PARASITE INTERACTIONS BETWEEN WILD AND FARMED YELLOWTAIL KINGFISH (*SERIOLA LALANDI*) IN SOUTHERN AUSTRALIA

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Kate Hutson
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Cover image: A 24.3 kg wild yellowtail kingfish (*Seriola lalandi*) captured at Port Augusta by Craig Pillion
Photo: Kate S. Hutson

Publications during the tenure of my PhD candidacy

Hutson, **K.S**., Whittington, I.D., Gillanders, B.M., Rowntree, J.E., Ernst, I., Chambers, C.B. & Johnston, C. (Submitted, 2 January 2007) Potential for parasite interactions between wild and farmed kingfish, discrimination of farmed and wild fish and assessment of migratory behaviour. Final Report, Fisheries Research and Development Corporation. Project No. 2003/220, 110 pp.

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Reggie Godfrey netting yellowtail kingfish from *Beez Neez* in Port Patterson
Photo: Bronwyn M. Gillanders

DEDICATION

To my Pop, Ian Cox

Who shines so much light on my life. He gave me my first guinea-pigs, taught me how to drive in his ute at his Hereford farm and took me fishing for flathead from Blairgowrie pier. Pop died peacefully on January 6, 2007.

And,

To Reggie Godfrey

Reggie was regarded in the fishing community as an authority on yellowtail kingfish and was frequently in demand for his fishing expertise. A true-blue Aussie bloke, Reggie followed in the footsteps of his father, fishing in upper Spencer Gulf between the 1950s to mid 80s. Over the past ten years he assisted the collection of yellowtail kingfish brood stock for aquaculture. More recently, Reggie helped to facilitate the research presented in this thesis. He was instrumental to Chapter Six which presents results from the only tag and release programme ever conducted on large wild yellowtail kingfish in South Australia. Reggie died suddenly on October 21, 2006 while assisting me in the field. I miss his fishing yarns and will never forget the friendship and knowledge he shared with me.

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Kate Hutson

Appendix

The two images of the ´yellowtail kingfish 'weigh your catch' ruler´ should be omitted from the thesis as copyright remains with Mr Scott Gray, Fishcare Victoria.

ABSTRACT

Metazoan parasites threaten the development and expansion of yellowtail kingfish (*Seriola lalandi*) sea-cage aquaculture in Australia. There is international speculation that parasite transmission from farmed to wild fish leads to increased incidence of parasitism in wild fish. Conversely, transfer of parasites from wild fish to farmed fish can negatively impact upon the health of farmed fish. Baseline information on the parasite assemblage of wild *S. lalandi* in Australia will: 1) allow informed judgments to be made in order to responsibly monitor, and perhaps remedy, potentially negative impacts and; 2) enable identification of parasite species of potential harm to the Australian *S. lalandi* aquaculture industry.

I collected wild *Seriola* spp. (Carangidae) throughout southern Australia and examined them for metazoan parasites. Fifty-six metazoan parasite species are identified, including one new species. A taxonomic listing is provided for the metazoan parasites found. Taxonomic descriptions are made for the blood fluke *Paradeontacylix godfreyi* n. sp. (Digenea: Sanguinicolidae) and a redescription is provided for the parasitic copepod *Naricolax chrysophryenus* (Cyclopoida: Bomolochidae).

A qualitative risk assessment was devised for the metazoan parasite taxa identified for the sea-cage aquaculture of *S. lalandi* in South Australia. Risk was interpreted considering the likelihood and consequence of parasite establishment and proliferation. The monogeneans *Benedenia seriolae* and *Zeuxapta seriolae* were considered extremely likely to establish and proliferate. *Benedenia seriolae* also poses high potential negative consequences for cost-effective *S. lalandi* sea-cage farming. However, the absence of potential mitigation methods and parasite management for *Paradeontacylix* spp. (Digenea), *Kudoa* sp. and *Unicapsula seriolae* (Myxozoa) indicates that these species may also present high negative consequences for *S. lalandi* aquaculture in Australia.

The nature of wild *Seriola* migrations is critical for an understanding of the potential impact of disease and parasite interactions between wild and farmed fish. A small-scale tagging programme of wild-caught *S. lalandi* and *S. hippos* in South Australia provided insight into the movements of these species. Recapture results indicate that large *S. lalandi* remain in, or return to, northern Spencer Gulf. *S. lalandi* also move past sea-cage farms in Fitzgerald Bay, northern Spencer Gulf, which is an important consideration in view of potential expansion of the *S. lalandi* sea-cage industry in Spencer Gulf.

There is surprisingly little experimental assessment on parasite transmission from farmed fish to wild fish. Studies assessing parasite interactions between wild and cultured fish employ models to quantify parasite population levels of cultured, wild and escaped fish, while others carry out comparative surveys of parasite prevalence and intensity over time, in areas close to and distant from farming activity. I provide preliminary data on ectoparasite prevalence and intensity on wild *S. lalandi* in areas close to, distant from and where there is no sea-cage farming in southern Australia. I review methods employed in the northern hemisphere to assess sea-louse transfer between wild and farmed salmon and propose methods for assessing monogenean parasite transmission from farmed to wild *S. lalandi* in Australia.

In summary, this thesis provides insight into the potential for parasite interactions between wild and farmed *S. lalandi*. I document the parasite assemblage of wild and farmed *S. lalandi* and wild *S. hippos* and provide baseline data on 'natural' parasite prevalence and intensity. I provide a taxonomic description of a new species of blood fluke. I indicate the likelihood of parasite transfer from wild fish to farmed *S. lalandi*, and identify parasite taxa with potentially negative consequences for sea-cage aquaculture. I provide the first firm data that wild *S. lalandi* move past one area where kingfish are farmed in sea-cages in South Australia. Finally, I propose procedures to better understand the potential for monogenean parasite transmission from farmed *S. lalandi* to wild fish. This thesis reports new information that is important when considering and managing expansion of the *S. lalandi* sea-cage aquaculture industry throughout Australia. It

also provides baseline data on natural parasite levels to enable ongoing monitoring of the potential impacts of the industry on wild fish populations.

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This thesis is the result of the encouragement, enthusiasm and help of many people. It has been an exhilarating journey, with a heady mix of triumphs and failures, new friends and old friends, early mornings and late nights, fish guts and seasickness. The fieldwork was extremely challenging. I was away from home for long periods at a time chasing wild yellowtail kingfish, a species that is not especially common and is difficult to catch. Fortunately, I was able to work with some of the most remarkable people in the Australian fishing industry. The laboratory work was also challenging and involved identification of a diverse range of parasite fauna. Again, I was fortunate to work with some of the most pre-eminent parasite specialists in the world. Without this help I wouldn't have made it. Thank you.

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Calypso Star Charter put me in pursuit of some big kings in wild waters. The 6 to 8 metre swell as we steamed out of Thorny Passage took my heart and breath away, as well as most of my lunch. Despite five days in walls of water at Greenly and Rocky Island, I did not see one kingfish. However, I got some good parasite samples from Samson fish thanks to Seth Boag, Rolf Czabayski, Michael McMahon and Shane Mensforth. My first aid course came in handy when one client's braided line caught around his finger at the same moment a tuna ran with his lure. The line cut his finger to the bone, nearly severing it. I pushed his finger back together and bandaged it. The doctor back in Port Lincoln reckons it healed well. I was a super-hero. I considered wearing my undies on the outside of my pants.

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Port Lincoln, Coffin Bay and Tumby Bay produced a mixed bag and a lot of memories. Greg Kent gave up a lot of his time to assist me fishing this area. I am

grateful for his persistence, humour, the lucky lure and for showing me some of the most beautiful coastal areas in South Australia by 4WD. He also allowed his laundry to become a make-shift parasite laboratory. Thank you to Navajo Aquaculture and the Stehr Group for technical support in Port Lincoln. So many people made fishing this region worthwhile: Robert Adlard, Jamie and Bec Crawford, Quinn Fitzgibbon, Paul Harrison, Craig Hayward, Peter Hutchins, Bob Hutchinson, Paul Hutchinson, Anthony McNair, Brad Smith and Tom and Judy Tierney.

When I wasn't working independently at Arno Bay, Clinton Chambers and Brad Smith provided much appreciated assistance. Neil from Port Neil and Clint Green made working the sea-cages at Arno a huge laugh. I'm glad they warned me about my silver watch (i.e. lure) before I jumped into a sea-cage on snorkel with 100 kg+ brood stock tuna! However, they didn't warn me that the builders got the hot and cold shower taps around the wrong way back on site. After three days at sea, having had no shower and reeking of fish guts, I was sprung trying to have a shower in the sink. Thank you to the Stehr Group for providing technical support in Arno Bay.

Whyalla! Only three wild kingfish were boated. Thank you to Whyalla Sea Rescue who provided a tow-in when *Congoli* conked out. Fortunately, Carlo Possagno introduced me to the excellent by-catch to be had in the region, so this site wasn't a complete write off (unlike *Congoli*). Melt in your mouth snapper, and my PB mulloway (fishers' lingo for personal best) at around 8 kilos (well maybe more like 5 kg - fishers tend to exaggerate). Ingo Ernst, Clinton Chambers, Simon Jones, Brad Mansell and Brad Smith were very helpful with fieldwork. Thank you to South Australian Aquaculture Management and Southern Star Aquaculture for technical assistance.

Port Augusta was humming and the mullet were jumping. The power station opposite the Spencer Gulf kingfish hatchery fried my brains while I fished - but at least the fish were there. Thanks to all the staff at Spencer Gulf Hatchery for technical assistance. Special thanks to John Bills, Clinton Chambers, Robbie Chenda, Travis Dymmott, Ingo Ernst, Anthony Everett, Darren, Kate and Jeanne

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Throughout this work Bradley Smith (aka *bradsmithi*) motivated me before first light, taught me to master the idiosyncrasies of *Thallasia*, dried my underwear on the stove (and burnt it), showed me how to catch big fish and helped me count parasites into the night. He helped me smile in times of immense sadness. Without him, this thesis wouldn't be what it is.

CHAPTER ONE

General Introduction

NOTE: This photograph is included on page 1 of the print copy of the thesis held in the University of Adelaide Library.

Hatchery reared yellowtail kingfish (*Seriola lalandi*) at Port Augusta, South Australia
Photo: Rissa E. Williams

CHAPTER ONE

GENERAL INTRODUCTION

Aquaculture is expanding rapidly to meet the demands of consumers worldwide. In 2000, farmed marine fish accounted for over one quarter of all fish directly consumed by humans (Naylor *et al.* 2000). As the human population continues to increase, its reliance on farmed fish production as an important source of protein will also increase. To ensure sustainability and profitability and to accommodate high public regulatory expectations for aquaculture developments, urgent solutions are required to address issues such as disease, waste, chemical use and escapes. Indeed, disease associated with pathogens (viruses, fungi, bacteria) and metazoan parasites is a severely limiting factor for the aquaculture industry.

Conditions sometimes associated with intense aquaculture such as confinement, overcrowding and stress can facilitate parasite transmission and elevate parasite intensities in farmed fish (Ogawa 1996). Losses may be experienced through stock morbidity and mortality, but treatment and management is costly and labour intensive. A key contributor to high production costs of Japanese yellowtail (*Seriola quinqueradiata*) in Japan is the monogenean parasite *Benedenia seriolae*, which is estimated to be responsible for up to 22% of total production costs (Ernst *et al.* 2002). While *Neobendenia melleni* (either an opportunistic species or species complex) has been reported from wild and/or cultivated fishes globally and outbreaks attributed to this species have contributed to considerable losses of stock (Whittington & Horton 1996). Certainly, the impact of parasites on farmed aquatic organisms can be devastating.

Aquaculture expansion may encounter fierce public resistance because of the potential for parasite transmission from farmed species to wild species. In the northern hemisphere, there is intense debate about the potential for parasitic crustaceans (e.g. sea-lice, *Lepeoptheirus salmonis*) to impact upon wild salmonids that migrate past salmon farms. Some scientists have linked increased parasite loads with declines in wild fish stocks (e.g. Bjørn *et al.* 2001; Bjørn & Finstad

2002), while others argue that over-fishing, habitat loss and climate change are responsible for the declines (Noakes *et al.* 2000). To establish whether or not aquaculture has a negative impact on the environment is critical to effective farm management and consumer acceptance. In particular, understanding whether increased parasite levels amongst cultured fish stocks are associated with increased parasitism or harmful outbreaks in wild species will help to determine whether or not management intervention is appropriate. Here, I will highlight the biological processes involved in metazoan parasite transmission and the current methods employed to assess transfer between wild and farmed marine finfish.

Parasite transfer from wild fish to farmed fish

Public perception is that 'wild' implies 'pristine' and that wild fish are therefore parasite-free (Noakes *et al.* 2000). Of course, this is not true and wild fish can be infected by a diverse range of parasite groups. Wild fish are believed to be the initial source of parasites for fish farmed in sea-cages (McVicar 1997; Bouloux *et al.* 1998). Fish that are grown from fertilised eggs in land-based hatcheries may be isolated from metazoan parasites through standard biosecurity practices. When fingerlings are moved into sea-cages, they may obtain parasites found in surrounding wild fauna. Conversely, fish such as southern bluefin tuna (*Thunnus maccoyii*) that are sourced from the wild and transferred to sea-cages to be 'fattened' may already harbour parasites (Deveney *et al.* 2005).

The sea-cage environment favours certain types of parasites. Uncontrolled exchange of water permits parasites with waterborne infective stages (e.g. crustaceans, monogeneans and sanguinicolids) to make contact with farmed fish (e.g. the monogenean *Zeuxapta seriolae*; Figure 1). Parasites with direct life-cycles are usually found commonly in sea-cage culture as they require only a single host species and are usually able to reproduce rapidly (e.g. Bouloux *et al.* 1998) (Figure 1). Conversely, parasites with life-cycles that require ingestion (e.g. acanthocephalans, cestodes and nematodes) of infected intermediate hosts (e.g. crustaceans, gastropods and fish) may be excluded from cultured fish as intermediate hosts may not be able to move through sea-cage netting. In addition,

there may be limited availability of suitable intermediate host species in the sea-cage environment to enable complex parasite life-cycles to be completed readily.

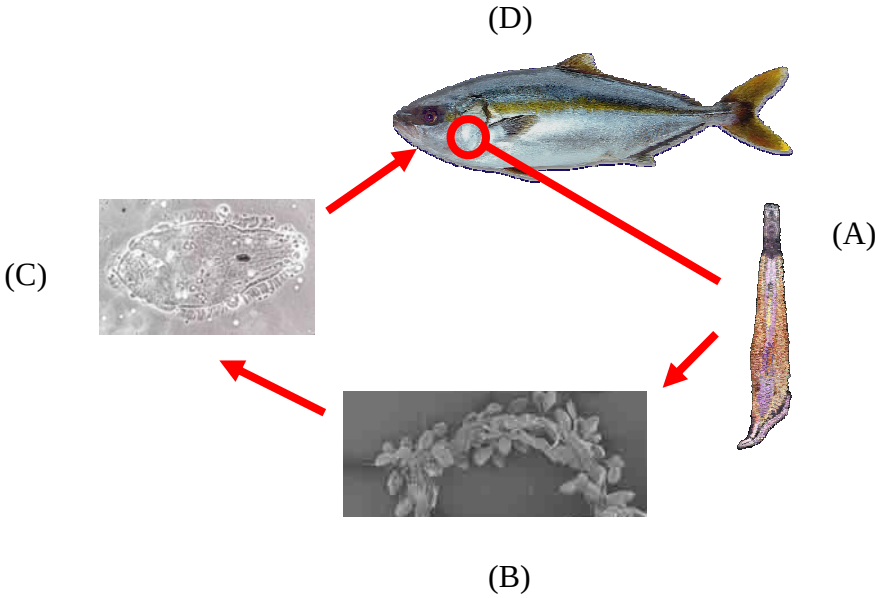

Figure 1. Stylised diagram of the direct life-cycle exhibited by *Zeuxapta seriolae* (Monogenea) in *Seriola lalandi*. Adult *Z. seriolae* (A) living on the gills of *S. lalandi* lay eggs connected by filamentous strings and release them into the ocean (B). In the sea the eggs hatch to release slow swimming ciliated larvae (C) that may directly infect their host (D) and mature into adults.

Although several studies in the northern hemisphere have documented parasite species on wild and farmed fish from aquaculture sites (Byrne *et al.* 2002; Ho *et al.* 2004; Sepúlveda *et al.* 2004), few have used qualitative risk analyses to determine the likelihood and consequence of parasite transfer from locally found wild fish to farmed fish. Most risk assessments for marine fish farming identify hazards from reports in other countries. The usefulness of this approach is limited if a local or endemic parasite species with potential to cause serious problems goes undetected before the establishment of aquaculture.

Parasite transfer from farmed fish to wild fish

Potentially, sea-cages could act as an infection reservoir of metazoan parasites for wild fish that move past or around farms. However, for parasite loads to increase on wild fish, farmed fish must have the capacity to amplify parasites to a higher level than the surrounding natural marine environment. Wild fish then must

become infected. To assess the potential for sea-louse transmission from farmed to wild fish in the northern hemisphere, researchers have used models to quantify parasite population levels on farmed, wild and escaped fish (Heuch & Mo 2001; Butler 2002; Murray 2002; Orr 2007). Other research has involved comparative surveys of parasite prevalence and intensity on wild fish over time, in areas close to and distant from farming activity (Bjørn *et al.* 2001; Bjørn & Finstad 2002). There is also awareness of the need to assess wild parasite levels using more appropriate methods, such as sampling wild fish in locations with similar environmental conditions to farmed locations, e.g. during fallowing periods (Marshall 2003).

Parasite dispersal around sea-cages is dependent on parasite ecology and environmental conditions. Infective stages shed from infected farmed fish into the water column are susceptible to currents, water turbulence, salinity and temperature. The survival time and dispersal of these infective stages varies with species and environmental conditions. Physical obstacles, such as sea-cage netting, may limit the extent of parasite dispersal (e.g. Ernst *et al.* 2002). Dilution of infective stages in open water may reduce the chance of transmission between wild and farmed stocks. Alternatively, it has been argued that tidal movement of water may enhance transfer from farmed to wild hosts by transporting parasite life stages away from farms (Gardner & Peterson 2003).

Farm location is another variable that determines the likelihood of exposure of wild fish to parasites from farms. Exposure of wild fish species to farmed fish is dependent on wild host associations with farmed regions. Certainly, structure (e.g. submerged cages, moorings, pontoons and floats) and unused feed that falls through sea-cages may enhance wild fish association with farming areas (Dempster *et al.* 2004). Nevertheless, wild hosts may be migratory or may only associate with farming regions seasonally. Sea-cage salmon farms in Norway and British Columbia, Canada, tend to be located along wild fish migration routes (Heuch & Mo 2001; Gardner & Peterson 2003). Although many factors are required for parasite transfer to occur, it is reasonable to suggest that close wild host association with aquaculture regions may result in transmission of parasites from farmed fish to wild fish.

Sea-cage aquaculture in Australia

There have been many studies assessing parasite transmission from farmed to wild fish in the northern hemisphere, but such research is notably absent in the southern hemisphere. This is most likely a result of the more recent development and comparatively less concentrated marine finfish aquaculture in this region. In Australia, naturally occurring species including yellowtail kingfish (*Seriola lalandi*), mulloway (*Argyrosomus japonicus*) and southern bluefin tuna (*Thunnus maccoyii*) are farmed in sea-cages in southern Australia, while barramundi (*Lates calcarifer*) are farmed in sea-cages in Australia's northern tropical waters. Unlike *T. maccoyii,* which is harvested from wild stocks and fattened in sea-cages, *S. lalandi*, *A. japonicus* and *L. calcarifer* fingerlings are produced in land-based hatcheries, and are normally free from metazoan parasites on hatching. However, when transferred to sea-cages, these farmed fish may acquire infections from local populations of wild fish. The natural occurrence of wild fish of the same species near sea-cage farms provides an opportunity for transmission of parasites, particularly those with direct life-cycles, between wild and farmed fish populations.

In this thesis, I present my research that investigates potential metazoan parasite interactions between wild and farmed *S. lalandi* in southern Australia. To determine the potential for parasite transmission from wild fish to farmed fish, rigorous surveys of the parasite fauna of *S. lalandi* were conducted on fish farms and in the surrounding natural environment (Chapters Two-Five). I present a risk assessment for parasites of wild *S. lalandi* for sea-cage aquaculture in South Australia (Chapter Five). To determine the potential for wild *S. lalandi* to associate with sea-cage farming, I carried out a tag and recapture programme (Chapter Six). Wild *S. lalandi* were surveyed for parasites in areas close to, distant from and where there is no sea-cage farming, to determine the incidence of parasites in wild fish (Chapters Two, Five and Seven). I review current methods used to model sea-lice transmission in the northern hemisphere and propose novel methods to assess monogenean parasite transmission from farmed to wild fish (Chapter Seven).

My research focused on four main areas:

1. Identification of metazoan parasites from wild and farmed *S. lalandi*
2. Development of a parasite risk assessment for *S. lalandi* aquaculture
3. Determination of movements of wild *S. lalandi* in South Australian waters
4. Assessment of parasite transmission from farmed fish to wild fish

Throughout my thesis, I have attempted to maintain a logical progression of ideas, but each chapter is written as a separate paper and can be read independently. The objectives of individual chapters are as follows.

