers of *B. seriolae* on the body surface may render fish unappealing to consumers (Table 2), but this can be overcome by removing the parasites before sale.

P. reticularis is not currently present in farmed *S. lalandi* in South Australia. Little is known about the biology of *P. reticularis*, but it likely exhibits similar biology to *Z. seriolae* (i.e. infects gills and feeds on blood). We considered that *P. reticularis* might exhibit high fecundity, given the biology of related organisms and based on the number of eggs observed in the uterus. For the purposes of this risk assessment, we propose that *P. reticularis* may have a similar impact on host health as *Z. seriolae* and be amenable to control via the treatments mentioned above (Table 2). *P. reticularis* was found to present a negligible risk of establishment and proliferation to *S. lalandi* farmed in South Australia (Table 3) because it was not detected on wild fish in the same region (Table 1). However, *P. reticularis* would present a higher risk if the industry were to develop for *S. lalandi* farms on the east coast of Australia where the parasite does occur in wild fish.

4.3. Acanthocephalans

No acanthocephalans were detected in the current study. *Australorhynchus tetramorphacanthus* and *Rhadinorhynchus* spp. have been recorded from wild *S. lalandi* in Australian waters (Lebedev, 1967; Hutson et al., 2007) (Table 1). These species were not embedded in the tissues, which is consistent with Costa et al. (2004) who observed *R. pristis* free in the intestine of *Scomber japonicus*. Although we are unaware of any current management practice for controlling acanthocephalan infection in fish, cotton-top tamarins (*Saguinus oedipus*) have been treated successfully for acanthocephalans with oral albendazole (Weber and Junge, 2000).

There are few reports of acanthocephalans in farmed finfish. It is unlikely that acanthocephalans could establish and proliferate in South Australian *S. lalandi* aquaculture because of limited interaction with infected intermediate hosts. It also appears as though acanthocephalan species previously detected in wild *S. lalandi* in Australian waters may not negatively impact upon host well being, given that they are not known to embed in tissue (Table 2). Albendazole may be a potential chemotherapeutic treatment for these parasites, but is not currently licensed for use in fish in Australia. Nevertheless, establishment and proliferation of these parasites in aquaculture is unlikely because they are transferred when infected intermediate hosts are eaten by the definitive host. We determined the consequence of these three acanthocephalan species to be negligible for *S. lalandi* sea-cage aquaculture (Table 3).

4.4. Cestodes

Cestodes transfer to piscivorous fish when they eat infected intermediate hosts. We detected immature larval *C. gracilis* encysted in the body cavity and viscera of wild *S. lalandi*. Cysts, suspected to be cestode blastocysts, observed in the viscera of a farmed *S. lalandi* from Whyalla and Port Lincoln and in wild *S. hippos* did not contain any cestode larva. It is not clear whether *Callitetrarhynchus* blastocysts are associated with a pathological host response. Adjei et al. (1986) found blastocysts containing *C. gracilis* in lizard fish (*Saurida tumbil* and *S. undosquamis*) adjacent to the ventral aorta and in the body cavity, but did not observe any associated necrotic tissue. We found no literature concerning potential pathology of larval tetraphyllideans and the trypanorhynch *Nybelinia thyrsites* documented from the digestive tract of *S. lalandi* (Table 1).

In Japan, farmed *S. quinqueradiata* fed parasitised raw fish became infected with a larval cestode, *C. nipponica*, which altered the appearance and reduced the marketability of the flesh (Ogawa, 1996). However, when raw fish was replaced with frozen food, the parasite disappeared from farm sites (Ogawa, 1996). Currently, all *S. lalandi* farms in South Australia use extruded feed, a practice that contributes to the

negligible likelihood of establishment of *C. gracilis* as determined in the risk assessment (Table 3). It is evident, however, that transmission can occur, considering that we found cestode cysts, presumably *C. gracilis* blastocysts, in farmed fish.

