Australian salmon (*Arripis trutta*): Population structure, reproduction, diet and composition of commercial and recreational catches

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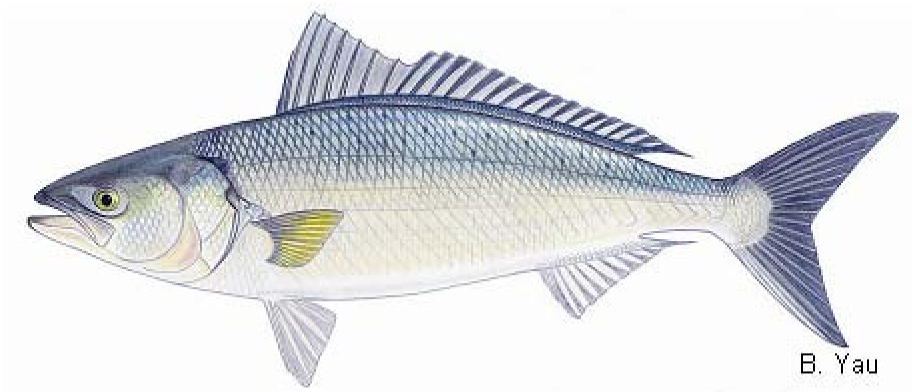

FRDC Project Nos. 2006/018 and 2008/056

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This work was done under the NSW Animal Care & Ethics approval No. 09/07.

NON-TECHNICAL SUMMARY

2006/018 and 2008/056	Australian salmon (*Arripis trutta*): Population structure, reproduction, diet and composition of commercial and recreational catches

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OBJECTIVES:

Project No. 2006/018

(1) Determine whether eastern Australian salmon comprise a single stock along S.E. Australia.

(2) Describe the catch composition of eastern Australian salmon taken by commercial and recreational fishers in NSW, including spatial patterns in sizes and ages.

(3) Describe the reproductive biology of eastern Australian salmon in NSW, including their size/age at maturity and where and when they spawn.

(4) Model growth (using otolith derived estimates of size-at-age) of eastern Australian Salmon.

(5) Develop yield per recruit and spawner-biomass per recruit models at present levels of fishing mortality.

(6) Analyse existing tagging data for patterns of movement and potential stock delineation.

(7) Describe diet and potential localised impacts on prey items.

(8) Describe the totemic and cultural significance of Australian salmon to the Aboriginal people of NSW.

Project No. 2008/056

(1) Collate existing information on eastern Australian salmon.

(2) Describe the recreational and commercial catch of eastern Australian salmon.

(3) Identify important nursery habitats and their contribution to the adult stock.

(4) Document the proportion of eastern and western Australian salmon in Bass Strait and Tasmanian waters.

(5) Use eastern Australian salmon as a case study in developing a model of co-operative multi-jurisdictional management of shared-stock fisheries to ensure global harvest sustainability.

NON TECHNICAL SUMMARY:

Outcomes Achieved

The primary outcome of this project has been to provide new information on the biology, life-history, stock structure and fisheries for eastern Australian salmon across its distribution in south-eastern (S.E.) Australia. Specifically, this information is now available to fisheries managers in each state to use in the management of this species, and also nationally to use when developing policies on managing straddling stocks. The life-history and fishery information has been synthesized into a model for cross-jurisdictional monitoring and assessment.

The new information on the diet and consumption rates of this species has addressed the concerns of various stakeholders (commercial fishers, recreational fishers, fisheries managers) in New South Wales (NSW) that schools of salmon were having large negative impacts on the juveniles of their target species. In addition, this dietary work has provided relevant input data for ecosystem models in S.E. Australia.

Analysis of otolith chemistry, tagging data and fish morphometrics indicated that salmon in S.E. Australia should be considered as a unit stock. While important for future management of this species, the work on otolith chemistry has also provided important new insights for fisheries scientists who are designing, analysing and interpreting such studies.