Chapter Two:

Before any assessment can be made on the nature, magnitude and significance of any parasite transfer between wild and farmed fish, the prevalence and incidence of parasites in wild fish must be ascertained. In Chapter Two, I document the parasites of wild *S. lalandi* from Sir John Young Banks, New South Wales and Killarney, Victoria. Both locations are completely free of finfish aquaculture, and provide an ideal basis for examining levels of parasite infection in the absence of any potential interaction with farming activities. I provide baseline information on parasite prevalence and intensity in wild *S. lalandi*.

Chapter Three:

Within *Seriola* spp., *Paradeontacylix* spp. (Digenea: Sanguinicolidae) are considered to be serious pathogens for aquaculture. I document three *Paradeontacylix* spp. from wild *S. lalandi*, including one new species, not previously reported from Australian waters. This chapter provides a taxonomic description of the new *Paradeontacylix* sp. Further research that identifies intermediate hosts of *Paradeontacylix* spp. will enable the development of *S. lalandi* aquaculture in areas away from potential infection sources.

Chapter Four:

Effective control of marine parasites can only be achieved through reliable identification and knowledge about them. Standard taxonomic methods and identification based primarily on morphological features are important tools for

species diagnosis. I found *Naricolax chrysophryenus* infecting wild and farmed *S. lalandi* in southern Australia. This genus has not previously been reported from a carangid host. This chapter provides a taxonomic redescription of the parasite and provides a key to species in the genus.

Chapter Five:

Parasite assemblages of wild *Seriola* spp. have not previously been studied in South Australia. Consequently, the *S. lalandi* sea-cage aquaculture industry is oblivious to local parasites of potential harm. In Chapter Five, I document parasites from wild and farmed *Seriola* spp. in South Australia and construct a risk assessment of parasites for *S. lalandi* sea-cage aquaculture in southern Australia. The risk assessment considers the likelihood and consequence of parasite establishment and proliferation. I identify parasite species with potentially negative consequences for Australian *S. lalandi* aquaculture and review potential mitigation methods.

Chapter Six:

The migratory movements of *S. lalandi* have been well studied on the east coast of Australia, but there is little knowledge of the seasonal migratory movements of *S. lalandi* in Spencer Gulf, South Australia. Understanding the migratory patterns and movements of wild fish is critical to determine potential interactions between wild and farmed *S. lalandi*. In Chapter Six, I present results from a small-scale tagging programme carried out in South Australian waters with the cooperation of recreational fishers and charter operators.

Chapter Seven:

In Chapter Seven, I provide preliminary data on the ectoparasite prevalence and intensity of wild *S. lalandi* close to, distant from and where there is no sea-cage aquaculture in Australia. I review the current methods used to examine sea-lice transmission from farmed fish to wild fish in the northern hemisphere. I propose methods for estimating monogenean parasite recruitment rates on wild fish from exposed and unexposed sites in South Australia.

Chapter Eight:

In Chapter Eight, I provide a brief general discussion of the preceding chapters, cover some interlinked themes and offer some directions for future research.

Notes on chapter style:

Each data chapter in my thesis (Chapters Two - Seven) present original information, and have been written in a style suitable for publication in scientific journals. As such, they can be read as individual papers, but collectively, they form my thesis. Where possible, I have attempted to maintain a logical progression of ideas. All Tables and Figures are embedded within the text of the relevant chapter. Literature cited in chapters is provided at the end of the thesis in a consolidated reference list, not at the end of each chapter. Parasite and host authorities have been omitted for clarity of reading throughout and are included in Appendix 5.

Where applicable, each chapter is preceded by a statement of authorship that describes the publication status at the time of thesis submission and the contributions of co-authors. Chapters Two-Six have been published, or accepted for publication, with co-authors and are therefore written in plural. Published versions of Chapters Two and Three are bound in Appendix Three. The format for my thesis follows Appendix Six, Section 2.2 in 'The Research Student Handbook 2007' of The University of Adelaide (February 2007).

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Dissection of a yellowtail kingfish (*Seriola lalandi*) from Killarney, Victoria
Photo: K.S. Hutson

CHAPTER TWO

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

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CHAPTER TWO

METAZOAN PARASITE ASSEMBLAGES OF WILD *SERIOLA LALANDI* (CARANGIDAE) FROM EASTERN AND SOUTHERN AUSTRALIA

2.1. 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. *Seriola 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* spp. aquaculture. Comparisons are made between ectoparasite and endoparasite prevalence and intensity of *S. lalandi* from New South Wales and Victoria. *Seriola 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* and the copepod *Parabrachiella seriolae* may be potentially useful for stock discrimination.

2.2. Introduction

Yellowtail kingfish, *Seriola lalandi*, 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 (Froese & Pauly 2005). In Australia, *S. lalandi* is a popular recreational species which inhabits southern coastal waters from Queensland to Western Australia, and northern Tasmania (Hutchins & Swainston

1986). The primary wild-caught commercial fishery is in New South Wales (NSW) and produces about 200 tonnes per year (Anon. 2005). This species is also farmed in sea-cages in Spencer Gulf, South Australia, and currently produces about 1,500 tonnes per annum with production expected to increase to 10,000 tonnes by 2012 (Anon. 2006).

Parasites infecting *Seriola* spp. 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*, which soften the flesh, making the fish unmarketable (Rohde 1976; Lester 1982). Outbreaks of monogeneans have caused significant mortalities in sea-cage farming of *Seriola* spp. in the Mediterranean (Grau *et al.* 2003), Japan (Ogawa 1996), New Zealand (Appendix One) and Australia (Whittington *et al.* 2001). 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 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 chapter 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; e) identify parasite species that could be used as biological tags.

2.3. Materials and Methods

Commercial fishers caught 25 *S. lalandi* at Sir John Young Banks off Greenwell Point, NSW (34º56′52″S, 150º55′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 (38º23′36″S, 142º20′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 (Mansell *et al.* 2005). Fish were then bathed in freshwater for approximately 10 min to remove all *Benedenia seriolae* (see Chambers & Ernst 2005). Fish were euthanased 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 (Chambers & Ernst 2005).

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 & Hopcroft (1986).

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. *Caligus spinosus* (C6310) and *Paramicrocotyloides reticularis* specimens collected by Ben Doolan from the gills of four *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 *et al.* (2003) 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 *et al.* (2004) were made available by Dr Peter Smith for study including *C. spinosus* (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. Parasites were identified following original descriptions or redescriptions. Parasite prevalence and intensity are given in whole numbers and follow Bush *et al.* (1997). 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.

2.4. 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 phylum in the Metazoa following Lom & Dyková (2006). 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*, *C. lalandei*, *Caligus* sp., *Dissonus hoi* and *Naricolax chrysophryenus* 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 (Ho & Lin 2004), *C. lalandei* has been recorded previously from the body surface of *S. lalandi* (see Sharp *et al.* 2003), *D. hoi* has been recorded previously from the nares of *S. hippos* (Tang & Kalman, 2005) and *N. chrysophryenus* is known to infect the nasal cavity of snapper, *Chrysophrys auratus* (see Sharples & Evans 1993).

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 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 *et al.* (2000). 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* and *Rhipidocotyle longicirrus* (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.* (2004) from *S. lalandi* in New Zealand. We agree with identifications of *Caligus spinosus* (reported as *C. aesopus*). We stained and mounted specimens of *Paramicrocotyloides* sp., which matched the description of *Paramicrocotyloides reticularis* following Rohde (1978). *Lernanthropus* sp. matched the description of *Lernanthropus paenulatus* following Wilson (1922). We were unable to provide further insight into an undetermined species of acanthocephalan, which Smith *et al.* (2004) suspected may be a *Longicollum* sp. Prevalence of *S. lalandi* ectoparasites from New Zealand and Australia are shown in Figure 1.

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]

Table 1. (*continued*)

Group/family	Taxon	Microhabitat	New South Wales	Victoria
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]
Endoparasites				
	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				
Tentaculariidae	*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)	Whittington (1996)
				New Zealand	Sharp *et al.* (2003)
			Farmed	Australia (SA)	Chambers & Ernst (2005)
				New Zealand	Appendix One
		S. quinqueradiata	Farmed	Japan	Izawa (1969)
		S. dumerili	Farmed	Japan	Egusa (1983)
		S. rivoliana	Farmed	Japan	Egusa (1983)
Paramicrocotyloides reticularis		*S. lalandi*	Wild	Australia (Qld)	Rohde (1978)
				New Zealand	Present study; Appendix One
Zeuxapta seriolae	*Axine seriolae*	*S. lalandi*	Wild	Australia (Qld)	Rohde (1978)
	Zeuxapta japonica			New Zealand	Sharp *et al.* (2003)
	Zeuxapta zyxivaginata		Farmed	Australia (SA)	Mooney *et al.* (2006)
				Japan	Ingo Ernst, unpublished data
		S. hippos	Wild	Australia (NSW)	Rohde (1981)
		S. dumerili	Wild	Mediterranean, Spain	Grau *et al.* (2003)
			Farmed	Japan	Ogawa & Yokoyama (1998)
Crustacea					
Caligus lalandei		*S. lalandi*	Wild	South Africa	Izawa (1969)
				Chile	Barnard (1948)
				New Zealand	Hewitt & Hine (1972)

Table 2. (*continued*)

Parasite taxa	Synonyms	Host species	Origin	Location	References
Caligus lalandei				Mexico	Baeza & Castro (1980)
				Korea	Ho *et al.* (2001)
				Japan	Ho *et al.* (2001)
		S. hippos	Wild	New Zealand	Jones (1988)
		S. quinqueradiata	Wild	Japan	Ho *et al.* (2001)
Caligus spinosus	*C. aesopus*	*S. lalandi*	Wild	Australia (Qld)	Rohde (1978)
				New Zealand	Jones (1988)
		S. hippos	Wild	New Zealand	Jones (1988)
		S. quinqueradiata	Farmed	Japan	Izawa (1969)
Dissonus hoi		*S. hippos*	Wild	Australia (WA)	Tang & Kalman (2005)
Lernanthropus paenulatus		*S. lalandi*	Wild	Australia (NSW)	Rohde *et al.* (1995)
				New Zealand	Present study
				Woods Hole, USA	Wilson (1922)
Parabrachiella seriolae		*S. quinqueradiata*	Farmed	Japan	Shiino (1959)
Parabrachiella sp.		*S. lalandi*	Wild	Australia (Qld)	Rohde (1978)
				New Zealand	Sharp *et al.* (2003)
Endoparasites					
Myxozoa					
Ceratomyxa seriolae		*S. quinqueradiata*	Farmed	Japan	Yokoyama & Fukuda (2001)
Ceratomyxa buri		*S. quinqueradiata*	Farmed	Japan	Yokoyama & Fukuda (2001)
Trematoda					
Bucephalus gorgon	*Gasterostomum gorgon*	*S. lalandi*	Wild	USA	Williams & Bunkley-Williams (1996)
	Nannoenterum gorgon	*S. dumerili*	Wild	Mediterranean, Corsica	Bartoli *et al.* (2005)
	Bucephalus introversus				

Table 2. (*continued*)

Parasite taxa	Synonyms	Host species	Origin	Location	References
Rhipidocotyle longicirrus	*Bucephalopsis longicirrus* *Bucephaloides longicirrus* *Bucephalopsis arcuatus* *Bucephaloides arcuatus*	*S. dumerili*	Wild	France	Bartoli & Bray (2005)
Stephanostomum petimba		*S. hippos*	Wild	Australia (WA)	Bray & Cribb (2003)
		S. dumerili	Wild	Corsica, France	Bartoli & Bray (2004)
Tormopsolus orientalis	*Tormopsolus medius*	*S. lalandi*	Wild	Australia (Qld)	Bartoli *et al.* (2004)
				British West Indies	Sogandares-Bernal (1959)
				Japan	Yamaguti (1934)
Tormopsolus orientalis		*S. dumerili*	Wild	Curaçao	Nahhas & Carlson (1994)
				Mediterranean, Corsica	Yamaguti (1934)
		S. dumerili	Wild	Mediterranean, Spain	Yamaguti (1934)
				Hawaii	Williams & Bunkley-Williams (1996)
				Japan	Williams & Bunkley-Williams (1996)
		S. quinqueradiata	Wild	Japan	Yamaguti (1934)
Erilepturus hamati	*Ectenurus hamati*	*S. lalandi*	Wild	Japan	Yamaguti (1934)
		S. quinqueradiata	Wild	Japan	Yamaguti (1934)
Parahemiurus merus		*S. dumerili*	Wild	Jamaica	Nahhas & Carlson (1994)
		S. quinqueradiata	Wild	Japan	Nahhas & Carlson (1994)
Paradeontacylix godfreyi		*S. lalandi*	Wild	Australia (SA)	Chapter 3
P. sanguinicoloides		*S. lalandi*	Wild	Atlantic coast, USA	McIntosh (1934)
		S. hippos	Wild	Australia (SA)	Chapter 3
Paradeontacylix sp.		*S. hippos*	Wild	Australia (SA)	Chapter 3
		S. dumerili	Wild	Mediterranean, Spain	Grau *et al.* (1999)
Acanthocephala					
Gorgorhynchoides elongatus		*S. dumerili*	Wild	Atlantic Ocean	Williams & Bunkley-Williams (1996)
		S. rivoliana	Wild	Atlantic Ocean	Williams & Bunkley-Williams (1996)

Table 2. (*continued*)

Parasite taxa	Synonyms	Host species	Origin	Location	References
Gorgorhynchoides lintoni		*S. lalandi*	Wild	Atlantic Ocean	Amin (1998)
Rhadinorhynchus seriolae		*S. quinqueradiata*	Wild	Japan	Golvan (1988)
Nematoda					
Anisakis sp.		*S. lalandi*	Wild	Australia (SA)	SAMA AHC 1186-1187[a]
				New Zealand	Smith *et al.* (2004)
Contracecum sp.		*S. lalandi*	Wild	New Zealand	Jones (1988)
Hysterothylacium sp.		*S. lalandi*	Wild	New Zealand	Johnston & Mawson (1944)

[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).

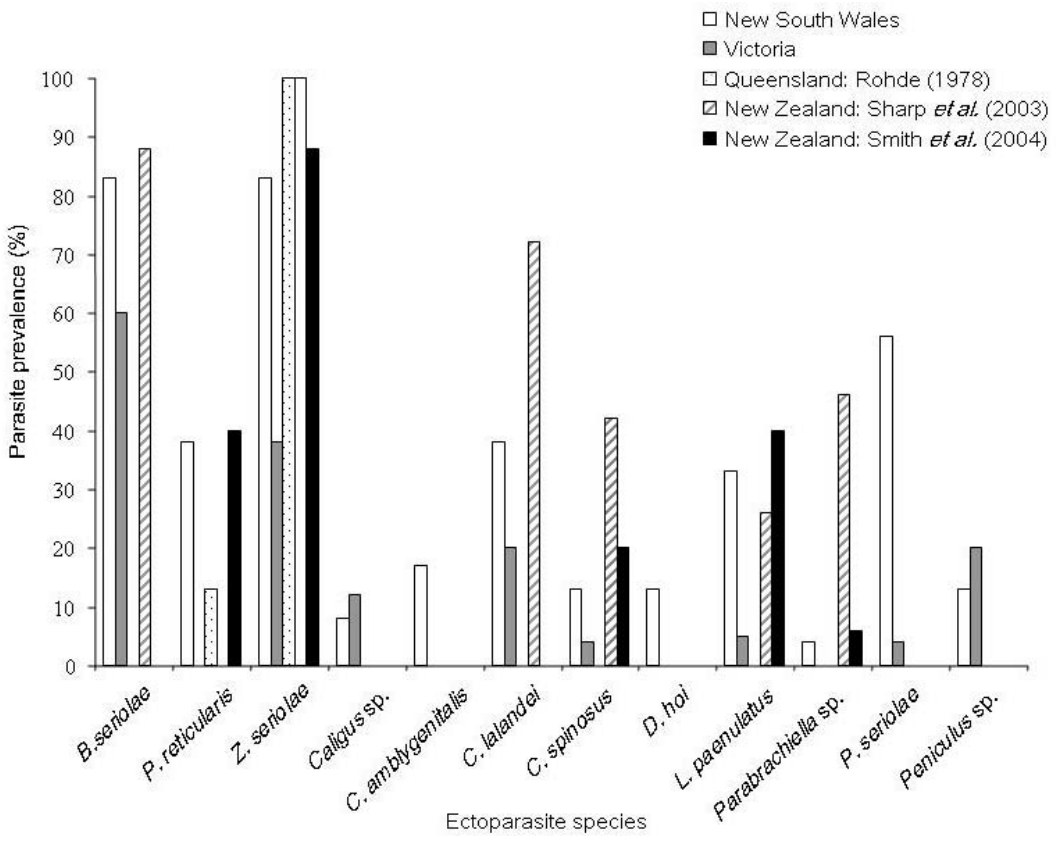

Figure 1. *Seriola lalandi* ectoparasite prevalence in New South Wales, Victoria and Queensland, Australia, and New Zealand.

2.5. 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 eight 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.* (1999) who documented the metazoan parasite community of wild amberjack, *S. dumerili* from the western Mediterranean Sea.

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 Rohde 1976), *Unicapsula seriolae* (Lester 1982), *Tetrarhynchus* sp. (see Johnston 1914), *Dinurus longisinus*, *Ectenurus trachuri* (see Bray *et al.* 1993a) and *Lecithaster stellatus* (see Bray *et al.* 1993b), while *Australorhynchus tetramorphacanthus* (Lebedev 1967), 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 (Johnston 1914), the softened flesh condition associated with these parasite infections is relatively rare in *S. lalandi* in NSW (Smith *et al.* 1991). 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*, occur in viscera of wild *S. lalandi* caught in South Australia (Chapter Five).

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.

Ectoparasite infection patterns

Monogeneans are important pathogens of farmed *Seriola* spp. and have been associated with considerable losses in aquaculture in Australia (Whittington *et al.* 2001; Ernst *et al.* 2002), New Zealand (Appendix One) and Japan (Ogawa 1996). We detected *Benedenia seriolae* on the body surface and *Paramicrocotyloides reticularis* and *Zeuxapta seriolae* on the gills (Table 1). *Benedenia seriolae* and *Z. seriolae* have been responsible for considerable losses of farmed *Seriola* spp. 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%) (Sharp *et al.* 2003) and slightly lower in Victoria (60%) (Table 1, Figure 1). The intensity of *B. seriolae* was similar in NSW and Victoria (eight and nine parasites, respectively) but higher in New Zealand (29) (Sharp *et al.* 2003). There are no previous published records of prevalence and intensity for *B. seriolae* of wild *S. lalandi* in Australia.

Paramicrocotyloides 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. In New Zealand, *P. reticularis* is known to infect *S. lalandi* brood stock (Appendix One), 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 (Figure 1). In NSW, *P. reticularis* infected at a lower intensity than *Z. seriolae*, with an intensity of two 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 two individuals.

Rohde (1978) and Sharp *et al.* (2003) 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.* (1995)

and Smith *et al.* (2004) who found *Z. seriolae* prevalence was 95% in NSW and ranged between 83 - 88% across three sites in New Zealand, respectively (Figure 1). Smith *et al.* (2004) suggested that Sharp *et al*. (2003) 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) (Sharp *et al.* 2003) were higher compared to Victoria (six; Table 1). Smith *et al*. (2004) detected the same intensity of *Z. seriolae* in New Zealand (six) 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*, *C. lalandei*, *C. spinosus* and an undetermined *Caligus* species. *Caligus lalandei* is well known from farmed *Seriola* spp. in Japan and Korea (Table 2) but has not been associated with disease problems (Ho *et al.* 2001). In contrast, *C. spinosus* has been associated with gill disease in farmed *S. quinqueradiata* in Japan (Egusa 1983). 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%) (Figure 1) (Sharp *et al.* 2003). *Caligus spinosus* prevalence was also lower in Australia (4% Victoria, 13% NSW) compared to New Zealand studies (42% and 20%) (Figure 1) (Sharp *et al.* 2003; Smith *et al.* 2004, respectively). *Caligus amblygenitalis* has not been documented previously from carangid hosts.

Parasites that infect the nasal cavity, *Naricolax chrysophryenus* and *Dissonus hoi*, were rare and were only found on *S. lalandi* in NSW (Table 1). *Naricolax chrysophryenus* has been previously reported from snapper, *Chrysophrys auratus*, and has not been reported previously from carangid hosts, while *D. hoi* was recently described from *S. hippos* in Western Australia (Table 2). There are no previous records of *Peniculus* spp. from *Seriola* spp., although they are known from other pelagic fishes in Australia (Hayward *et al.* 1998). *Lernanthropus paenulatus* from NSW exhibited similar prevalence (33%) to those determined in New Zealand (26% and 40%) (Sharp *et al.* 2003; Smith *et al.* 2004, respectively), but was only detected on one *S. lalandi* sampled in Victoria. *Parabrachiella seriolae*, 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%) (Sharp *et al.* 2003; Smith *et al.* 2004, respectively). We found low prevalence of *Parabrachiella* sp. in NSW (4%), which is consistent with Smith *et al.* (2004) who found 6% of fish were infected. However, we recorded higher parasite intensity in NSW (15) compared to New Zealand (two).