Considering that we did not find any blastocysts containing *C. gracilis* in the flesh (Table 1) this parasite is unlikely to have any impact on the marketability of *S. lalandi* (Table 2). Additionally, the risk of parasite establishment and proliferation can be minimised by maintaining an extruded pellet diet. This would also reduce the potential for infection by larval tetraphyllideans and the trypanorhynch *N. thyrsites*.

4.5. Myxozoans

Myxozoa are now recognised as relatives of cnidarians and most are believed to have a two-host life-cycle involving fish and invertebrates (Moran et al., 1999). We recovered *Ceratomyxa seriolae* and *C. buri* from the gall-bladder of wild and farmed *S. lalandi* (Table 1). These species and *Myxobolus spirosulcatus* (see Maeno et al., 1995) are also known from the gall-bladder of farmed *S. quinqueradiata* in Japan (Yokoyama and Fukuda, 2001), but there have been no apparent pathological changes or mortality associated with infection. It is believed that myxozoan parasites in the gall-bladder may cause discolouration of the liver, by blocking the normal flow of bile from the bile ducts to the gall-bladder (Egusa, 1983). However, it has also been suggested that liver discolouration is related to the quality of vegetable protein within extruded feed (Sheppard, 2004).

An undetermined *Kudoa* sp. and *U. seriolae* have been detected in the flesh of wild *S. lalandi* on the east coast of Australia (Rohde, 1976; Lester, 1982) (Table 1). In Japan, farmed *S. quinqueradiata* are infected with similar myxosporean parasites *Kudoa pericardialis* and *K. amamiensis* (see Egusa, 1983; Moran et al., 1999). Although these infections are apparently not associated with mortality (Egusa, 1983), they can have detrimental effects on product quality and consumer acceptance. Infections of myxosporeans in the flesh have been associated with large, unsightly cysts or regions of lysis within the musculature (e.g. *K. amamiensis* in *S. quinqueradiata*, see Moran et al., 1999) and/or accelerated muscle degeneration and post-mortem myoliquefaction (e.g. *U. seriolae* in *S. lalandi*, see Lester, 1982).

Moran et al. (1999) discussed potential strategies for controlling diseases induced by myxosporeans. There are currently no chemotherapeutic treatments available, while avoiding host exposure in sea-cages appears difficult to impossible. This is not helped by the lack of knowledge of the specifics of myxozoan life-cycles. Frequent net changes may reduce accumulation of potential intermediate hosts and therefore reduce the risk of exposure to infective stages of the parasite (Moran et al., 1999). However, we are unaware of any documented evidence to indicate that this can effectively manage or control myxosporean infections.

Given current information available on the distribution of *Kudoa* sp. and *U. seriolae* in Australia, these species present a negligible likelihood of establishment and proliferation in *S. lalandi* aquaculture in South Australia (Table 3). However, it is important to note that we are aware of unconfirmed reports of myxosporean infections in the flesh of wild *S. lalandi* in Spencer Gulf, South Australia. Farmed *Thunnus maccoyii* in Spencer Gulf (Deveney et al., 2005) and wild *S. hippos* in Western Australia (Andrew Rowland, personal communication) are also known to experience myxosporean infections in flesh. Considering the potential reduction in market value and negative consumer acceptance for infected fish, we found that these species present a low consequence for *S. lalandi* aquaculture (Table 3). Clearly, *Kudoa* sp. and *U. seriolae* are very important parasite species to consider if the industry were to develop on the northern east coast of Australia where myxosporean infection is common in wild *S. lalandi*.

4.6. Nematodes

Hutson et al. (2007) noted evidence of granuloma formation associated with larval nematodes in the viscera of wild *S. lalandi*. Nematode migration and encapsulation within body tissues and visceral organs often cause the development of lesions (Dezfuli et al., 2000).