Ectoparasitic copepods can have a considerable impact on wild and farmed fish (Johnson *et al.* 2004). In the northern hemisphere, fish farms have been implicated in the spread of salmon lice (e.g. *Lepeoptheirus salmonis*) to wild fish and the subsequent decline of wild salmon populations (Tully *et al.* 1993; Butler 2002), while others argue that over-fishing, habitat loss and climate change are primarily responsible for stock declines (Noakes *et al.* 2000). 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 *et al.* (1997) 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.

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* and *C. buri* were recovered from the gall bladder (Table 1). These species are known from the gall bladder of farmed *S. quinqueradiata* in Japan (Table 2) (Yokoyama & Fukuda 2001). There has been no apparent associated illness or mortality with myxozoan infections of the gall bladder in *Seriola* spp. in aquaculture (Sheppard 2004). *Myxobolus spirosulcatus* was described from *S. quinqueradiata* in Japan, but was not recovered from *S. lalandi* in this study. Grau *et al.* (1999) also recovered *Myxobolus* sp. from the brain of wild *S. dumerili*, but 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.* (1999) recovered 10 trematode species from wild *S. dumerili* representing all of these families, except for Lepocreadidae. The acanthocolpids *Stephanostomum petimba* and *Tormopsolus orientalis* 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* 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 (Table 2). Identifying *Rhipidocotyle longicirrus* 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* spp. are well-

known parasites of Australian salmon, *Arripis trutta*. We found an undetermined *Telorhynchus* sp. in the digestive tract of *S. lalandi* from Victoria (Table 1). *Seriola lalandi* from Victoria hosted the lepocreadid species *Opechona kahawai* and the lecithasterid species *Aponurus laguncula*, along with the majority of hemiurid species, including *Erilepturus hamati*, *Elytrophallus* sp., *Elytrophalloides oatesi*, *Parahemiurus merus* and *Hirudinella* sp. *Lecithocladium* sp. and *Plerurus digitatus* 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* spp. We detected an undetermined species of didymozoid in the digestive tracts and viscera of *S. lalandi* from NSW and Vic, respectively. Grau *et al.* (1999) found two species of didymozoid infecting *S. dumerili* including *Nematobothrium scombri* in the gills, abdominal cavity and liver and *Wedlia bipartite*, in the gills.

Three species of blood fluke, *Paradeontacylix godfreyi*, *P. sanguinicoloides* and *Paradeontacylix* sp. infected *S. lalandi* at low intensities (Table 1). Detecting *Paradeontacylix* spp. in these regions is an important finding with regard to potential development of aquaculture in Australia (Chapter 3). Species of *Paradeontacylix* have been associated with mass mortalities of farmed *S. dumerili* in the Spanish Mediterranean (Crespo *et al.* 1992) and Japan (Ogawa & Fukudome 1994). 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 (Appendix One). It has been suggested that blood fluke infestation in farmed *S. quinqueradiata* in Japan may also promote mortality of fish with bacterial infections (Kumon *et al.* 2002).

Cestode species *Nybelinia thyrsites* and tetraphyllidean metacestodes Types 1 and 4 following Chambers *et al.* (2000) 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* known from *Scomber japonicus* in Japan. *Rhadinorhynchus* sp. 2 is similar to the description of *R. seriolae* and *R. trachuri* which have been recorded previously from Japan from *S. quinqueradiata* (see Fukui & Morisita 1937) and *Trachurus japonicus*, respectively. Further taxonomic discrimination of *Rhadinorhynchus* spp. from *S. lalandi* is warranted, but was beyond the scope of this study. Interestingly, *Australorhynchus tetramorphacanthus* in the same acanthocephalan family, Rhadinorhynchidae, is known from *S. lalandi* in the Great Australian Bight and the Tasman Sea (Lebedev 1967) while a suspected *Longicollum* sp. (Pomphorhynchidae) was recovered from *S. lalandi* in New Zealand (Smith *et al.* 2004).

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).

Parasite assemblages from different regions

Seriola 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 (Gillanders *et al.* 2001). *Seriola lalandi* in Victoria were a smaller size class (mean 54 cm FL), while fish from NSW were

typically larger (mean 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.

Seriola 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*, *Caligus spinosus*, *C. lalandei*, *Lernanthropus paenulatus* and *Parabrachiella* sp. (see Sharp *et al.* 2003; Smith *et al.* 2004). This is not surprising considering that Nugroho *et al.* (2001) 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 (Gillanders *et al.* 2001). *Seriola lalandi* from NSW hosted additional external parasites (*C. amblygenitalis*, *Caligus* sp., *Dissonus hoi*, *Naricolax* sp. and *Parabrachiella 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.

Potential stock discriminators

Parasites have been used on many occasions to determine the probable degree of movement of individual fish (e.g. Mackenzie 2002) and thus provide clues about population homogeneity and the degree of mixing of different populations (Lester *et al.* 2001). Mackenzie (2002) 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 (Criscione *et al.* 2006). 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 (Gillanders *et al.* 2001). 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 Western Australia 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 (Mackenzie & Abaunza 1998). 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 *Paramicrocotyloides reticularis* and the copepod *Parabrachiella 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. *Paramicrocotyloides reticularis* has a reliable prevalence in Queensland (13%, Rohde 1978), NSW (38%, present study) and New Zealand (27-40%, Smith *et al.*

2004). *Parabrachiella 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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NOTE: This plate is included on page 39 of the print copy of the thesis held in the University of Adelaide Library.

A histology section through the heart of a yellowtail kingfish (*Seriola lalandi*) infected with an undetermined *Paradeontacylix* sp. (Digenea: Sanguinicolidae)

Scale bar = 1,200 µm

Photo: Ben Diggles

CHAPTER THREE

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

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CHAPTER THREE

PARADEONTACYLIX GODFREYI N. SP. (DIGENEA: SANGUINICOLIDAE) FROM THE HEART OF WILD *SERIOLA LALANDI* (PERCIFORMES: CARANGIDAE) IN SOUTHERN AUSTRALIA

3.1. Abstract

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

3.2. Introduction

Sanguinicolids are digenean parasites that inhabit the circulatory system of a broad diversity of fish species worldwide. For *Seriola* spp. (Carangidae), *Paradeontacylix* spp. are serious pathogens of farmed amberjacks, *S. dumerili*, and have been associated with mass mortalities in the Spanish Mediterranean

(Crespo *et al.* 1992) and Japan (Ogawa & Fukudome 1994). A *Paradeontacylix*-like blood fluke has also been associated with low-level mortalities of farmed yellowtail kingfish, *S. lalandi*, in New Zealand (Appendix One). Five *Paradeontacylix* spp. have been described: *P. sanguinicoloides* (the type species) from wild *S. lalandi*; *P. odhneri* from purple puffer, *Takifugu porphyreus* (= *Spheroides borealis*); *P. sinensis* from puffer fish, *T. oblongus* (= *Fugu oblongus*); *P. grandispinus* and *P. kampachi* from farmed *Seriola dumerili* (= *S. purpurascens*).

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

3.3. Materials and Methods

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

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

were dehydrated in an ethanol series, cleared in cedar wood oil and mounted on slides in Canada balsam.

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

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

3.4. Results

Sanguinicolidae

Paradeontacylix

Paradeontacylix godfreyi n. sp.

Type-host: *Seriola lalandi* (Carangidae).

Type-locality: Port Augusta, northern Spencer Gulf, South Australia (32º 42′04″S, 137º46′17″E).

Other locality: Killarney, Victoria (38º23′36″S, 142º20′24″E).

Site: Heart.

Infection details: Port Augusta: number of infected fish = 4; prevalence 12.5%; mean intensity 2 (1–5); host sizes 1,410–1,500 FL (350–1,500 FL, n = 32). Victoria: number of infected fish = 1; prevalence 4%; intensity 1; host sizes 760 FL (460–790 FL, n = 25). The single infected specimen of *S. lalandi* from Victoria was also parasitised by a specimen of *Paradeontacylix* sp. (see below). Nodules, resulting from parasite eggs, were observed in the inner muscle layers of the heart in the ventricle and atrium.

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

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

Description (Figures 1, 2A)

Paradeontacylix sensu Smith (2002). Description and measurements based on 8 mature adult specimens. Body slender, dorsoventrally flattened, 4,080 (3,739–4,215, n = 6) long by 428 (357–566, n = 8) wide; approximately 10 times longer than wide, width consistent throughout most of specimen only narrowing at anterior and posterior extremities (Figure 1A). Lateral body margins slender, skirt–like (Figure 1A), bearing numerous transverse rows of marginal tegumental

spines spanning entire length of parasite except for anterior extremity. Marginal tegumental spines ventrolateral, arranged in numerous transverse rows, 816 (690–890, n = 6) (Table 1) on both sides of body, rows regularly spaced (Figure 1B); number of spines per row increasing from 4 posteriorly to 22 at mid–body region. Posteriorly, 16 large tegumental spines, 33 (22–40, n = 16) long by 4 (2–6, n = 16) wide at base; conspicuous, claw–like distally, arranged in 4 longitudinal rows each comprising 4 spines (Figure 2A). Additionally, 2–4 rows of medium–sized spines 19 (11–23, n = 8) long by 3 (2–5, n = 8) wide at base, arranged on either side of large spines (Figure 2A).

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

Testes 99 (n = 1), mostly transversely elongate, some rounded, stacked irregularly mostly between posterior extremities of caeca. Testicular field 852 (642–1,112, n = 4) long representing 21 (18–25)% of total body length; posteriorly, overlapping anterior third of ovary (Figure 1A). Vas deferens descending at mid–line from posterior region of testicular field, passing dorsal to ovary, following curved path to form seminal vesicle filling entire cirrus sac. Cirrus cylindrical, 60 (47–75, n = 4) long. Male genital pore dorsal, near left body margin, 461 (343–569, n = 7) from posterior end of body (Figure 1B). Ovary heart-shaped, overlapped anteriorly by testes, 196 (149–279, n = 8) long and ~4% of body length, 330 (222–443, n = 8) wide or 76% of body width, located 696 (438–959, n = 7) or

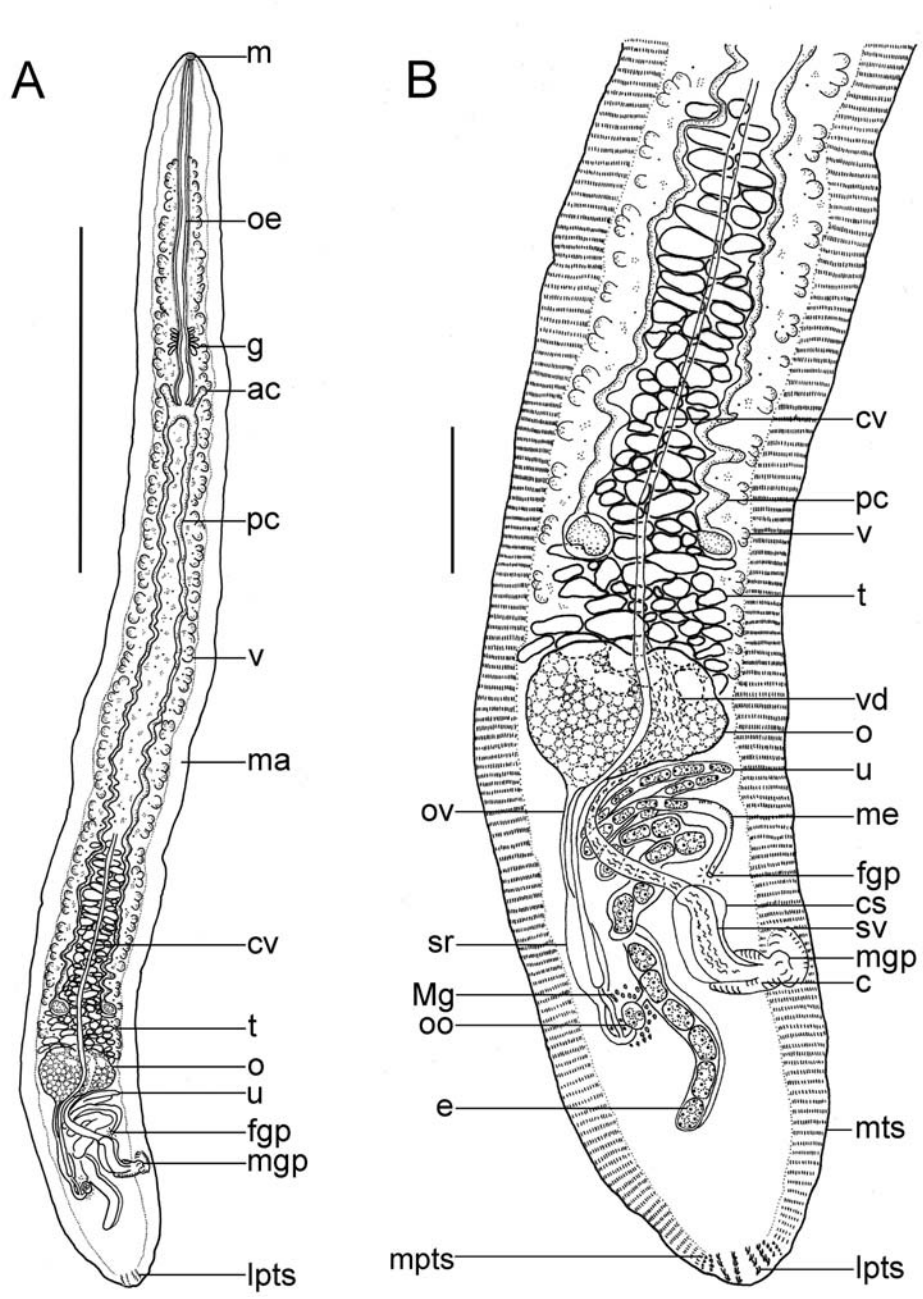

Figure 1. *Paradeontacylix godfreyi* n. sp. A. Whole adult parasite, holotype, ventral view. B. Posterior portion, holotype, ventral view, showing testicular field and post–ovarian region. Abbreviations: ac, anterior caecum; c, cirrus; cs, cirrus sac; cv, common vitelline duct; e, egg; fgp, female genital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

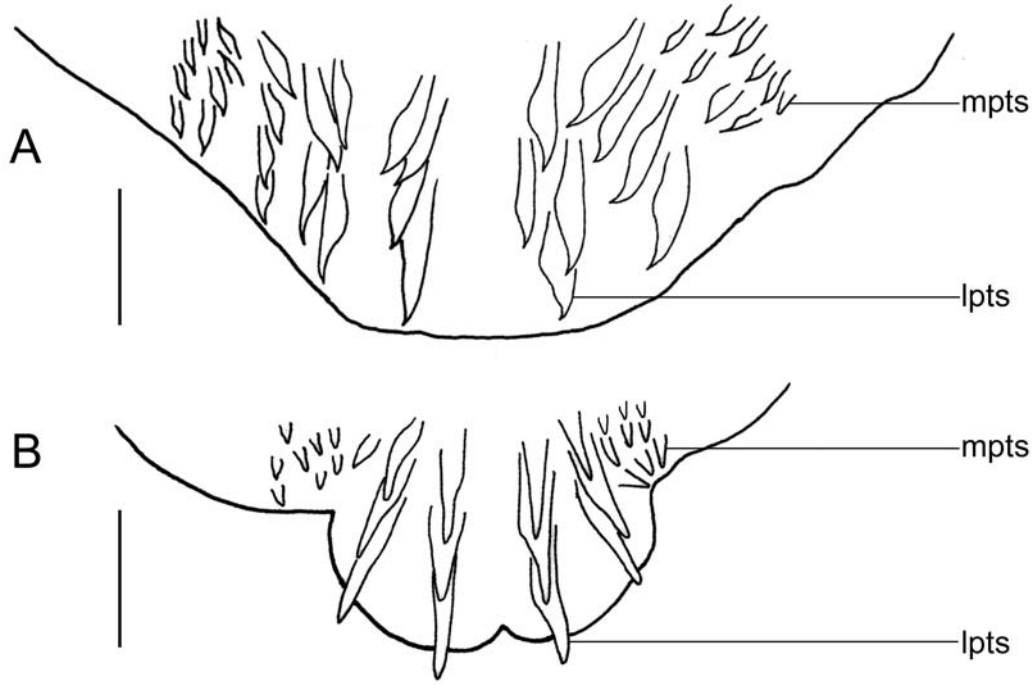

Figure 2. Large posterior tegumental spines (lpts) and medium posterior tegumental spines (mpts), ventral view of Australian *Paradeontacylix* spp. A. *Paradeontacylix godfreyi* n. sp, holotype, showing claw-like large posterior tegumental spines arranged in 4 longitudinal rows each comprising 4 spines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

~17% of body length from posterior end of body (Figure 1B). Oviduct originating from right side of ovary, passing posteriorly, dilating to form seminal receptacle, 199 (139–261, n = 6) long, 38 (17–53, n = 7) wide. Posteriorly, seminal receptacle narrows, receives common vitelline duct, turns left to join oötype 55 (41–64, n = 7) long by 49 (36–56, n = 7) wide, ovoid, near level of cirrus sac, surrounded by Mehlis' glands (Figure 1B). Uterus descending 137 (92–202, n = 7) posterior to oötype, then ascending through several coils filling space immediately posterior to ovary, finally descending to form slender metraterm. Female genital pore opening dorsally, anterior to male pore, at level of junction of vas deferens with seminal vesicle (Figure 1B). Distance between male and female

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

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

pores 152 (84–206, n = 4). Eggs ovoid 38 (36–41, n = 4) long, 30 (29–34, n = 4) wide, measured *in utero*. Vitellarium follicular, follicles extending from level one-third along length of oesophagus posteriorly to anterior margin of ovary (Figure 1A). Common vitelline duct first observed medianly, just anterior to testicular field, passing posteriorly ventral to testes and ovary, terminating at level of oötype. Excretory vesicle and pore not observed.

Remarks

Smith (2002) provided a key to the genera of the Sanguinicolidae and revised the generic diagnosis for *Paradeontacylix*. According to the revision, *Paradeontacylix* spp. possess 19 to 71 testes. However, the new species described here has up to 99 testes. The number of testes in most specimens we collected was difficult to determine with accuracy, except in the holotype. While the greater number of testes is noteworthy, we have not revised the generic diagnosis here based on this single character. Testes number can be highly variable in some species, and degeneration of the testes has been observed in adult specimens of *Aporocotyle simplex* and *Cruoricola lates* (see Thulin 1980; Herbert *et al.* 1994). A revision may be necessary when more material of *P. godfreyi* becomes available. Table 1 presents a comparison of the important morphological characters of *Paradeontacylix* spp. reported from *Seriola* spp.

Paradeontacylix sanguinicoloides

Host species: *Seriola hippos* (Carangidae).

Locality: Greenly Island, offshore from Port Lincoln, South Australia (34º38′29″S, 134º47′28″E).

Site: Heart.

Infection details: number of infected fish = 1; prevalence 25%; intensity 1; host sizes 1,160 FL (1,120–1,160 FL, n = 4). This Samson fish was also parasitised by a *Paradeontacylix* sp. (see below).

Material deposited: 1 voucher specimen SAMA AHC 28910.

Previous records: *S. lalandi*: blood vessels of the gills, Atlantic Ocean, off Miami, Florida, USA (holotype: USNPC 34329, McIntosh 1934); heart,

Sir John Young Banks, New South Wales, Australia (34º56′52″S, 150º55′45″E) (voucher: SAMA AHC 28909, Appendix One).

Remarks

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

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

Material studied: single specimen from the heart of *S. lalandi* (Carangidae) from Killarney, Victoria (38º23′36″S, 142º20′24″E) and a single specimen from the heart of *S. hippos* (Carangidae) from Greenly Island, offshore from Port Lincoln, South Australia (34º38′29″S, 134º47′28″E).

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

intensity 1; host sizes 1160 FL (1120–1160 FL, n = 4). This Samson fish was also parasitised by a specimen of *P. sanguinicoloides* (see above).

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

Remarks

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

***Paradeontacylix kampachi* of Montero *et al.* (1999; 2003)**

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

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

Remarks

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

3.5. Discussion

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

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

shorter testicular field relative to total body length (McIntosh 1934, Table 1). *Paradeontacylix godfreyi* can also be separated from *Paradeontacylix* sp. reported here by its claw-like posterior spines, numerous rows of transverse marginal tegumental spines, greater number of marginal tegumental spines per row and a shorter testicular field relative to total body length (Table 1).

The new species is similar to specimens of *P. kampachi* from Japan and Spain (see Ogawa & Egusa 1986 and Montero *et al.* 2003, respectively), as both possess a short testicular field relative to total body length. However, *P. godfreyi* can be discriminated from this species by the presence of large posterior tegumental spines, numerous marginal tegumental spines in rows and a greater number of testes (Table 1). The new species also differs from *P. odhneri* and *P. sinensis* reported from puffer fish (Tetraodontidae) off Japan and China, respectively (Layman 1930; Liu 1997). Unlike *P. godfreyi*, *P. sinensis* lacks posterior tegumental spines and has fewer testes (29–32 arranged in pairs of bilateral lobes) that occupy a greater proportion of the total body length (~69%) (Liu 1997). *Paradeontacylix odhneri* differs from *P. godfreyi* as the vitellarium extends posterior to the ovary and the testicular field terminates anterior to the ovary (Layman 1930). The original description of *P. odhneri* does not include detailed information on the marginal tegumental transverse spines, posterior tegumental spines or the number of testes (Layman 1930), so these features could not be compared with *P. godfreyi*.

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

of rows of marginal tegumental spines and maximum number of marginal tegumental spines per row, a short testicular field relative to total body length and have a similar number of testes (Table 1).

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

With low host-specificity within *Seriola* spp. and the possibility of multiple species infections, *Paradeontacylix* spp. may be of potential concern for Australian *S. lalandi* aquaculture. However, to date, *Paradeontacylix* spp. have not been detected in farmed *S. lalandi* in Australia. Unlike Japan where farmed *S. dumerili* are stocked from the wild and may already harbour adult specimens of *Paradeontacylix* spp., juvenile *S. lalandi* in Australia are spawned from wild caught brood stock and reared in land-based hatcheries. Consequently, juvenile fish are unlikely to be exposed to infective cercariae of sanguinicolids until they are stocked into sea-cages where wild intermediate molluscan or annelid hosts may reside nearby. Nevertheless, *Paradeontacylix*-like blood flukes have been detected in histological sections of the heart, brain and internal organs from farmed *S. lalandi* in New Zealand, despite juveniles being reared in a hatchery (Appendix One). One explanation for the apparent absence of *Paradeontacylix* spp. in Australian *S. lalandi* aquaculture may be the lack of availability, abundance and proximity of appropriate wild invertebrate intermediate hosts near sea-cages. However, the intermediate host species for *Paradeontacylix* spp. are currently unknown.

It is essential to identify potential intermediate host species for *Paradeontacylix* spp. so that sea-cages containing *Seriola* spp. can be positioned to keep definitive fish hosts and invertebrate hosts spatially segregated. Bullard & Overstreet (2002) suggest that control of blood fluke infections may only be achieved by separating intermediate and final hosts, as elimination of susceptible intermediate hosts is impractical and cost-prohibitive. It appears that an appropriate intermediate host is absent for *P. godfreyi* in kingfish farming areas in Spencer Gulf, South Australia because adult parasites have not been detected in farmed fish. However, this is not the case for the blood fluke *Cardicola forsteri* infecting southern bluefin tuna, *Thunnus maccoyii* in Spencer Gulf. Within two months of the capture of wild tuna and their transfer into sea-cages, *C. forsteri* intensity increased from a single specimen found in 10 wild tuna sampled to 100% prevalence and an average intensity of 27 specimens per caged tuna (n = 30) (Aiken *et al.* 2006). Aiken *et al.* (2006) suggest that the intermediate host, which is currently unknown, must be in close proximity to the caged tuna for so many to become infected in such a short period.

Surveys of potential intermediate hosts for *P. godfreyi* around *S. lalandi* cages in Spencer Gulf, South Australia may prove futile as no blood flukes have yet been reported from farmed kingfish. However, identifying the species of blood fluke infecting farmed *S. lalandi* in New Zealand and further examination of potential intermediate hosts near kingfish sea-cages in New Zealand may allow us to draw comparisons or assess potential intermediate host species for *Paradeontacylix* in Australia. Identification of the intermediate host(s) would help to determine suitable sea-cage sites for *S. lalandi* away from potential infection sources as the industry expands. An alternative approach would be to monitor sentinal fish for infection in areas proposed for sea-cage farming or to adopt a land-based farming system that excludes potentential intermediate hosts.

The description of *P. godfreyi* and documentation of *Paradeontacylix* sp. increases the number of sanguinicolid species infecting wild *S. lalandi* in Australian waters to three, together with *P. sanguinicoloides* from *S. lalandi* in New South Wales (Appendix One). Before this investigation, no sanguinicolids

were reported from *S. hippos* but we have documented a new host record for *P. sanguinicoloides* from *S. hippos* and provide information on an unidentified *Paradeontacylix* sp. from *S. hippos* in South Australia and *S. lalandi* in Victoria.

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Left antennule of female *Naricolax chrysophryenus* (Cyclopoida: Bomolochidae)
ventral view
Scale bar = 0.50 µm
Photo: Nicholas B. Stevens and Kate S. Hutson

CHAPTER FOUR

Naricolax hoi n. sp. (Cyclopoida: Bomolochidae) from *Arius maculatus* (Siluriformes: Ariidae) off Taiwan and redescription of *N. chrysophryenus* (Roubal, Armitage & Rohde, 1983) from a new host, *Seriola lalandi* (Perciformes: Carangidae), in Australian waters

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Systematic Parasitology v.68 (2), pp. 97-113, October 2007

Net change for yellowtail kingfish (*Seriola lalandi*) at Arno Bay, Spencer Gulf, before a hydrogen peroxide bath for treatment of monogenean parasites
Photo: Kate S. Hutson

CHAPTER FIVE

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

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CHAPTER FIVE

RISK ASSESSMENT FOR METAZOAN PARASITES OF YELLOWTAIL KINGFISH *SERIOLA LALANDI* (PERCIFORMES: CARANGIDAE) IN SOUTH AUSTRALIAN SEA-CAGE AQUACULTURE

5.1. 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 elsewhere. 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. *Benedenia seriolae* is currently regarded to have the highest potential negative consequence for cost-effective sea-cage farming of *S. lalandi* in Australia and should the industry expand elsewhere, this monogenean species must be monitored closely. 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.

5.2. 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) and other wild marine fish and invertebrate species 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 41 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 (Chapter Two). 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 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.

5.3. Materials and Methods

Fish and parasite collection

Wild *S. lalandi* (n = 62) were caught by rod and reel in Spencer Gulf near Port Augusta (32º 42′04″S, 137º46′17″E), Fitzgerald Bay (32º 24′14″S, 137º19′16″E), Arno Bay (33º55′21″S, 136º36′14″E). Boston Bay (34º44′3″S, 135º55′46″E) and offshore at Greenly Island (34º38′29″S, 134º47′28″E) and Kangaroo Island (35º34′48″S, 137º25′35″E), South Australia between May 2003 and May 2005 (Figure 1). Wild *S. hippos* (n = 6) were caught at Greenly Island (34º38′29″S, 134º47′28″E) and Rocky Island (34º48′23″S, 134º42′40″E), South Australia in April 2004 and April 2005 (Figure 1). Wild *Seriola* spp. ranged between 320 and 1,410 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 (Figure 1). Farmed fish ranged between 282 and 652 mm FL. Methodology

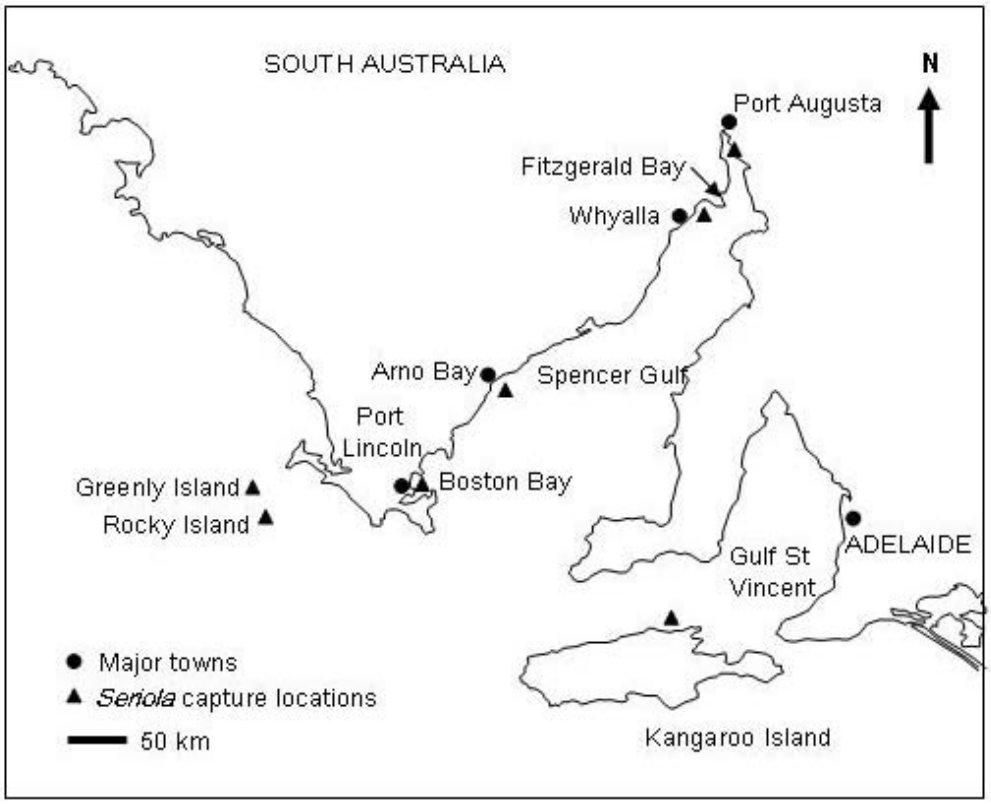

Figure 1. Wild and farmed *Seriola* capture locations in South Australia, Australia

for parasite sampling was similar to that described previously (Chapter Two). 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) 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).

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.* 2004; Nowak 2004; Murray & 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.

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* spp. 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), 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).

Estimate of exposure of farmed fish to wild parasitised Seriola *spp.*

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 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 2,400 km along the south coast of Australia into South Australian waters (Rowland *et al.* 2006). *Seriola 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 (Figure 1), where they are frequently captured (Fowler *et al.* 2003). Given 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.

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.

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 that met one criterion were assigned a low consequence and parasites that meet 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).

5.4. Results

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. A greater sample size may have revealed parasite species that are less common in the population. Indeed, distributions of parasite in host-populations are typically over-dispersed and FreeCalc base their confidence levels on the assumption that parasites are distributed at random. Consequently, this risk assessment is provided for more common parasite species in the host population.

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.

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

Group	Taxon	Microhabitat	Host	Locality	Wild	Farmed	Ref/Accession no
Acanthocephala							
	Australorhynchus tetramorphacanthus	Intestine	*lalandi*	EC, SA	Yes	No	Lebedev (1967)
	Rhadinorhynchus sp. 1	Intestine	*lalandi*	EC	Yes	No	Chapter Two
	Rhadinorhynchus sp. 2	Intestine	*lalandi*	Vic	Yes	No	Chapter Two
Cestoda							
Tetraphyllidea	*Callitetrarhynchus gracilis*	Body cavity	*lalandi*	SG	Yes	Cyst: W, PL	AHC 29179
	Nybelinia thyrsites	Intestine	*lalandi*	EC	Yes	No	Chapter Two
	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	Chapter Two
	C. epidemicus	Body surface*	*lalandi*	EC, SG	Yes	No	C6313
	C. lalandei	Body surface*	*lalandi*	EC, Vic	Yes	No	Chapter Two
		Body surface	*hippos*	SA	Yes	No	C6314
	C. spinosus	Gill arch	*lalandi*	EC, Vic	Yes	No	Chapter Two
	Caligus sp. 1	Not determined	*lalandi*	EC, Vic, SA, SG	Yes	W, AB, PL	C6232 & 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 & Kalman (2005)
	Lepeophtheirus sp.	Not determined	*hippos*	SA	Yes	No	C6318
	Lernanthropus paenulatus	Gills	*lalandi*	EC, Vic, SG	Yes	No	C6239& 6309
		Gills	*hippos*	SA	Yes	No	C6319
	Naricolax chrysophryenus	Nasal cavity	*lalandi*	EC, SG	Yes	AB, PL	Chapter Four
	Parapetalus spinosus	Gills	*hippos*	SA, WC	Yes	NA	C6320
	Parabrachiella seriolae	Buccal folds	*lalandi*	EC, Vic, SG	Yes	No	C6321
		Buccal & fin sulcus	*hippos*	SA	Yes	NA	C6322
	Parabrachiella sp.	Gills	*lalandi*	EC	Yes	No	Chapter Two
	Peniculus sp.	Body surface	*lalandi*	EC, Vic	Yes	No	Chapter Two

Table 1. (*continued*)

Group	Taxon	Microhabitat	Host	Locality	Wild	Farmed	Ref/Accession no
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)
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	Chapter Two
		Stomach	*hippos*	SA	Yes	NA	AHC 34263
	*Hysterothylacium s*p.	Stomach, caeca	*lalandi*	EC, SG	Yes	No	AHC 34264
		Stomach	*hippos*	SA	Yes	NA	AHC 34265
	Pseudoterranova sp.	Intestine	*lalandi*	EC	Yes	No	Chapter Two
	Rhabdochona sp.	Stomach	*lalandi*	Vic	Yes	No	Chapter Two
(adult)	*Hysterothylacium* sp.	Stomach	*lalandi*	SG	Yes	No	AHC 34266
Trematoda							
Acanthocolpidae	*Tormopsolus orientalis*	Stomach, intestine	*lalandi*	EC, Vic, SG	Yes	PL	AHC 29143 & 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

Table 1. *(continued)*

Group	Taxon	Microhabitat	Host	Locality	Wild	Farmed	Ref/Accession no
Bucephalidae	*Rhipidocotyle longicirrus*	Digestive tract	*lalandi*	EC, SG	Yes	PL	AHC 29150-29151
	Telorhynchus sp.	Digestive tract	*lalandi*	Vic	Yes	No	Chapter Two
Didymozoidae	*Undetermined species*	Viscera	*lalandi*	EC, Vic	Yes	No	Chapter Two
Hemiuridae	*Aponurus laguncula*	Stomach	*lalandi*	Vic	Yes	No	Chapter Two
	Dinurus longisinus	Stomach	*lalandi*	EC	Yes	No	Bray *et al.* (1993a)
	Ectenurus trachuri	Stomach	*hippos*	SA	Yes	No	Chapter Two
	Erilepturus hamati	Stomach	*lalandi*	EC, Vic, SG	Yes	No	AHC 29152
	Elytrophallus sp.	Stomach	*hippos*	SA	Yes	NA	AHC 29153
	Elytrophalloides oatesi	Stomach	*lalandi*	Vic	Yes	No	AHC 29154
	E. humerus	Stomach	*lalandi*	SG	Yes	AB	Chapter Two
	Hirudinella sp.	Stomach	*lalandi*	Vic	Yes	No	AHC 29155
	Lecithocladium sp.	Stomach	*lalandi*	EC	Yes	No	Chapter Two
Lecithasteridae	*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	Chapter Two
	Aponurus laguncula	Stomach	*lalandi*	Vic	Yes	No	Chapter Two
	Opechona kahawai	Stomach	*lalandi*	Vic	Yes	No	Chapter Two
Sanguinicolidae	*Paradeontacylix godfreyi*	Heart	*lalandi*	SG, Vic	Yes	No	AHC 28904-28908
	P. sanguinicoloides	Heart	*lalandi*	EC	Yes	No	Chapter Three
		Heart	*hippos*	SA	Yes	No	Chapter Three
	Paradeontacylix sp.	Heart	*lalandi*	Vic	Yes	No	Chapter Three
		Heart	*hippos*	SA	Yes	No	Chapter Three

Parasites identified in the present study and documented previously from wild and farmed *Seriola 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.

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 and 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

Table 2. (*continued*)

Parasite taxa	Potential mass mortality	Pathology	Marketability	Consumer health	Consequence
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 & adult)	-	X	-	-	Low
Pseudoterranova sp. (larvae)	-	X	-	-	Low
*Rhabdochon*a 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.

Table 3. Parasite risk analysis in *Seriola lalandi* sea-cage aquaculture in Spencer Gulf, South Australia. Likelihood of parasite establishment and proliferation including 1) estimate of exposure of farmed fish to parasitised *Seriola* spp. 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.

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
Naricolax chrysophryenus	High	High	High	Negligible	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

Table 3. (*continued*)

Parasite taxa	1) Exposure	2) Pathway	Likelihood	Consequence	Ability to treat
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	Ye
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

Table 3. (*continued*)

Parasite taxa	1) Exposure	2) Pathway	Likelihood	Consequence	Ability to treat
Lecithocladium sp.	Negligible	Low	Negligible	Negligible	Yes
Lecithaster stellatus	Negligible	Low	Negligible	Negligible	Yes
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

5.5. 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. The framework for risk assessment provided here offers a method to integrate new data to reassess the risks posed.

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). *Caligus 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).

Caligus lalandei, well known from farmed *Seriola* spp. in Japan (Ho *et al.* 2001) and New Zealand (Appendix One) was not recovered from wild or farmed *S. lalandi* in South Australia 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 (Chapter Two) (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* (Table 1). 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 & 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.

Monogeneans

The capsalid *Benedenia seriolae* and the heteraxinid *Zeuxapta 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 (Appendix One). 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 and on the east coast of Australia (Rohde 1978) (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* (Mansell *et al.* 2005). Cycles of reinfection can also be prevented if treatments are coordinated strategically to break the life-cycle (Ernst *et al.* 2005; Lackenby *et al.* 2007).

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.

Paramicrocotyloides reticularis is not currently present in farmed *S. lalandi* in South Australia (Table 1). 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 (Chapter Two).

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; Chapter Two, respectively) (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, primates (cotton-top tamarins, *Saguinus oedipus*) have been treated successfully for acanthocephalans with oral albendazole (Weber & Junge 2000).

There are few reports of acanthocephalans in farmed finfish. It is unlikely that acanthocephalans could establish and proliferate in South Australian *Seriola*

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 acanthocephalan species to be negligible for *S. lalandi* sea-cage aquaculture (Table 3).

Cestodes

Cestodes transfer to piscivorous fish when they eat infected intermediate hosts. We detected immature larval *Callitetrarhynchus 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 *Seriola 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. 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, 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*.

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 & 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 *Unicapsula 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 1986; 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, pers. comm.) 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 east coast of Australia where myxosporean infection is common in wild *S. lalandi*.

Nematodes

In Chapter Two we 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 practise 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.

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 (Chapter Three). 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 & Fukudome 1994). 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 (Appendix One). 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 & 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 (Chapter 3). However, the intermediate host(s) is currently unknown.

5.6. 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. This will enable proactive rather than reactive parasite management and prevention of serious outbreaks.

NOTE: This photograph is included on page 119 of the print copy of the thesis held in the University of Adelaide Library.

John Marsh, Adelaide Game Fishing Club, releases a 20 kg tagged kingfish at Port Augusta
Photo: Bradley P. Smith

CHAPTER SIX

A tagging study on yellowtail kingfish (*Seriola lalandi*) and Samson fish (*S. hippos*) in southern Australian waters

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CHAPTER SIX

A TAGGING STUDY ON YELLOWTAIL KINGFISH (*SERIOLA LALANDI*) AND SAMSON FISH (*S. HIPPOS*) IN SOUTHERN AUSTRALIAN WATERS

6.1. Abstract

Wild yellowtail kingfish (*Seriola lalandi*) and Samson fish (*S. hippos*) were tagged with nylon-headed, single-barbed dart tags between December 1, 2004 and December 31, 2006 in Spencer Gulf and offshore from the west coast of Eyre Peninsula, South Australia. Two-hundred and forty-one *S. lalandi* and 73 *S. hippos* were tagged. Twenty-four *S. lalandi* were recaptured and the maximum distance between capture points was 130 km and the maximum time at liberty was 442 days. Two *S. hippos* were recaptured, of which one was at liberty for a maximum of 378 days. Both *S. hippos* were recaptured at the original capture site. Recapture results indicate that large *S. lalandi* remain in, or return to, northern Spencer Gulf. This region may be important for aggregations of large, reproductively mature *S. lalandi*. One large *S. lalandi* tagged at Port Augusta was recaptured near Fitzgerald Bay, indicating that wild fish may move past *S. lalandi* sea-cage farms in this region. This course of movement may provide opportunities for disease and parasite interactions between wild and farmed fish. An additional outcome of this research was the residual impact that it has had on sustainable fishing practices in South Australia with increased recreational fisher participation in the tag and release of *S. lalandi* and *S. hippos*.

6.2. Introduction

Yellowtail kingfish (*Seriola lalandi*) and Samson fish (*S. hippos*) are pelagic, schooling fish, which generally inhabit rocky reefs and adjacent sandy areas in coastal waters. Both species are capable of migrating considerable distances (Gillanders *et al.* 2001; Rowland *et al.* 2006). In Australia, *S. lalandi* inhabits

southern coastal waters from Queensland to Western Australia and northern Tasmania, while *S. hippos* has a disjointed distribution from southern Queensland to Montague Island in New South Wales and from Yorke Peninsula, South Australia to Shark Bay in Western Australia (Hutchins & Swainston 1986). Despite intensive tagging programmes in Australia for *S. lalandi* on the east coast (Gillanders *et al.* 2001) and for *S. hippos* on the west coast (Rowland *et al.* 2006), there are limited data available concerning the movements of wild *Seriola* spp. in South Australian waters. A likely reason for this is the negligible economic significance of the commercial fishery. Indeed, the total catch for *S. lalandi* has only exceeded 2 tonnes once in the last 32 years (McGlennon 1997). Furthermore, *Seriola* spp. are mobile and migratory species which makes them difficult to study. Nevertheless, *S. lalandi* and *S. hippos* are popular recreational target species in South Australia and are highly regarded by fishers for their sporting attributes and large size. Consequently, there may be opportunities for recreational fishers to contribute to research programmes on *Seriola* spp. *Seriola lalandi* also supports an expanding aquaculture industry in Spencer Gulf, South Australia, where it is farmed in sea-cages in Fitzgerald Bay near Whyalla, Arno Bay and Boston Bay near Port Lincoln (Figure 1). The nature of wild *Seriola* spp. movements is critical for informed management of the recreational fishery and to understand potential interactions between wild and farmed carangids in Spencer Gulf (e.g. Windsor & Hutchinson 1990).