Larval nematodes present a negligible likelihood of establishment and proliferation in *S. lalandi* sea-cage farming (Table 3) because of the current farming practice of using an extruded pellet diet. Given that these parasites were detected in the viscera and not in the flesh, the risk of human consumption is substantially reduced. Consequently, we did not consider that these parasites present a negative consequence for consumer health or marketability (Table 2). Nevertheless, nematodes still pose a low consequence for *S. lalandi* aquaculture because of the potential for harm to the host (Table 2). Although there are no registered anthelminthics in Australia that can be used to treat nematodes in fish destined for human consumption, nematode parasites could be managed by maintaining an extruded pellet diet.

4.7. Trematodes

We found *Parahemiurus merus*, *Rhipidocotyle longicirrus* and *Tormopsolus orientalis* in farmed *S. lalandi* in Boston Bay, Port Lincoln, which may be a result of fish being fed a raw/frozen pilchard diet at the time of sampling (Table 1). At Fitzgerald Bay, Whyalla, where *S. lalandi* were fed an extruded pellet diet exclusively, specimens of *Bucephalus gorgon* were detected (Table 1). This indicates that farmed fish may consume some wild infected intermediate hosts. Trematode parasites can be easily managed in farms by feeding fish with an uninfected diet. Some farmed fish may still become infected by trematodes, by feeding opportunistically on infected wild species moving through the netting, but it is unlikely that these parasite species will be able to proliferate in the farmed population. Given the lack of information available in the literature concerning the relative pathogenicity of bucephalids and hemiurids, we could not determine the consequence of these families for *S. lalandi* sea-cage farming (Table 2).

Sanguinicolids have been problematic in aquaculture because their intermediate mollusc or annelid host may inhabit areas close to farmed fish, such as on cage structures or sediment, and infection of the definitive host by emerging cercariae is direct. The likelihood of sanguinicolid establishment and proliferation was determined to be moderate for *Paradeontacylix godfreyi* and negligible for *Paradeontacylix* sp. and *P. sanguinicoloides* (Table 3). Although the latter two species are only known from *S. hippos* in South Australian waters, both are known to infect *S. lalandi* elsewhere in Australia (Hutson and Whittington, 2006). We did not detect sanguinicolids in farmed *S. lalandi* in South Australia (Table 1). The likelihood of these species establishing in *S. lalandi* aquaculture should not be underestimated, as the extent of their current range is unknown.

Sanguinicolids in *Paradeontacylix* have been associated with mass mortalities of farmed amberjacks, *S. dumerili,* in the Spanish Mediterranean (Crespo et al., 1992) and in Japan (Ogawa and Fukudome, 1994). They are also concerns 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 (Diggles and Hutson, 2005). We determined that *Paradeontacylix* spp. present a moderate consequence for *S. lalandi* farming in Australia (Table 3).

Control of blood fluke infections may only be achieved in semi-open aquaculture systems by separating intermediate and definitive hosts, because elimination of susceptible intermediate hosts in open water is impractical and cost-prohibitive (Bullard and Overstreet, 2002). We are aware that some farms in Japan use orally delivered praziquantel to treat *Seriola* spp. infected with blood fluke, however, to our knowledge, the effectiveness of this treatment has not been quantified. Identifying the intermediate host or hosts for *Paradeontacylix* spp. would help to determine suitable sea-cage sites for *S. lalandi* away from potential infection sources as the industry expands (Hutson and Whittington, 2006). However, the intermediate host(s) is currently unknown.

5. Conclusion

Parasite risk analyses provide a disciplined and consistent approach for the calculation of the relative level of risk associated with individual parasite species. This risk assessment has determined the likelihood of parasite establishment from wild Australian *Seriola* hosts to farmed *S. lalandi* in sea-cages in South Australia and the potential consequences of parasite establishment and proliferation. Sampling of parasite fauna of wild and farmed fish should be incorporated into an ongoing sampling program for effective parasite management, risk identification and impact assessment at farm locations (McVicar, 1997). This will enable proactive rather than reactive parasite management and prevention of serious outbreaks.

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