We conducted a small-scale tagging programme in Spencer Gulf and offshore from Eyre Peninsula in South Australia to investigate the timing and nature of *Seriola* spp. movements. The purpose of this paper is to report on preliminary recapture data and movements for *Seriola* spp. in South Australian waters. This research provides new information on *Seriola* spp. movements and will be a useful foundation for future management of the recreational fishery and assessment of interactions between wild *Seriola* spp. and the *S. lalandi* aquaculture industry.

6.3. Materials and Methods

Conventional tagging programmes and participation

A tagging programme for *Seriola* spp. in South Australia was conducted in conjunction with the South Australian branch of the Australian National Sportfishing Association's tagging programme, called 'Saftag'. Tag data from fish we captured between December 1, 2004 and December 31, 2006 were provided to Saftag for inclusion in their locally administered database. We sought additional tag records from New South Wales Fisheries (NSWF) because game fishing clubs in South Australia commonly use NSWF tags. Data were gathered from Saftag (Marcel Vandergoot, 288 Hayman Road Lewiston South Australia 5501 Australia) and NSWF databases (Karen Woodrick, Game Fish Tagging Program, NSW Department of Primary Industries, PO Box 21 Cronulla NSW 2230 Australia) for all existing tag and recapture records for *Seriola* spp. captured or recaptured in South Australian waters up to and including December 31, 2006.

Fish capture

Seriola lalandi were captured by line in Arno Bay in March 2005 and at Port Augusta in Spencer Gulf between December 2004 and December 2006 (Figure 1). Four charter operators fishing offshore from Port Lincoln participated in the tag programme and captured, tagged and released fish at Rocky Island in 2005 (Figure 1). Recreational fishers assisting the programme tagged fish at Coffin Bay, Fitzgerald Bay, Port Augusta and Yatala Reef in 2005 and 2006 (Figure 1). In addition, we netted small schools of *S. lalandi* in northern Spencer Gulf in October 2005 and in October 2006 (Primary Industries and Resources South Australia exemption no. 9901854). When a fish was landed, a nylon-headed, single-barbed dart tag (Hallprint Pty Ltd) with a unique identification number was inserted into the muscle adjacent to the dorsal fin at a 45º angle, so that the barb on the tag would lock into the pterygiophores. Total length (TL) was measured to the nearest mm, where possible. We considered and carried out capture-recapture analysis to estimate population numbers in northern Spencer Gulf but these data did not meet the assumptions required and are not presented here.

6.4. Results

A total of 340 *S. lalandi* and 88 *S. hippos* specimens has been tagged between February 1991 and December 31, 2006, in South Australia (Table 1) at 25 locations (Figure 1). Of this total, we tagged and released 241 *S. lalandi* and 73 *S. hippos* specimens for this study with the assistance of charter operators and recreational fishers. Before this tag programme, only 53 *S. lalandi* and 1 *S. hippos* had ever been tagged and released in South Australian waters since the first record in 1991. In period of the current study, 86 large *S. lalandi* (>1000 mm TL) were tagged near Port Augusta in northern Spencer Gulf (Table 2). Approximately 8.2% of *S. lalandi* tagged between February 1991 and December 31, 2006 were recaptured across South Australia after being at liberty for between 3 to 442 days, while 2.3% of *S. hippos* tagged were recaptured following 302 and 378 days at liberty (Table 1).

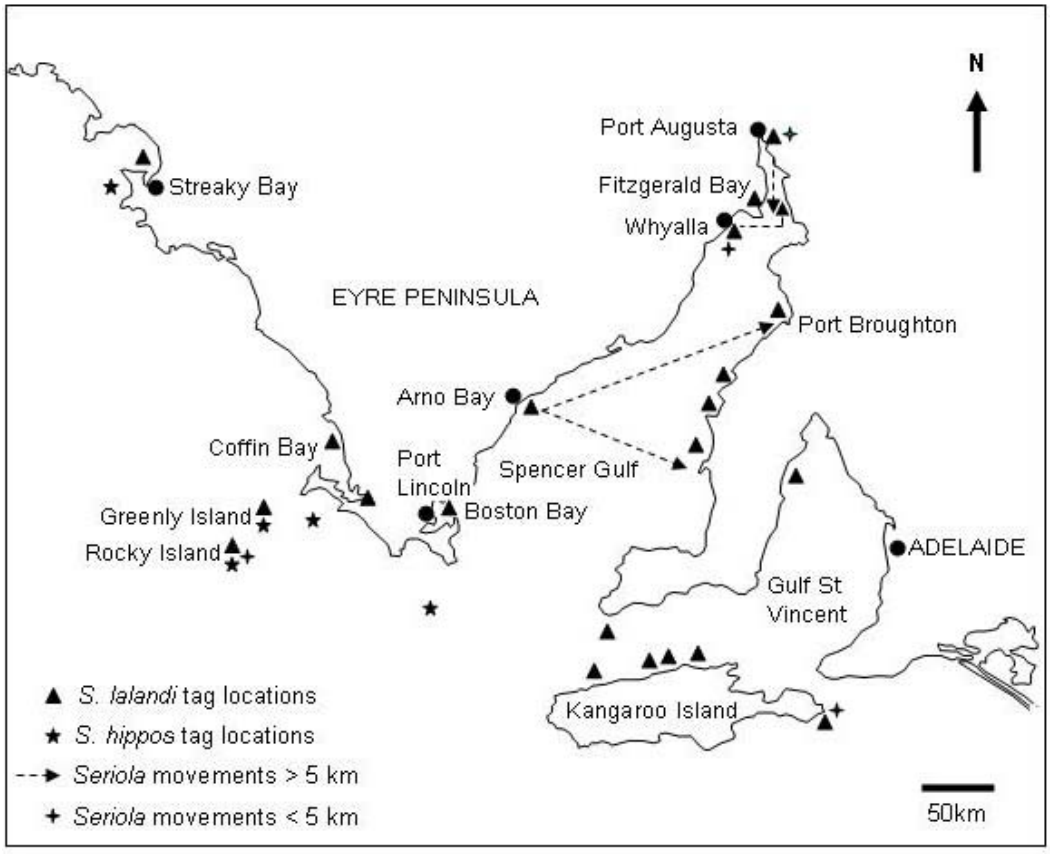

Figure 1. Tag and release localities and inferred movement of *Seriola* spp. in South Australia between February 1991 and December 31, 2006. (Yatala Reef, west of Streaky Bay not shown)

Movements

Four recaptured fish showed movements >5 km (Figure 1). One small *S. lalandi* (480 mm TL) tagged at Whyalla in 2002 was recaptured 51 days later, 40 km north towards Port Augusta (Figure 1). Two small *S. lalandi* (380 and 430 mm TL) tagged at Arno Bay in 2005 (33º55′21″S, 136º36′14″E) were recaptured approximately 100 km southeast after 39 days at Wardang Island (34º27′35″S, 137º23′15″E) and approximately 130 km northeast after 49 days at Port Broughton (33º21′35″S, 137º33′21″E), respectively (Figure 1). A larger individual (1110 mm TL) tagged at Port Augusta in 2006 (32º 42′04″S, 137º46′17″E) was recaptured 50 km south at Point Lowly, near Fitzgerald Bay (32º 24′14″S, 137º19′16″E) and was at liberty for 46 days (Figure 1). Two *S. lalandi* (950 and 870 mm TL) tagged at Rocky Island were recaptured 18 and 41 days later, respectively, at the same location. Twenty-one *S. lalandi* tagged at Port Augusta were recaptured at Port Augusta, including four individuals (>1000 mm TL) tagged in May 2005 or May 2006 and recaptured in the same area eight, 88, 98 and 149 days after release. A further four large fish were recaptured at Port Augusta following 326, 328, 383 and 442 days at liberty. Two recaptures of *S. hippos* (910 and 1070 mm TL) tagged at Rocky Island were made at the same location 302 and 378 days later.

Observations in northern Spencer Gulf

We observed *S. lalandi* schools during October 2005 and October 2006 while netting in shallow water (1 to 4 m depth) in northern Spencer Gulf. Large *S. lalandi* (>1000 mm) were observed alone, in pairs and in small to large schools containing from 10 to >200 individuals. Schools of large fish contained individuals of various sizes (1110 to 1480 mm TL). One fish originally captured on rod and reel (1220 mm TL) was recaptured 149 days later (1290 mm TL) in the net with another 19 individuals.

Table 1. Total tag records for *Seriola lalandi* and *S. hippos* captured in South Australia between February 1991 and December 31, 2006. Location abbreviations: Ardrossan (A), Arno Bay (AB), Althorpe Islands (AI), Balgowan (B), Coffin Bay (CB), Cape Willoughby, Kangaroo Island (CW), west coast Eyre Peninsula at Convention Beach, Sceales Bay, Streaky Bay and Yalata Reef (EP), Fitzgerald Bay (F), Greenly Island (GI), northern shore of Kangaroo Island at Cape Dutton, Emu Bay, Smiths Bay and Western River (KI), offshore Port Lincoln at Cabbage Patch Reef and Four Hummocks Island (OPL), Port Augusta (PA), Port Broughton (PB), Port Hughes (PH), Port Lincoln (PL), Rocky Island (RI), Wallaroo (Wa), Wardang Island (WI) and Whyalla (Wh). Total length omitted for clarity and is included in the text. All recaptures were by line unless otherwise indicated.

Species	Year	No. tagged	Location	No. recaptured (line and net)	% recapture rate (line and net)	Days at liberty	Movements > 5km	No. released after recapture
Seriola	1991	2	CW	0	0	-	-	-
lalandi	1993	1	EP	0	0	-	-	-
	1995	2	CW	0	0	-	-	-
	1999	2	EP, KI	0	0	-	-	-
	2000	2	A, CW	0	0	-	-	-
	2002	21	B, CW, PA, PB, PL, KI, Wh	2	9.5	25 and 51	Wh to PA	1 (KI)
	2003	18	B, PA, PH, KI, Wa	2	11.1	3 and 24	-	0
	2004	14	B, GI, PA, PH	3	21.4	32 [a], 40 [a], 95 [a]	-	0
	2005	205	AB, AI, EP, KI, OPL, PA, RI, Wh	18 (16 and 2)	8.7 (7.8 and 1.0)	8 – 442 [a, b]	AB to PH and WI	6 (PA)
	2006	73	CB, PA, F, OPL	3	4.1	46, 85, 98	PA to F	1 (F)
Total		**340**		**28 (26 and 2)**	**8.2 (7.6 and 0.6)**			**8**
Seriola	2003	1	EP	0	0	-	-	NA
hippos	2005	77	RI, OPL	2	2.6	302 [a] and 378 [a]	-	1 (RI)
	2006	10	GI, RI, OPL	0	0	NA	NA	NA
Total		**88**		**2**	**2.3**			**1**

[a] Includes fish tagged in the year indicated, but recaptured in the following year

[b] Includes four fish recaptured in the following year, at liberty for 326, 328, 383 and 442 days

Table 2. *Seriola lalandi* >1,000 mm TL tagged near Port Augusta during 2005 and 2006

Year	2005	2006	Total
Total no. tagged	39	47	86
Mean total length in mm	1,212	1,215	1,180
(range)	(1,110-1,480)	(1,100-1,250)	(1,110-1,480)
Total no. recaptured	7	2	9
(line and net)	(5 and 2)	(2 and 0)	(7 and 2)
Min and max days at liberty	8-442 [a]	46 and 98	8-442
Number released after recapture	3	2	5
% recapture	17.9%	4.3%	10.5%
(line and net)	(12.8% and 5.1%)		(8.1% and 2.3%)

[a] Includes fish tagged in the year indicated, but recaptured in the following year

6.5. Discussion

Seriola spp. *movements*

Although *S. lalandi* can swim considerable distances (Gillanders *et al.* 2001), the observed distance between mark and recapture locations for the majority of fish was <5km. We found that large *S. lalandi* remained near, or returned to, Port Augusta for up to five months, as shown by four individuals (>1000 mm TL) tagged in May (2005 or 2006) and recaptured in the same area eight, 88, 98 and 149 days after release. *Seriola lalandi* may return to Port Augusta seasonally, as indicated by four large fish recaptured in the same area after 326, 328, 383 and 442 days at liberty. The absence of recaptures and landings between November 2005 and April 2006 may indicate lowered recreational fishing pressure during this time. Alternatively, large fish may leave the area during summer, returning in late autumn/early winter. Indeed, one large *S. lalandi* captured at Port Augusta in October 2006 and recaptured near Fitzgerald Bay in December 2006, suggests a seasonal southerly movement.

Our annual observations in northern Spencer Gulf in October 2005 and October 2006 indicate that Port Augusta is visited by aggregations of large, mature *S. lalandi*. This area comprises a sheltered, shallow region with mangrove habitat. McGlennon (1997) suggests some *S. lalandi* spawning may occur at Port Augusta

and that spawning was imminent for some fish caught in a fishing competition in August 1996. In contrast, it is speculated that *S. lalandi* in New South Wales are pelagic spawners, moving offshore to spawn (Smith *et al.* 1991). Knowledge about whether *S. lalandi* aggregate at in northern Spencer Gulf as part of a spawning event is important for the management of the recreational fishery. Port Augusta is the most accessible location from the state capital (Adelaide) where large *S. lalandi* between 15 and 45 kg (~1000 to 1530 mm total length, TL) can be captured. Indeed, *S. lalandi* may be susceptible to localised depletion in this region if large numbers of fish are being removed before they spawn.

Two *S. hippos* tagged in autumn (March 2005 and May 2005) were recaptured at their original capture location, around one year later (302 and 378 days). In a similar conventional tagging programme of *S. hippos* in Western Australia, approximately 8,850 fish have been tagged off Rottnest Island where they form spawning aggregations in summer (December to February). Recapture data indicate these fish migrate east along the south coast of Western Australia as far as the south coast of Kangaroo Island, South Australia and return to Rottnest Island in summer to spawn (Rowland *et al.* 2006). It is likely that *S. hippos* in South Australia form part of this migratory stock and the time of recapture fits with the spawning notion.

Recapture rates

The recapture rate of *S. lalandi* by recreational anglers (8.2%) throughout South Australia was similar to that recorded for *S. lalandi* tagged on the east coast of Australia (8%) (Gillanders *et al.* 2001). Recaptures are considerably lower for *S. hippos* tagged in South Australia (2.3%) and Western Australia (1.8%) (A. Rowland, pers. comm.). The recapture rate of large *S. lalandi* tagged in 2005 at Port Augusta by fishers was greater (12.8%) than in 2006 (4.3%). This may be because fish tagged in 2006 have been at liberty for a relatively shorter period of time (a maximum of 232 days in 2006 compared to 603 days for 2005, up to and including December 31, 2006). Recreational fishing pressure in this region combined with fish remaining in the area for an extended period (i.e. five months) may subject this species to local depletion. However, promotion of appropriate

tag and release approaches may reduce any possible danger of depletion in northern Spencer Gulf.

Recaptures of tagged fish in this study indicate that individuals survive the capture, tag and release procedure. Certainly, an individual fish captured by line, tagged, and subsequently netted in a school, demonstrates that individuals are capable of locating and reforming with a school. However, Gillanders *et al.* (2001) found that fish marked by more experienced taggers have better recovery rates. In this study, the majority of fish were tagged by experienced taggers. Therefore, it may be necessary to educate inexperienced taggers about appropriate tagging and handling methods for large *S. lalandi* to reduce tag-associated mortality. This would also ensure that tags are inserted correctly, thereby minimising tag loss.

Interaction between wild and farmed S. lalandi

The nature of wild *Seriola* spp. movements is critical to understand the potential impact of parasite interaction between wild and farmed fish. In the northern hemisphere, there is intense debate about the potential for parasitic crustaceans (= sea lice e.g. *Lepeophtheirus salmonis*) to impact upon wild salmonids that migrate past salmon farms. Some scientists have linked increased parasite loads in the northern hemisphere with declines in wild fish stocks (e.g. Tully *et al.* 1993; Butler 2002; Krkošek *et al.* 2005) while others argue that over-fishing, habitat loss and climate change are responsible for the declines (Noakes *et al.* 2000). In South Australia, a large *S. lalandi* tagged at Port Augusta in October 2006 and recaptured near Fitzgerald Bay in December 2006 indicates that large wild fish may migrate past *S. lalandi* sea-cage farms during summer. Consequently, interaction between wild and farmed fish may be more likely to occur at this time of year. Currently, summer in South Australia is the period where farmed fish have to be treated frequently for monogenean parasites. This is because parasite eggs hatch more quickly in warmer sea temperatures. However, increased interaction between farmed and wild fish in warmer months may also contribute to seasonally elevated infection levels.

Research development and interest in the community

The South Australian fishing community expressed an overwhelming interest in the tagging programme documented here. In northern Spencer Gulf, retired commercial netters and recreational fishers volunteered their time to locate fish schools and informed us when *S. lalandi* were sighted. Anglers' dogged pursuit to participate in this programme in order understand more about the nature of *S. lalandi* movements is a testament to an emerging tag and release ethos for this species in the recreational fishing community. Integration of this tag programme with the activities of fishers enabled us to tag an unprecedented number of wild *S. lalandi* and *S. hippos*. We believe this work has helped to promote sustainable recreational fishing practices for *Seriola* spp. in South Australia and expect this will be reflected in further tag and recapture records at more localities off the coast of South Australia. Pop-up satellite archival tags may provide information on specific movements, but they may have problems such as increased expense, limited battery length, marine fouling, increased drag and increased predation (e.g. Kerstetter *et al.* 2004; Grusha & Patterson 2005). As an alternative, cooperative tagging programmes provide a cost-effective method to obtain useful biological data such as movements between areas (Gillanders *et al.* 2001). Multiple recapture data would be especially informative to determine seasonal movements of *Seriola* spp. and collaborating with willing fishers and capitalising on their good will and mutually beneficial outcomes is a practical way to ensure that this information source is used.

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CHAPTER SEVEN

Ectoparasite transmission in areas of sea-cage aquaculture

A recent *Benedenia seriolae* (Monogenea) recruit on the body surface of *Seriola lalandi*
Scale bar = 5 mm
Photo: Kate S. Hutson

NOTE: This photograph is included on page 119 of the print copy of the thesis held in the University of Adelaide Library.

Adult *Zeuxapta seriolae* (Monogenea) attached to the gills of *Seriola lalandi*
Scale bar = 5 mm
Photo: Clinton B. Chambers

CHAPTER SEVEN

ECTOPARASITE TRANSMISSION IN AREAS OF SEA-CAGE AQUACULTURE

7.1. Abstract

Expansion of sea-cage aquaculture can encounter fierce public resistance at least partly due to the potential for ectoparasites to spread from farmed to wild species of fish. In the northern hemisphere, elevated infestations of ectoparasitic crustaceans (species of caligid copepods; sea-lice) on wild fish, and subsequent declines in wild fish populations, have raised concerns about the potential for parasitised farmed salmon to impact upon ectoparasite burdens of wild salmonids that migrate past farms. Similarly, wild yellowtail kingfish (*Seriola lalandi*) move past farmed *S. lalandi* in sea-cages in Spencer Gulf, South Australia, but the potential for cultivated fish to influence parasite burdens on wild fish has not been examined. I provide preliminary data on ectoparasite prevalence and intensity of wild *S. lalandi* in areas close to, distant from and where no sea-cage farming occurs in southern Australia. Current methods used to determine the extent of sea-lice transmission from farmed to wild fish in the northern hemisphere largely use models to estimate louse egg production on farmed fish which are then compared to observed parasite burdens on wild fish. I propose methods to determine recent monogenean recruitment on wild fish in South Australia.

7.2. Introduction

For over a decade, farmed Atlantic salmon (*Salmo salar*) have been implicated in sea-lice outbreaks on wild salmonids in the northern hemisphere (e.g. Tully *et al.* 1993; Heuch & Mo 2001; Bjørn & Finstad 2002; Butler 2002; Heuch *et al.* 2005; Krkošek *et al.* 2005; Morton *et al.* 2005; Orr 2007). Collectively, farmed salmon hosting sea-lice can produce large numbers of parasite eggs and larvae during spring, precisely when wild salmonids leave natal rivers and enter coastal waters

(Heuch & Mo 2001). Parasite outbreaks and subsequent declines in the number of wild fish returning to spawn in rivers have raised concerns for the health of wild fish stocks relative to farming activities. Indeed, sea-lice are one of the most serious problems facing the salmon industry world-wide (Heuch *et al.* 2005).

After salmonids, *Seriola* spp. aquaculture is the most valuable marine finfish culture industry in the world (FishstatPlus 2006). Despite expansion of *Seriola* sea-cage farming in Australia (Whittington *et al.* 2001), Hawaii (Chou 2006), Japan (Nakada 2002) and New Zealand (Appendix One), the potential for *Seriola* farms to increase ectoparasite burdens of wild fish has not been considered or examined. In Australia, wild yellowtail kingfish (*S. lalandi*) move past sea-cage farms in Fitzgerald Bay, South Australia during summer, presenting an opportunity for parasite interactions between wild and farmed fish (Chapter Six). Farmed *S. lalandi* can be infected by a variety of copepod parasite species (Chapter Five), however, the current major health concerns are monogenean parasites (Ernst *et al.* 2002; Mansell *et al.* 2005; Lackenby *et al.* 2007).

Monogeneans are able to proliferate rapidly in aquaculture because of their direct, single host life-cycle. Farmed *S. lalandi* in South Australia are known to be infected by two naturally occurring monogenean parasite species; *Benedenia seriolae* which feeds on epithelium on external body surfaces and *Zeuxapta seriolae* which feeds on blood from the gills. Each can affect growth and survival of farmed fish. Both monogenean species have phenomenal fecundity. One adult *B. seriolae* can lay up to 100 eggs/h *in vivo* at ~19ºC (Ernst *et al.* 2002), while adult *Z. seriolae* produces a mean of 21.6 eggs/h at ~18ºC (Mooney *et al.* 2006). At optimum temperatures (~ 22 to 26ºC for *B. seriolae* and ~22ºC for *Z. seriolae*), embryonation is faster, time to first hatch is shorter and there is greater hatching success (Ernst *et al.* 2005; A.J. Mooney, unpublished data, respectively). Warm seawater also reduces the time taken for parasites to reach sexual maturity in both species (Lackenby et al 2007; A.J. Mooney, unpublished data). Consequently, monogenean populations on farmed fish can escalate rapidly, particularly during summer when seawater temperatures are warmer (average surface seawater temperature 23.2ºC at Fitzgerald Bay, Nov-Feb; South Australian Aquaculture

Management, unpublished data), favouring monogenean population growth and host mortalities can occur if fish are not treated.

The principal method used to treat infections of *B. seriolae* and *Z. seriolae* in South Australia is bathing fish in hydrogen peroxide (Mansell *et al.* 2005). Although this is highly effective at killing adult parasites on farmed fish, it does not kill monogenean eggs and larvae in the immediate environment (Ernst *et al.* 2005). Consequently, reinfection of farmed fish can occur immediately following treatment. Drifting monogenean eggs can become entangled on sea-cage material and associated fouling organisms (Ernst *et al.* 2002), which may also aid rapid reinfection.

Structures around sea-cage sites may not only facilitate elevated monogenean parasite 'production' in the surrounding environment, but can also attract aggregations of wild fish (Dempster *et al.* 2002; 2004). Recapture data indicate that wild *S. lalandi* move past sea-cage farms in Fitzgerald Bay during summer (Chapter Six), coinciding with seawater temperatures that promote monogenean population growth. To determine whether wild *S. lalandi* do host elevated levels of ectoparasites in sea-cage areas requires baseline data before farming commences as well as rigorous on-going monitoring and sound data from wild and farmed fish. It is also possible that fish captured outside sea-cages may be escaped farmed fish, which may limit the interpretation of observed parasite burdens. A technique to distinguish between wild and escaped farmed fish, such as use of isotopes in otoliths, is essential to provide validity on host origin.

The aims of this chapter are to: 1) present preliminary data of ectoparasite prevalence and intensity on wild *S. lalandi* populations in areas close to, distant from, and where no *S. lalandi* sea-cage farming occurs in southern Australia; 2) review methods that have been used to assess possible sea-lice transmission from farmed fish to wild fish based on experiences in the northern hemisphere.

7.3. Methods

Fish collection

Wild *S. lalandi* were caught by line in regions where there is no sea-cage aquaculture (a minimum of 200 km away) at: Sir John Young Banks, New South Wales (34º56′52″S, 150º55′45″E; n = 25 in June/July 2003) (see Chapter Two); Killarney, Victoria (38º23′36″S, 142º20′24″E; n = 25 in January 2004 and 2005) (see Chapter Two); Greenly Island, South Australia (34º38′29″S, 134º47′28″E; n = 2 in April 2004); Kangaroo Island, South Australia (35º34′48″S, 137º25′35″E; n = 1 in March 2004) (Figure 1) (see Chapter Five). Wild *S. lalandi* captured where no sea-cage aquaculture occurs ranged between 520 and 1,440 mm total length (TL). Wild fish were also targeted where there is no sea-cage aquaculture at Coffin Bay, South Australia, but none was captured. Because of low sample sizes, fish sampled at Greenly Island and Kangaroo Island were pooled and are referred to as being captured 'offshore from South Australia'. *Seriola lalandi* distant to sea-cage aquaculture (~50 km away) were sampled at Port Augusta (32º 42′04″S, 137º46′17″E; n = 10, 3 and 10 in April to December 2003, August/September 2004 and March 2005, respectively). Fish distant to sea-cage aquaculture ranged between 360 and 1,320 mm TL.

Wild *S. lalandi* close to *S. lalandi* sea-cage farms were captured in Spencer Gulf outside, or in close proximity to sea-cages (<5 km away). Wild fish were captured at: Fitzgerald Bay (32º 24′14″S, 137º19′16″E; n = 2 in May 2003), Arno Bay (33º55′21″S, 136º36′14″E; n = 6, 4 and 10 in November 2003, March 2004 and March 2005, respectively), and Boston Bay (34º44′3″S, 135º55′46″E; n = 8 in April 2004). Farmed fish, sampled immediately following wild fish capture to indicate intensity of infection in sea-cages at the time that wild fish were sampled, were captured at Fitzgerald Bay (n = 5), Arno Bay (n = 7, 4 and 10) and Boston Bay (n = 10). Wild *S. lalandi* captured close to sea-cages ranged between 320 and 640 mm TL and farmed fish ranged between 282 and 652 mm TL.

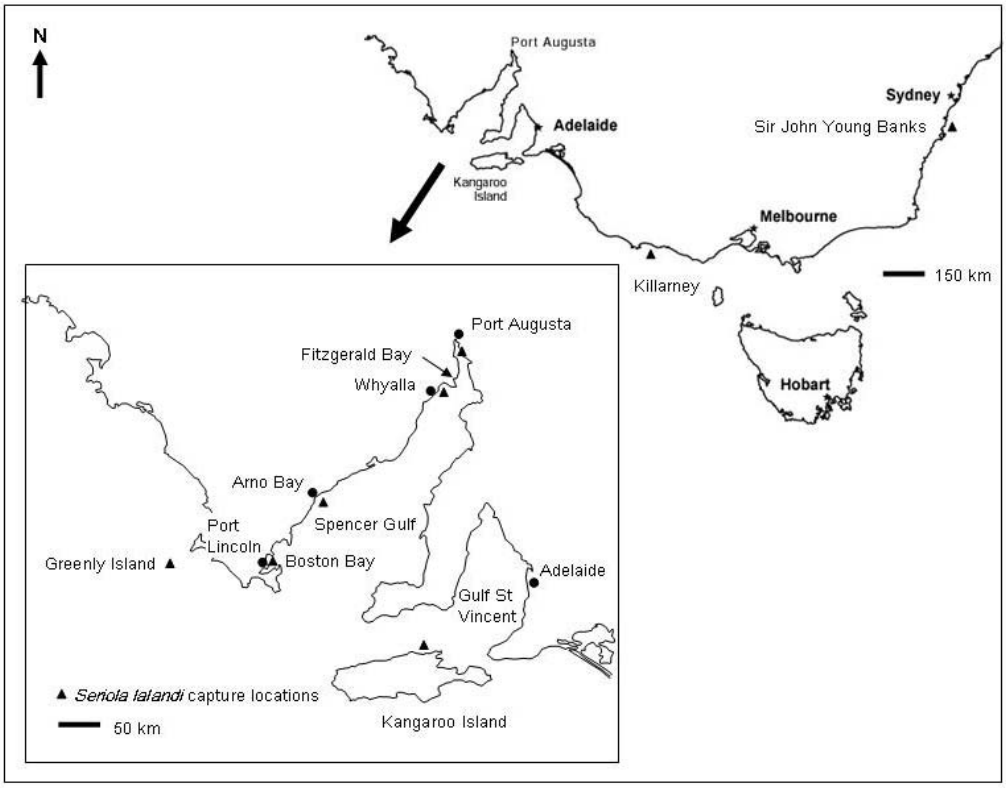

Figure 1. Sample sites for wild *Seriola lalandi* captured where there is no sea-cage aquaculture (Sir John Young Banks, New South Wales; Killarney, Victoria; Greenly Island and Kangaroo Island, South Australia), distant to sea-cage aquaculture (Port Augusta, South Australia) and outside, or in close proximity to, sea-cage sites (Fitzgerald Bay near Whyalla, Arno Bay and Boston Bay near Port Lincoln, South Australia).

Ectoparasite collection

Live fish were bathed individually in 10-20 L of seawater containing 5 mg/L praziquantel for 10 min to dislodge all gill monogeneans (Mansell *et al.* 2005). Fish were then bathed in freshwater for approximately 10 min to remove all *Benedenia seriolae* (see Chambers & Ernst 2005) and copepods. Fish were euthanased 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 praziquantel and freshwater treatments by filtration through a 75 µm sieve and fixed in 10% formalin. The exterior surface of the fish was examined for ectoparasites. *Zeuxapta seriolae* prevalence and intensity could not be determined on frozen fish donated by fishers that were captured offshore from South Australia because *Z. seriolae* degrade if not collected immediately

following host capture. Ectoparasites were sorted and counted using a dissecting microscope. Prevalence and intensity are presented following Bush *et al.* (1997).

7.4.1. Results

Fish collection

Wild *S. lalandi* are not especially common in Spencer Gulf and specimens are difficult to catch. I used line and floating fish traps, sought the assistance of commercial and recreational fishers, attended game fish tournaments and accompanied fishing charters to increase sample sizes. Despite regular and considerable efforts to catch wild *S. lalandi* close to and distant from farming locations in multiple seasons between 2003 and 2005, successful sampling was sporadic and small sample sizes were obtained. Sample size where no sea-cage aquaculture occurs (n = 53), distant to sea-cage aquaculture (n = 23) and close to sea-cage aquaculture (n = 30) were low.

Copepod prevalence and intensity

Wild *S. lalandi* were infected by 11 species of copepods (Chapters Two and Five), however, only *Dissonus hoi*, *Naricolax chrysophryenus* and an unidentified *Caligus* sp. 1 were recovered from wild and farmed fish (Chapter Five). Prevalence and intensity of *N. chrysophryenus* was low in farmed fish and is reported in Chapter Four. *Dissonus hoi* was rare and was only found on two wild *S. lalandi* at Sir John Young Banks, one wild fish at Port Augusta and one farmed fish at Boston Bay. *Caligus* sp. 1 was only found on farmed fish sampled at Boston Bay and Arno Bay, but was recovered from wild fish at all sites except Fitzgerald Bay (Figure 2). Data collected over the three years were pooled because of low recovery of *Caligus* sp. 1. Prevalence of *Caligus* sp. 1 on wild fish was variable, ranging from 8% at Sir John Young Banks, New South Wales to 62% in wild fish captured close to sea-cages at Boston Bay (Figure 2). Mean *Caligus* sp. 1 intensity did not exceed 2, except on wild *S. lalandi* captured at Boston Bay (8) and offshore from South Australia (7) (Figure 3).

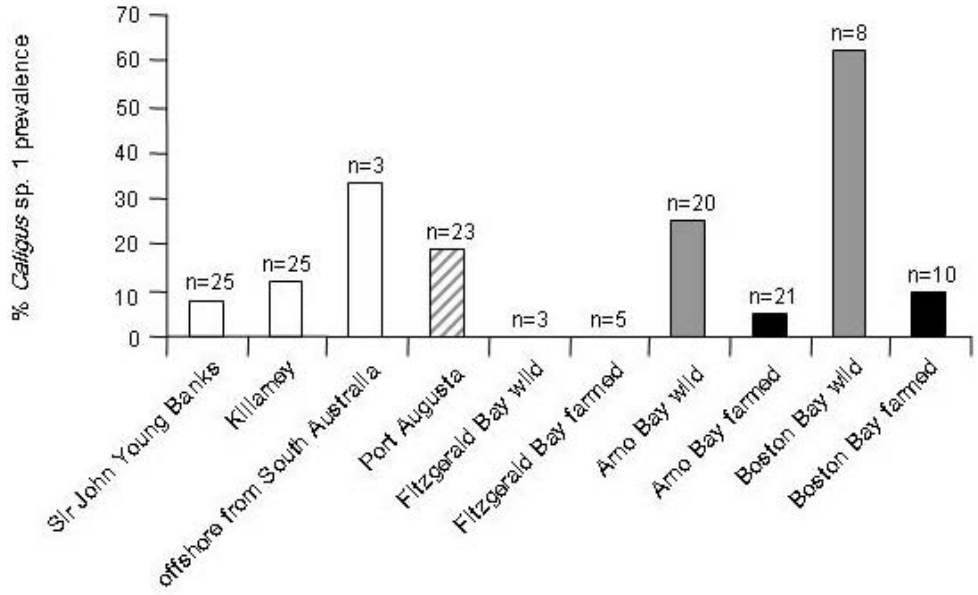

Figure 2. *Caligus* sp. 1 prevalence on wild *Seriola lalandi* where there is no sea-cage aquaculture (white: Sir John Young Banks, New South Wales; Killarney, Victoria; offshore from South Australia), distant to sea-cage aquaculture (grey and white banded: Port Augusta), close to sea-cages (grey) and on farmed stock (black) (Fitzgerald Bay, Arno Bay and Boston Bay). Data collected between 2003 and 2005 has been pooled.

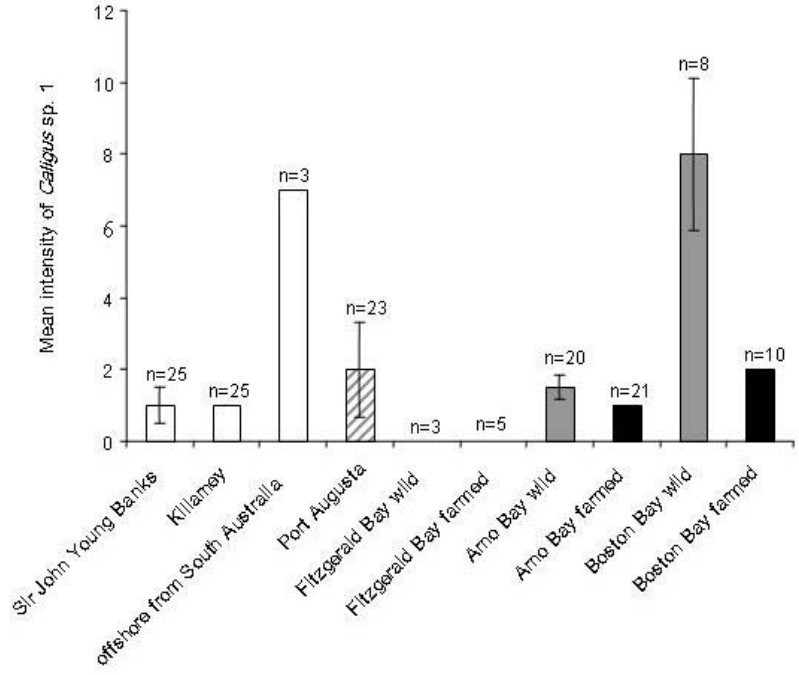

Figure 3. Mean *Caligus* sp. 1 intensity in wild *Seriola lalandi* where there is no sea-cage aquaculture (white: Sir John Young Banks, New South Wales; Killarney, Victoria; offshore, South Australia), distant to sea-cage aquaculture (grey and white banded: Port Augusta), close to sea-cage sites (grey) and on farmed stocks (black) (Fitzgerald Bay, Arno Bay and Boston Bay). Error bars are not indicated for samples from offshore from South Australia, Arno Bay farmed and Boston Bay farmed *S. lalandi* because only one host was infected at these locations. *S. lalandi* in Killarney were only infected by one parasite on all occasions. Data collected between 2003 and 2005 has been pooled.

Monogenean prevalence and intensity

Benedenia seriolae and *Z. seriolae* were recovered from all sites, while *Paramicrocotyloides reticularis* was only found at Sir John Young Banks, New South Wales (Chapter Two). Prevalence of *B. seriolae* and *Z. seriolae* was high, except for farmed *S. lalandi* sampled at Arno Bay in 2005 (Figure 4). *Seriola lalandi* sampled close to sea-cages in Fitzgerald Bay were not infected with *B. seriolae* (n = 2) (Figure 4), while *Z. seriolae* prevalence could not be determined in wild fish captured offshore from South Australia. Prevalence and intensity of *B. seriolae* and *Z. seriolae* on wild *S. lalandi* as determined by Sharp *et al.* (2003) across three sites sampled in New Zealand is shown in my Figures 4-6 for comparison. Their study in 1999 and 2000 was carried out prior to the commencement of sea-cage farming in New Zealand.

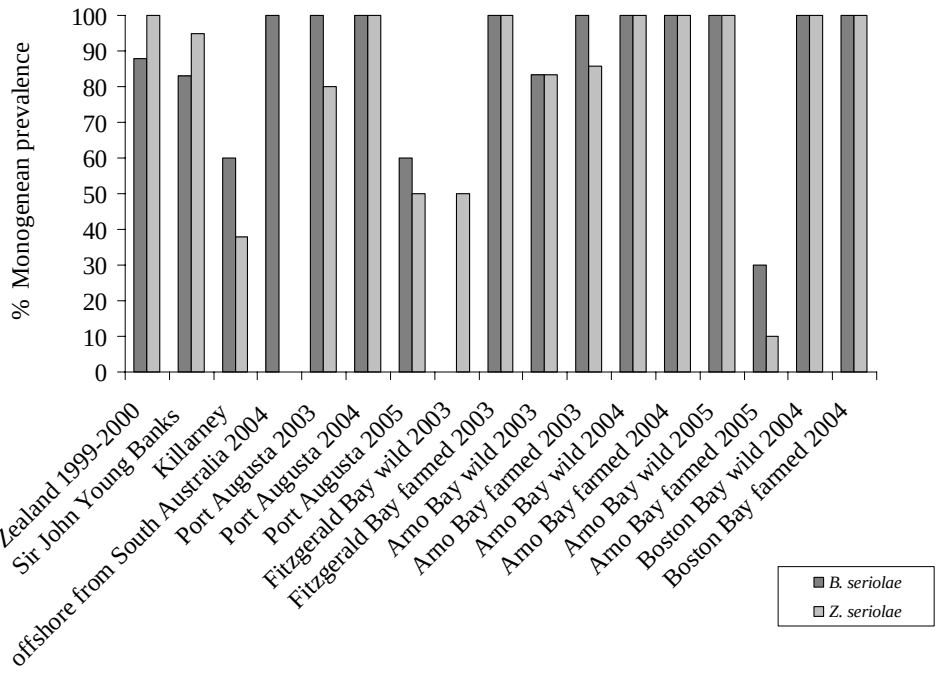

Figure 4. *Benedenia seriolae* and *Zeuxapta seriolae* prevalence where there is no sea-cage aquaculture (New Zealand [Sharp *at al.* 2003]; Sir John Young Banks, New South Wales; Killarney, Victoria; Greenly Island and Kangaroo Island, South Australia), distant to sea-cage aquaculture (Port Augusta), close to sea-cage sites and on farmed stock (Fitzgerald Bay, Arno Bay and Boston Bay).

Mean intensity of *B. seriolae* ranged between eight and 12 on wild fish at locations where no sea-cage farming occurs in Australia, compared to distant from farming (Port Augusta) where intensity ranged between 24 and 49 over three

successive years of sampling (Figure 5). Mean *B. seriolae* intensity on wild *S. lalandi* where no sea-cage farming occurs in New Zealand (29) was similar to that

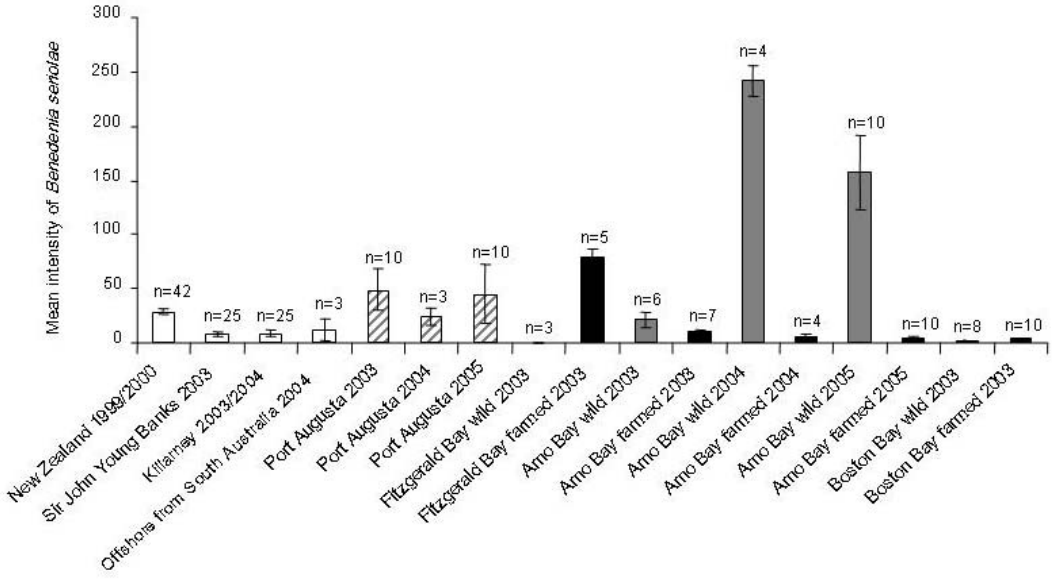

Figure 5. *Benedenia seriolae* intensity where there is no sea-cage aquaculture (white: Sir John Young Banks, New South Wales; Killarney, Victoria; Greenly Island and Kangaroo Island, South Australia), distant to sea-cage aquaculture (grey and white banded: Port Augusta), close to sea-cage sites (grey) and from farmed *S. lalandi* (black)(Fitzgerald Bay, Arno Bay and Boston Bay).

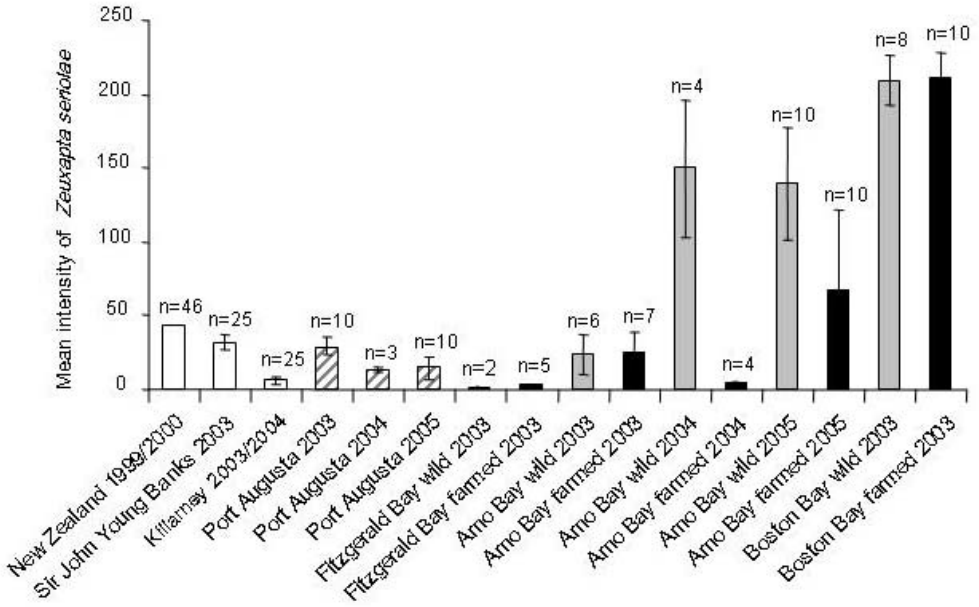

Figure 6. Mean *Zeuxapta seriolae* intensity where there is no sea-cage aquaculture (white: Sir John Young Banks, New South Wales; Killarney, Victoria; Greenly Island and Kangaroo Island, South Australia), distant to sea-cage aquaculture (grey and white banded: Port Augusta) close to sea-cage sites (grey) and from farmed *S. lalandi* (black: Fitzgerald Bay, Arno Bay and Boston Bay).

found at Port Augusta (Figure 5). Mean intensity of *B. seriolae* on wild fish outside sea-cages at Arno Bay was high, but considerably variable, compared to farmed fish at the same site (Figure 5).

Mean intensity of *Z. seriolae* was variable where no sea-cage aquaculture occurs at Killarney, Victoria and Sir John Young Banks (6 and 32, respectively) and distant to farming at Port Augusta (6-29 between 2003 and 2005) in Australia (Figure 6). Mean *Z. seriolae* intensity in New Zealand was slightly higher (44) compared to fish sampled where there is no sea-cage aquaculture in Australia. Mean intensity was higher on wild fish outside sea-cages at Arno Bay in 2004 and 2005 (106 and 139, respectively) and Boston Bay (210) compared to areas where no sea-cage farming occurs (Figure 6).

7.4.2. A brief review of methods used to assess sea-lice transmission from farmed to wild fish in the northern hemisphere

Comparative analysis

Comparative analysis can be used to quantify and contrast parasite prevalence on wild fish within farming and non-farming regions. Investigations in the northern hemisphere have shown that sea-lice (*Lepeophtheirus salmonis*) infection on wild stocks was significantly higher in regions of intensive farming compared to regions of little farming activity (Bjørn *et al.* 2001; Bjørn & Finstad 2002; Marshall 2003). In these studies, changes in disease patterns over time are used to propose a causal relationship. However, comparisons made between fish from exposed and unexposed regions should be treated with caution, because parasite load may also be influenced by local environmental conditions. Fish may also move long distances and their parasite loads may not be a true reflection of parasite levels near the site of capture. Lack of information on the prevalence and intensity of parasites in wild fish before the establishment of farms in the northern hemisphere (i.e. baseline data) also makes it difficult to assess natural levels of parasitism. In this chapter (and in Chapter Two and Five) I have provided baseline data on the parasites of wild *S. lalandi* and *S. hippos* in Australia which

can be applied in further studies assessing potential parasite interactions between wild and farmed fish.

More recently, there has been increased awareness of the need to assess wild parasite prevalence and intensity using appropriate controls. Marshall (2003) used a year long fallow period to assess lice abundance in wild salmon stock in Sutherland, Scotland. She found that during fallow years, parasite abundance in wild fish was low or declining. Parasite prevalence increased (approximately doubling) when cultured fish were introduced and maintained in nearby sea-cages. Marshall suggests that variability in the data set is a consequence of other environmental factors that have a greater impact on lice abundance or their natural variation and that the relationship between farmed and wild populations is not direct. However, variation in parasite numbers could be a consequence of sampling over a prolonged temporal scale; two years in fallow (1998 and 2001) and two years with aquaculture present (1999 and 2000). This methodology has significant scientific merit because it employs a more appropriate 'control' sample site that experiences similar environmental conditions to farm locations. However, this type of monitoring is restricted to aquaculture industries that use fallowing strategies.

Estimating sea-louse egg production

Models of parasites in sea-cage aquaculture are primarily used to measure 'parasite production' (e.g. Heuch *et al.* 2000; Heuch & Mo 2001; Orr 2007). Parasite production relates to a theoretical number derived from the number of sexually mature sea-lice on a host, multiplied by fecundity in optimal conditions. Although various factors such as farm location, current flow, water temperature and salinity have been suggested to influence sea-louse levels in the northern hemisphere, clear and quantifiable relationships between infestation levels and environmental or management factors remain elusive (Revie *et al.* 2002).

Heuch & Mo (2001), Butler (2002) and Orr (2007) developed models for louse and egg production in farmed, wild and escaped fish in Norway, Scotland and British Columbia, Canada, respectively. Studies were based on approximations of

host numbers and ovigerous lice in an attempt to establish sources of infection and effectiveness of management measures. Heuch and Mo's model is useful, but does not account for other potential factors influencing egg production such as temperature, despite acknowledging its importance in a previous publication by the primary author (Heuch *et al.* 2000). Butler (2002) suggested that farmed salmon posed the greatest threat of parasite transmission to migrating wild salmon, based purely on an approximation of egg production and not on parasite prevalence data collected from wild fish. Recently, Orr (2007) showed that lower abundance and prevalence of *L. salmonis* on juvenile pink salmon (*Oncorhynchus gorbushca*) and chum salmon (*O. keta*) near farms was associated with lowered numbers of Atlantic salmon (and lower numbers of sea-lice) in farms. Revie *et al*. (2002) also showed insight into the problem and factored in exposure of wild fish to sea-cages and the level of treatment intervention on farms.

The experience of sea-lice infections on salmonids in the northern hemisphere has highlighted the practical difficulties associated with quantifying the influence that farmed fish may have on infection levels of wild fish. New models that extrapolate and extend findings from these studies may enable increased confidence in correlations of egg production and observed parasite levels in wild fish populations. This requires accurate data for parasite infection dynamics, larval longevity, hydrodynamics, temperature, salinity and the ecology of wild and escaped hosts. In addition, Orr (2007) suggests collaboration and cooperation between researchers and the aquaculture industry may also help to improve data quality. To date, there has been no comprehensive study on parasite prevalence on a wild fish species in farming and non-farming regions in continental Australia. With the exception of tuna and yellowtail kingfish sea-cage aquaculture (and mulloway and barramundi on a smaller scale), there are no other endemic candidate fish species that are currently farmed in Australia with a large local focus. The subject of my thesis, *S. lalandi*, has provided the opportunity with which to explore ectoparasite transmission between farmed and wild fish hosts, albeit on a preliminary basis.

7.6. Discussion

The common occurrence of natural parasites makes it difficult to infer causal links or transmission from farmed fish to wild fish (Noakes *et al.* 2000). Although several studies in the northern hemisphere show support for sea-lice transmission from farmed to wild stocks, there is no direct evidence to suggest that parasites were acquired from farms as opposed to wild sources (Noakes *et al.* 2000). Similarly, *Caligus* sp. 1 is a widespread parasite that commonly occurs on wild *S. lalandi* throughout southern Australia (Chapter Two). Mean intensity on wild and farmed *S. lalandi* was low, with a maximum mean intensity of only eight parasites observed on wild fish close to sea-cages in Boston Bay (Figure 3). In contrast, mean intensity of *Caligus* sp. 1 on wild fish close to sea-cages at Arno Bay was 1.5 (Figure 3). Caligids can be difficult to sample because individuals may detach from their host during handling, which could result in underestimations of prevalence and mean intensity. It is also important to consider that caligids tend to exhibit seasonal variation in prevalence and intensity (e.g. Tingley *et al.* 1997; Revie *et al.* 2002) and further rigorous sampling is required to assess trends of copepod infection in wild fish from different regions across different seasons.

Ectoparasite intensity on wild *S. lalandi* captured close to sea-cage sites at Arno Bay and Boston Bay was generally higher compared to fish sampled where no farming occurs in Australia (Figure 3, 5 and 6). However, high mean infection intensities detected on wild *S. lalandi* close to sea-cages does not necessarily indicate that sea-cage aquaculture increases parasite burdens on wild fish. Indeed, it is likely that fish captured outside sea-cages in the present study were in fact escaped farmed fish and that their parasite burdens were high prior to their escape from the sea-cages. Accidental release of farmed fish can occur through faulty equipment, vandalism, weather and predator damage. Farmed fish parasite populations can be controlled by regular treatments, but parasite populations on escaped fish cannot be managed.

Benedenia seriolae and *Z. seriolae* mean intensities on wild *S. lalandi* captured close to sea-cage sites in Arno Bay were generally higher compared to fish sampled where no farming occurs (Figures 5 and 6). It is likely that these fish

were of farm origin considering escapes occurred irregularly over the three years of my sampling period (Anon. 2007a). In one incident in February 2005, one month prior to fish being sampled, up to 40,000 fish escaped at Arno Bay (Anon. 2007a). Indeed, all *S. lalandi* captured outside sea-cages in this study were small (640 mm TL maximum) and could not be visually discriminated from farmed fish and many showed morphological features indicative of farmed fish.

Differences in monogenean mean intensity on *S. lalandi* sampled outside and inside sea-cages at Arno Bay in 2004 and 2005 may be explained by the timing of hydrogen peroxide bathing. In these years, monogenean intensity was low in farmed fish because caged stock had been treated prior to the samples taken for study (Figures 5 and 6). If *S. lalandi* outside the sea-cages were of farmed origin, they may have escaped prior to treatment, indicated by the high levels of monogenean infection observed (Figures 5 and 6). In contrast, *S. lalandi* sampled close to sea-cages at Boston Bay had very similar monogenean prevalence and mean intensities as farmed fish in the region, suggesting that if these fish were of farm origin, they may have escaped recently (Figures 4-6).

Once fish have escaped, it can be difficult to determine their persistence in wild fish populations. Few reliable methods are available to distinguish natural fish from farmed fish and while subjective judgments may use fish appearance, size and morphology to assess fish origin, these characteristics do not allow definitive determination and may not be repeatable (Nordhagen *et al.* 2000). Distinguishing fish using molecular tools is expensive and may not be valid for *S. lalandi* in Australia since brood stock are sourced from the wild population. However, elemental analysis of otoliths has emerged as a potential tool that could be used to discriminate between escaped and naturally occurring *S. lalandi* (see Gillanders & Joyce 2005). Since escaped farmed fish could not be discriminated from small wild fish in the present study, the mean monogenean intensities observed on wild fish close to sea-cage aquaculture (Figures 5 and 6) may or may not be a consequence of transmission from farmed sources.

Elevated *B. seriolae* mean intensities were also observed distant to sea-cage farms at Port Augusta (Figure 5). There are several possible explanations for these

observed infections: 1) wild *S. lalandi* appear to aggregate in northern Spencer Gulf for up to six months (Chapter Six), and higher mean intensities of *B. seriolae* may reflect increased rates of reinfection due to aggregation; 2) a sea-cage containing large *S. lalandi* brood stock is maintained in Port Augusta and could act as an additional source of *B. seriolae* infection; 3) wild *S. lalandi* moving to Port Augusta from southerly regions in Spencer Gulf may accumulate parasites during their movement past sea-cage farms; 4) there is the possibility that smaller wild fish captured at Port Augusta may be escaped farmed fish carrying higher mean intensities of *B. seriolae* than usually occur in wild fish; 5) the levels of infection observed were similar to those of Sharp *et al.* (2003) recorded for wild *S. lalandi* in New Zealand before sea-cage farming began there, and may, therefore, represent natural parasite intensity levels.

Assessing monogenean parasite transmission

A model for monogenean transmission should account for parasite dispersal near sea-cage aquaculture. This is because some monogenean species may have eggs that attach via filaments to sea-cage netting whereas eggs of other species may move out of the culture system (Fujita *et al.* 1969; Ogawa & Yokoyama 1998). Consequently, the source of infection may remain in the immediate aquaculture environment and not spread to regions that overlap with wild migration routes. *Benedenia seriolae* and *Z. seriolae* exhibit different egg morphology which may result in different dispersal patterns around sea-cages. Indeed, *B. seriolae* eggs are laid singly and can disperse from *S. lalandi* sea-cage farms in South Australia (Chambers & Ernst 2005). Conversely, *Z. seriolae* eggs are produced with a single filament that is intertwined around other filaments to form a 'string' of eggs (Mooney *et al.* 2006), however, it is not known whether the egg-strings are caught on sea-cage material.

Despite suggestions that eggs of *B. seriolae* may tangle on cages (Ernst *et al.* 2002), their eggs are capable of dispersing considerable distances from *S. lalandi* sea-cage farms (Chambers & Ernst 2005). In a study investigating strategic positioning of sea-cages as a technique to limit population growth of *B. seriolae*, Chambers & Ernst (2005) placed uninfected sentinel *S. lalandi* in experimental

cages for seven days at 0, 1, 2, 4, 8 and 18 km from sea-cages in Fitzgerald Bay, Spencer Gulf. The mean infection intensity of farmed fish was 40 *B. seriolae*. They found 100% prevalence of *B. seriolae* on fish positioned at 0, 1, 2 and 4 km from the source and 60% and 20% for sites at 8 and 18 km, respectively, after seven days. Infection rates ranged from 1.470 *B. seriolae*/fish/day at the source to 0.067 *B. seriolae*/fish/day at 18 km. Although it is possible that sentinel fish held in experimental sea-cages experienced heightened infection rates because *B. seriolae* eggs may have become entangled in netting, it is evident that hydrographic conditions in Fitzgerald Bay allow for considerable dispersal of *B. seriolae*. Wild *S. lalandi* moving past sea-cages in Fitzgerald Bay, or remaining within close proximity, may be exposed to elevated levels of infective *B. seriolae* larvae from sea-cage farms.

Parasite prevalence and intensity on wild *S. lalandi* that move past farms may represent the influence of a sequence of sites along a migratory path rather than at the site of capture. However, in the case of monogeneans, parasites can be divided into age classes and recruitment can be determined to reflect parasite transmission during a brief period immediately prior to the capture of an individual *S. lalandi*. Larvae of *B. seriolae* and *Z. seriolae* begin to feed and grow immediately after they find a suitable host. Growth rate is temperature dependent (e.g. Ernst & Whittington 2001; Whittington & Ernst 2002; Lackenby *et al.* 2007). Recent experimental research has determined that the mean anterior hamulus length on the haptor of *B. seriolae* is a reliable indicator of parasite age (Lackenby *et al.* 2007) while the total number of clamps on the haptor of *Z. seriolae* is correlated with age (Mooney *et al*. 2006; A.J. Mooney, unpublished data). Consequently, specimens of *B. seriolae* and *Z. seriolae* can be readily divided into age classes. Age can be assessed by enumeration of parasite attachment sclerites, enabling the determination of local parasite recruitment rates on wild *S. lalandi*, at a given water temperature, to be determined for regions where sea-cage farming does and does not occur.

I have made no attempt to determine recent parasite recruitment in the present study because sample sizes were small (sample size where no sea-cage aquaculture occurs n = 53, distant to sea-cage aquaculture n = 23 and close to sea-

cage aquaculture n = 30) and *S. lalandi* captured outside sea-cages were of small size (maximum 640 mm TL) and could not be discriminated from recently escaped farmed fish. Escaped fish tend to remain in close proximity to a farm for an extended period of time (Anon, 2007b) which may not reflect the natural behaviour of wild *S. lalandi*. Consequently, escaped fish are not an appropriate model to estimate recruitment rates on wild fish as their abnormal behaviour may jeopardise the validity and interpretation of the extent of parasite transmission.

7.7. Conclusion

The movements of large, pelagic marine fish species are difficult to study (Chapter Six). In contrast, the seaward migrations of anadramous salmon in the northern hemisphere can be more easily determined. This is because these salmonids have a longer aquaculture history and better known biology. Increased capture, tag and release effort will pinpoint the movements of wild *S. lalandi* in Spencer Gulf, South Australia, and enable determination of the extent of interaction between wild and farmed fish (i.e. whether wild individuals remain in sea-cage aquaculture areas). Based on recapture data and personal observations (Chapter Six), wild fish can be captured in Fitzgerald Bay, where there are sea-cage farms, in late spring to mid autumn (November to April).

To overcome problems associated with sampling escaped farmed fish outside sea-cages, future studies should investigate parasite recruitment on large wild *S. lalandi* that move past Fitzgerald Bay sea-cages. Large fish in excess of 1,000 mm TL should be targeted as they are likely to be of wild origin, compared to smaller fish sampled in the present study. Fish could be sampled non-destructively by bathing, tagging and subsequently releasing them (Chapter Six), or alternatively, otoliths could be used to confirm fish origin. I suggest that netting schools of large *S. lalandi* would enable a sufficient sample of fish to be assessed simultaneously for ectoparasites. If parasite recruitment rates were higher than those determined in regions where there is no farming activity in South Australia, more efficient parasite management strategies may need to be developed on farms.

People's opinion of modern aquaculture is largely polarised, fuelled by the differing agendas of the public, towards environmental sustainability, and investors towards expansion and profits. Robust, unbiased data are required before any speculation can be made on potential parasite transmission from farmed *S. lalandi* to local wild populations. Strategically timed treatment baths to kill adult parasites on farmed *S. lalandi*, followed by a second, timed treatment, that kills new parasite recruits before they reach maturity (e.g. Lackenby *et al.* 2007), has proved effective in controlling monogeneans on farms. It is reasonable to assume that regular, timed treatments may reduce numbers of monogeneans on fish in and around the sea-cage environment. In addition, copepods are notorious parasites in many aquaculture systems (e.g. Johnson *et al.* 2004), and should be closely monitored on farmed *S. lalandi* to identify whether an outbreak could occur. Appropriate management of parasite infections is an immediate and necessary action to be taken on farms to reduce the potential for parasite transmission from farmed to wild fish.

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CHAPTER EIGHT

General Discussion

NOTE: This photograph is included on page 155 of the print copy of the thesis held in the University of Adelaide Library.

Sampling farmed *Seriola lalandi* at Arno Bay, Spencer Gulf, South Australia
Photo: Bradley P. Smith

CHAPTER EIGHT

GENERAL DISCUSSION

In this thesis I have provided an extensive inventory of metazoan parasite species infecting wild *Seriola* spp. in southern Australian waters (Chapters Two and Five) including a new species description, *Paradeontacylix godfreyi*, and a redescription of *Naricolax chrysophryenus* (Chapters Three and Four, respectively). Some parasite species are more likely than others to establish and proliferate in sea-cage aquaculture with low to moderate consequences to the *S. lalandi* industry (Chapter Five). A small-scale tag and release programme has indicated that wild *S. lalandi* move past *S. lalandi* farms, confirming that parasite interaction between wild and farmed fish in northern Spencer Gulf waters is plausible (Chapter Six). Finally, I have reviewed methods used in the northern hemisphere to estimate parasite transmission from farmed to wild fish and discuss approaches to determine monogenean parasite recruitment on wild kingfish near sea-cage farming sites (Chapter Seven).

8.1. Parasite assemblages of wild fish populations

Knowledge of parasite assemblages has intrinsic value for monitoring and enables appropriate risk mitigation practices to be implemented (Chapters Two-Five). For example, an outbreak of the monogenean *Neobenedenia melleni* caused considerable mortality in sea-cage aquaculture of *Lates calcarifer* (barramundi) resulted in the loss of 200 000 fish (50 tonnes) (Deveney *et al.* 2001). The origin of this outbreak is unclear because *N. melleni* has not been recorded from any wild host species in Australia and strict quarantine regulations exclude the possibility of its introduction on imported fish. Deveney *et al.* (2001) propose that *N. melleni* occurs naturally on wild populations of some teleost species in Australian waters and that the few surveys of wild fish conducted along the east coast have failed to report this species. This specific incident highlights the importance of research that identifies naturally occurring parasites or pathogens

that may be potentially harmful in aquaculture conditions. With an understanding of potential parasite risks, aquaculture industries would be in a position to implement risk mitigation strategies (e.g. awareness training, quarantine measures) and to prepare contingency plans to guide the management of major disease and parasite outbreaks.

My thesis has also established data about natural infection in wild *S. lalandi* populations in regions where there is no sea-cage farming activity (Chapter Two). From commercial, environmental and scientific points of view it is highly preferable that parasite surveys of wild fish occur before fish farming commences in a region (Scholz 1999). From a commercial perspective, surveys will identify parasites of potential risk (Chapter Five), while from environmental and scientific perspectives, sound baseline data that is a realistic representation of the natural incidence of parasites can be obtained (Chapter Two and Five). Epidemiology of parasitic infections in wild populations of *S. lalandi* could also be studied to determine other key environmental factors that may influence parasitism. This baseline information is fundamental for early detection of abnormal events. Knowledge of which parasite species occur in wild fisheries is also important for Australian biosecurity, enabling rapid detection of introduced or translocated species (Chapter Two-Five).

8.2. Parasite risk analyses for sustainable sea-cage aquaculture

Some parasite species recovered in this study have previously been associated with disease and mortality in *Seriola* spp. aquaculture in Australia, Asia, Europe and New Zealand. The risk assessment described in Chapter Five identified the need to promote awareness of, and regularly monitor, parasites that have been determined to pose risk of establishment and proliferation in sea-cage aquaculture. The likelihood of parasite establishment is dependent upon current information available on parasite presence, distribution and biology. As new information on parasite distributions and biology in wild fish populations becomes available, assessments of the likelihood of parasite establishment and proliferation in sea-cage aquaculture may change.

Aquaculture husbandry practices can also have a direct impact on the presence or absence of parasite species and their relative infection intensity on a farm. The risks posed by parasites can be alleviated by a variety of management practices. Moran *et al.* (1999) suggest that regular net changes may reduce the accumulation of potential intermediate hosts for myxozoans. It is reasonable to suggest that regular net changes may also reduce potential intermediate hosts for trematodes (e.g. sanguinicolids) (Chapters Three and Five). In addition, Ernst *et al.* (2002) found an association between the number of *B. seriolae* eggs caught on sea-cages and the weight of fouling organisms present. Therefore, net changes may also reduce the accumulation of monogeneans eggs on cage material. Stocking sea-cages in an area with similar age classes of fish and adopting fallowing strategies has been shown to reduce crustacean infections in farmed salmon in the northern hemisphere (e.g. Bron *et al.* 1993; Morton *et al.* 2005). Feeding with extruded pellets can lower the likelihood of parasite establishment by cestodes and anisakid nematodes that require their definitive host to consume infective parasite stages in intermediate hosts. Spatial segregation of sea-cages and strategically timed treatments across entire farm leases can lower the likelihood of parasite establishment and proliferation. Prevention measures may include restrictions on the translocation of hosts to/from certain areas of different or unknown disease status. Certainly, 'eggs-only' importation policies have proved effective in controlling disease transfers in fish (Noakes *et al.* 2000) but they may still may carry viral and bacteria pathogens.

8.3. Future research

8.3.1 Parasite identification

In Chapter Two, I identified standard sampling methods that can be used for ongoing assessment of parasite prevalence and intensity in wild and farmed kingfish. I have described one new trematode species from wild *S. lalandi* (Chapter Three). I also provide a redescription of a parasitic copepod species not

previously reported from a carangid host (Chapter Four). Sampling of the parasite fauna of wild kingfish should be incorporated into ongoing sampling programs for effective parasite management, risk identification and impact assessment at farm locations (McVicar 1997). Information on the parasite assemblage of wild and farmed species could result in improved prevention of serious outbreaks by enabling proactive rather than reactive parasite management.

Further taxonomic descriptions were beyond the scope of this thesis. It is likely that many more new parasite species infect wild *Seriola* spp. in Australian waters. Additional sampling and collection of parasite specimens from *S. lalandi* and *S. hippos* will aid the description of new species. Voucher specimens of the parasite species documented herein have been deposited in the South Australian Museum (Chapters Two-Five) and can be accessed for further study.

8.3.2 Aquaculture expansion

Currently, 1,500 tonnes of *S. lalandi* are produced in South Australia, with production expected to increase to 10,000 tonnes by 2012 (Anon. 2006). The expansion of this industry may require identification of new sites for sea-cage aquaculture. The results of my research may help inform decision criteria for allocation of aquaculture sites so that there is ecologically sustainable expansion and development of the sea-cage aquaculture industry. Below I discuss potential sources of parasite infection, migratory behaviour of wild *S. lalandi* and fish stock structure, all factors that may influence decision criteria for allocating suitable sites for sea-cage aquaculture.

Sources of infection

One of the most important discoveries from my thesis was the recovery of three species of *Paradeontacylix* (Digenea: Sanguinicolidae) from wild *Seriola* spp. in Australian waters (Chapter Three). The association of this digenean genus with mass mortalities of *S. dumerili* in the Spanish Mediterranean (Crespo *et al.* 1992) and Japan (Ogawa & Fukudome 1994) and the absence of mitigation methods has

serious implications for the future development of *S. lalandi* sea-cage aquaculture globally. More specifically, the blood fluke *P. godfreyi* presents a moderate likelihood of establishment and proliferation in *S. lalandi* sea-cages in Spencer Gulf, South Australia (Chapter Five). It is desirable to identify potential intermediate host species for *Paradeontacylix* spp. so that sea-cages containing *Seriola* spp. can be positioned to spatially segregate definitive fish hosts from invertebrate intermediate hosts. Alternatively, if the intermediate host was found to inhabit the sea-cage netting, procedures could be put in place for regular net changes or appropriate de-fouling of the nets.

Identifying the species of blood fluke infecting farmed *S. lalandi* in New Zealand and examination of potential intermediate hosts near *S. lalandi* sea-cages in New Zealand may allow us to draw comparisons or assess potential intermediate host species for *Paradeontacylix* spp. in Australia. Identification of the intermediate host(s) would help to determine suitable sea-cage sites for *S. lalandi* away from potential infection sources as the industry expands in Australia and New Zealand.

Wild kingfish migratory behaviour

My research has provided data on large (>1,000 mm TL) wild kingfish movements in northern Spencer Gulf (Chapter Six). The results indicate that wild fish move south from Port Augusta, past *S. lalandi* sea-cages in Fitzgerald Bay in summer. Consequently, interaction between wild and farmed fish may be more likely to occur during this time. Currently, summer is the period when farmed fish must be treated frequently for monogenean parasites. This is because the eggs of *Benedenia seriolae* and *Zeuxapta seriolae* embryonate faster in warmer sea temperatures. However, increased interaction between farmed and wild fish in warmer months may also contribute to seasonally enhanced infection levels. Further recapture data from wild *S. lalandi* tagged in my study (Chapter Six) may indicate the extent of wild fish association with sea-cage farms and whether large numbers of wild fish make regular migratory movements past sea-cage areas.

The discovery that large wild kingfish remain in, or return to, Port Augusta between May and October indicates aquaculture expansion in this region may

experience heightened interactions between wild and farmed fish. Currently, Clean Seas Tuna produces kingfish in a land based hatchery facility at Port Augusta. In some years, juvenile fish are moved into sea-cages between August and November near the warm water outlet (~23-28ºC; Travis Dymmott, Clean Seas Tuna, unpublished data) of the Port Augusta power station to increase growth rates of fish before transportation. Therefore, juvenile fish may be exposed to wild fish pathogens and parasites at elevated temperatures before being towed or transported by road to Fitzgerald Bay for grow-out.

High recapture rates of large wild kingfish in Port Augusta by fishers (12.8% in 2005) suggest that a limited number of individuals congregate in this area (Chapter Six). At present, wild brood stock are collected at Port Augusta to supply kingfish hatcheries in Port Augusta and Arno Bay. These wild fish are valuable for future supply of local brood stock to support kingfish aquaculture and may be important for recruitment of wild stocks. Consequently, wild fish populations in the Port Augusta region require careful on-going monitoring and management.

Stock structure

Identifying the parasite assemblages of fish in different regions of Australia may allow for the selection of suitable locations for *S. lalandi* sea-cage aquaculture where parasites of potential problems may be absent. It appears as though some parasite species of *S. lalandi* may only occur on the east coast of Australia (e.g. *Paramicrocotyloides reticularis*) (Chapter Two). In Chapter Two, I found evidence that wild *S. lalandi* in the Tasman Sea comprise a single stock. This was supported by previous genetic analysis of fish sampled from Australasia (Nugroho *et al.* 2001) and conventional tagging (Gillanders *et al.* 2001). Mackenzie (2002) 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 (Criscione *et al.* 2006). Research into parasite genotypes of key parasite species would assess the degree of mixing in *S. lalandi* populations between South Australia and eastern Australia (Chapter Two).

Tissue from wild *S. lalandi* captured from New South Wales, Victoria and South Australia during my study was provided to the Australian Biological Tissue Collection (ABTC) at the South Australian Museum. In the future, these tissues may be useful to supplement future research into *S. lalandi* population structure throughout southern Australia. Similarly, further recapture data from wild *S. lalandi* tagged in my study (Chapter Six) may indicate whether fish tagged in South Australia move greater distances.

8.3.3 Parasite management and prevention

Parasite risk analyses provide a disciplined and consistent approach for the calculation of the relative level of risk associated with individual parasite species. My assessment methods can be used to predict the risk posed by parasites found in local fish populations (Chapter Five). The parasite species determined to threaten the sustainability and profitability of the kingfish industry in Australia are now identified and appropriate parasite management strategies can be developed. However, it is also possible that further parasite problems not identified here may emerge in the future. Suitable control measures may be developed to help alleviate parasite levels and prevent parasite outbreaks.

Aquaculture husbandry practices can have a direct impact on the presence or absence of parasite species and their relative infection intensity on a farm. Prevention measures may include restricting movement of fish from different localities. In this study, local parasite species determined to be of potential risk can be alleviated by a variety of management practices (Chapter Five). Regular net changes may reduce the accumulation of monogeneans eggs and potential intermediate hosts of myxozoans and sanguinicolids. Stocking sea-cages with similar age classes and adopting fallowing strategies has been shown to reduce crustacean infections in farmed salmon in the northern hemisphere (e.g. Bron *et al.* 1993; Morton *et al.* 2005). Feeding with extruded pellets can reduce the likelihood of parasite establishment by cestodes and anisakid nematodes that require their definitive host to consume infective stages in intermediate hosts.

Spatial segregation of sea-cages and strategically timed treatments across entire farm leases may also lower the likelihood of parasite establishment and proliferation. However, this may not be possible economically or logistically in some farming regions. Clearly, maintaining the health of farmed fish may reduce numbers of parasites and the potential for farms to act as a reservoir of parasite infective stages.

Recent improvements in fish husbandry, including the development and widespread use of vaccines in salmon (Noakes *et al.* 2000), may reduce disease transfer from farmed fish to wild or hatchery fish in the northern hemisphere. In the *Seriola* spp. aquaculture industry in New Zealand, a variety of chemotherapeutants have been trialled for eradication of the monogeneans *B. seriolae* and *Z. seriolae* (see Sharp *et al.* 2004; Tubbs & Tingle 2006). Medicated feed is also being trialled to control these species in Australia (R.E. Williams, unpublished data). Parasite treatments delivered orally to fish may provide a cheaper, less labour intensive and less stressful alternative to fish hosts compared to the current method of bathing fish in chemical treatments.

8.4. Conclusion

Knowledge of parasite assemblages of wild fish and farmed fish enables proactive rather than reactive parasite management. Procedures and control measures can reduce the likelihood of establishment and proliferation of harmful parasite species and may prevent serious outbreaks in sea-cage aquaculture. A continued parasite monitoring programme of wild and farmed fish would identify parasites of potential risk. In turn, appropriate parasite management practices can be implemented, which may improve and optimise the welfare of farmed and wild fish.

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Brad Smith with a Samson fish (*Seriola hippos*) captured aboard Shikari Charters, Western Australia
Photo: K.S. Hutson

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APPENDICES

NOTE: This photograph is included on page 183 of the print copy of the thesis held in the University of Adelaide Library.

Seriola lalandi sea-cages at Fitzgerald Bay, Spencer Gulf, South Australia
Photo: Ingo Ernst

Appendix 1: Diseases of kingfish (Seriola lalandi) in Australasia

This appendix provides a reprint of a co-authored article published in *Aquaculture Health International* written by Dr Ben Diggles and myself. The article provides an overview of the parasite species in farmed and wild yellowtail kingfish in Australasia. *Aquaculture Health International* is an industry-focused magazine, published quarterly. This article was not peer-reviewed. This article can be cited as:

Diggles, B. & **Hutson**, **K.S.** (2005) Diseases of kingfish (*Seriola lalandi*) in Australasia. *Aquaculture Health International* VIP Publications Ltd, Auckland Issue 3, Nov 2005, 3 pp.

Permission for reproduction of this article in this thesis was obtained from the Editor of *Aquaculture Health International*, Dr Scott Peddie (See Appendix Four).

NOTE: This publication is included in the print copy of the thesis held in the University of Adelaide Library.

Appendix 2: Yellowtail kingfish 'weigh your catch' ruler

I worked with Scott Gray at Fish Care Victoria to help develop a non-legislative fisheries-related educational product (in the form of a sticker). This project enabled the wider fishing community to understand more about the biology of yellowtail kingfish (*Seriola lalandi*).

The main aims of this project were to: 1) encourage recreational anglers to foster responsible attitudes and practices towards key recreational species; 2) raise community awareness about the biology of recreationally important fish species and fisheries management; 3) alleviate the effects of increasing recreational fishing pressure; 4) provide currently accurate scientific information. I provided Scott Gray with information on the length-weight relationship of wild *S. lalandi* from southern Australian waters and interesting facts about the species.

NOTE: This image is included on page 185 of the print copy of the thesis held in the University of Adelaide Library.

The content of the sticker ruler incorporates:

- Average weight of each species at given lengths (from the species specific length-weight relationship)
- An image of the species and its distinguishing features to ensure positive identification (in line with government fishing regulations)
- Minimum recorded length at which fish reach maturity and breed
- Research facts – What do we know about the species?
- How to release fish carefully
- What to do if an angler catches a tagged fish

This project is an interactive and educational venture that will have direct impacts on the general understanding of fish and will increase the enjoyment of recreational fishing. It may also encourage 'catch and release', which will enable sustainable fishing to continue into the future.

NOTE: This image is included on page 186 of the print copy of the thesis held in the University of Adelaide Library.

´Yellowtail kingfish 'weigh your catch' ruler´ Copyright: Scott Gray, Fishcare Australia

Appendix 3: Published papers

This appendix presents reprints of four papers published to date from my thesis in peer-reviewed journals.

Hutson, **K.S.**, Mooney, A.J., Ernst, I. & Whittington, I.D. (2007) Metazoan parasite assemblages of wild *Seriola lalandi* (Perciformes: Carangidae) from eastern and southern Australia. *Parasitology International* **56**, 95-105.

Hutson, **K.S.** & Whittington, I.D. (2006) *Paradeontacylix godfreyi* n. sp. (Digenea: Sanguinicolidae) from the heart of wild *Seriola lalandi* (Perciformes: Carangidae) in southern Australia. *Zootaxa* **1151**, 55-68.

Hutson, **K.S.**, Smith, B.P., Godfrey, R.T., Whittington, I.D., Chambers, C.B., Ernst, I. & Gillanders, B.M. (2007) A tagging study on yellowtail kingfish (*Seriola lalandi*) and Samson fish (*S. hippos*) in South Australian waters. *Transactions of the Royal Society of South Australia* **131**, 128-134.

Hutson, **K.S.**, Ernst, I. & Whittington, I.D. (2007) Risk assessment for parasites of *Seriola lalandi* (Carangidae) in South Australian sea-cage aquaculture. *Aquaculture* **271**, 85-99.

Hutson, K.S., Ernst, I., Mooney, A.J. and Whittington, I.D. (2007) Metazoan parasite assemblages of wild Seriola lalandi (Carangidae) from eastern and southern Australia. *Parasitology International v.56 (2), pp. 95-105, June 2007*

Hutson, K.S. and Whittington, I.D. (2006) *Paradeontacylix grodfreyi* n. sp. (Digenea: Sanguinicolidae) from the heart of wild *Seriola Ialandi* (Perciformes: Carangidae) in southern Australia.
Zootaxa, v. 1151, pp. 55-68, March 2006

Hutson, K.S., Smith, B.P., Godfrey, R.T., Whittington, I.D., Chambers, C.B., Ernst, I. and Gillanders, B.M. (2007) A tagging study on yellowtail kingfish (Seriola lalandi) and Samson fish (S.hippos) in South Australian waters.
Transactions of the Royal Society of South Australia v. 131 (1), pp. 128-134, May 2007

Hutson, K.S., Ernst, I., and Whittington, I.D. (2007) Risk assessment for metazoan parasites of yellowtail kingfish *Seriola lalandi* (Perciformes: Carangidae) in South Australian sea-cage aquaculture.
Aquaculture v. 271 (1/4), pp. 85-99, October 2007

Appendix 4: Permission to reproduce published papers

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To whom it may concern,

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Marloes.
Publishing Editor
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Dear Dr Marloes deJong,

Thank you for letting me know that the revised paper "Risk assessment for metazoan parasites of yellowtail kingfish Seriola lalandi (Perciformes: Carangidae) in South Australian sea-cage aquaculture" has been accepted for publication in Aquaculture. That is excellent news, we are really pleased with the outcome. I look forward to receiving the proofs.

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Authors: K.S. HUTSON, B.P. SMITH, R.T. GODFREY, I.D. WHITTINGTON, C.B.
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Hi Kate,

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Thanks very much for an excellent article and best of luck with your thesis.

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Dear Dr. Peddie,

I am writing to ask permission to include the article 'Diseases of kingfish (Seriola lalandi) in Australasia' in my doctoral dissertation. The article was co-authored by Dr. Ben Diggles and myself and was published in Aquaculture Health International, Issue 3, November 2005.

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Appendix 5: Parasite and host authorities

Parasites

Group/family	Taxon	Authority
Ectoparasites		
Monogenea		
Capsalidae	*Benedenia seriolae*	(Yamaguti 1934) Meserve, 1938
	Neobendenia melleni	(MacCallum, 1927) Yamaguti, 1963
Heteraxinidae	*Paramicrocotyloides reticularis*	Rohde 1978
	Zeuxapta seriolae	(Meserve, 1938) Price, 1962
Crustacea		
Bomolochidae	*Naricolax chrysophryenus*	(Roubal, Armitage & Rohde, 1983) Lin 2006
	N. hoi n. sp.	Hutson & Tang, in press
Caligidae	*Caligus amblygenitalis*	Pillai 1961
	C. elongatus	Nordmann
	C. lalandei	Barnard 1948
	C. spinosus	Yamaguti 1939
	Lepeoptheirus salmonis	(Kroyer 1837)
Dissonidae	*Dissonus hoi*	Tang & Kalman 2005
Lernanthropidae	*Lernanthropus paenulatus*	Wilson 1922
Laernaeopodidae	*Parabrachiella seriolae*	Yamaguti & Yamasu 1960
Endoparasites		
Myxozoa		
Ceratomyxidae	*Ceratomyxa buri*	Yokoyama & Fukuda 2001
	C. seriolae	Yokoyama & Fukuda 2001
Trematoda		
Acanthocolpidae	*Stephanostomum petimba*	Yamaguti 1970
	Tormopsolus orientalis	Yamaguti 1934
Bucephalidae	*Bucephalus gorgon*	(Linton 1905) Eckmann 1932
	Rhipidocotyle longicirrus	(Nagaty 1937) Bartoli & Bray 2005
Hemiuridae	*Erilepturus hamati*	(Yamaguti 1934) Manter 1947
	Elytrophalloides oatesi	(Leiper et. Atkinson, 1914)
	Parahemiurus merus	(Linton, 1910)
	Plerurus digitatus	(Looss, 1899)
Lecithasteridae	*Aponurus laguncula*	Looss, 1907
Lepocreadidae	*Opechona kahawai*	Bray & Cribb 2003
Sanguinicolidae	*Cardicola forsteri*	Cribb, Daintith & Munday 2000
	Paradeontacylix godfreyi	Hutson & Whittington 2006
	P. sanguinicoloides	McIntosh 1934
	P. grandispinus	Ogawa & Egusa 1986
	P. kampachi	Ogawa & Egusa 1986
Cestoda		
Tentaculariidae	*Nybelinia thyrsites*	Korotaeva 1971

Host fish

Group/family	Taxon	Authority
Carangidae	*Seriola dumerili*	(Risso 1810)
	S. hippos	Günther 1876
	S. lalandi	Valenciennes 1833
	S. quinqueradiata	Temminck & Schlegel 1845
	S. rivoliana	Valenciennes 1833
Salmonidae	*Salmo salar*	Linnaeus 1758
	S. trutta	Linnaeus 1758
Latidae	*Lates calcarifer*	(Bloch 1790)
Scombridae	*Thunnus maccoyii*	(Castelnau 1872)