The study into the importance of Australian salmon to the indigenous people of NSW was successful in documenting important indigenous values and cultural uses. An outcome from this work should be better consultation and incorporation of indigenous needs and interests in the management of fisheries.

Management of eastern Australian salmon has been hampered by a lack of understanding of the species basic biology, life-history, stock structure and fisheries. Anecdotally, the stock has expanded in its size and distribution northwards, with schools of very large fish being observed in southern Queensland in recent years. Commercial landings are also at historically high levels. Eastern Australian salmon are distributed across four state jurisdictions (Tasmania, Victoria, New South Wales, and Queensland), each of which has different management arrangements for the species. The aim of the current collaborative study between scientists and managers from Tasmania, Victoria and New South Wales, was to provide new and updated information on the biology, life-history, stock structure and fisheries for eastern Australian salmon across its distribution in Australia. The results will be used in improved management of the species, and in developing future collaborative monitoring and assessments.

Growth of eastern Australian salmon was estimated by counting daily increments in the otoliths of small juvenile fish and annual increments in the otoliths of larger juveniles and adults. Growth was rapid initially with fish reaching ~ 16 cm fork length (FL) after one year and ~ 27 cm FL after 2 years. Females grew slightly faster than males after ~ 5 years of age and fish sampled from northern NSW grew faster than those sampled from further south. The largest fish sampled was 65 cm FL and was estimated to be 8 years old. The oldest fish sampled was estimated to be 12 years old and was 59 cm FL.

Evidence of spawning was recorded as far north as Coffs Harbour in NSW, some 740 km northwards of the previous northernmost observed spawning location in Bermagui. Spawning occurs in Victorian and NSW waters; however no sexually mature fish have been sampled from Tasmanian waters. Spawning occurs through an extended period between October and March, but occurs earlier in more northern latitudes. Sexual maturity occurs in 50% of fish at ~ 31 cm FL in NSW waters, but may occur at ~ 42 cm fork length when fish from Tasmanian waters are considered too. Eastern Australian salmon are multiple batch spawners with asynchronous oocyte development. They spawn up to ~ 1.8 million eggs per batch. Eggs and larvae are transported southwards by the East Australian Current. Simple calculations suggest that larvae spawned as far north as Coffs Harbour (NSW) may be capable of reaching the northernmost tip of Tasmania before settling as juveniles. Small salmon were observed recruiting to inshore Tasmanian waters during summer.

Juveniles eat mainly small crustaceans and become more reliant on fish prey as they grow. Adult salmon eat a wide variety of prey but mainly (~93%) small baitfish such as Australian sardines, anchovies, scads and blue mackerel. Their diet changes with seasons and latitudes, reflecting the relative abundance of baitfish present. Dietary consumption rate analyses indicate that salmon consume between 3.6 and 4.8 times their own body weight annually.

Analyses of the chemical composition of otoliths from fish from each state showed ontogenetic changes and some indications of area-specific chemical signatures. Tag/recapture data indicated a 1 way northwards movement of fish from Tasmania to Victorian waters and then to NSW with the onset of sexual maturity. Extensive seasonal mixing of fish occurs in Victoria and NSW, with an overall northward movement occurring with increasing age. These observations indicate that eastern Australian salmon in S.E. Australia belong to a single biological stock.

The progressive northward movement of the species with age along with the pattern of high juvenile recruitment occurring towards the southern end of the species range is reflected in the age compositions of commercial landings. The commercial fishery in Tasmania is based on 2 to 4 year old fish with none older than 7 years observed. In Victoria most fish are between 2 and 5 years old. In southern NSW fish are mainly 4 to 6 year olds with a few older individuals. Landings in northern NSW contained fish between mostly 3 and 10 years old but with the most abundant age classes being 7 years and older.

The commercial fisheries for Australian salmon are similar in each state in being relatively high volume, low market price, net-based operations, whilst also being important recreational targets. Most of the commercial catch in each state is taken by only a few fishers operating large vessels that generally fish to market requirements. The major methods used are purse seine and hauling nets. Recent commercial landings across all states have been at historically high levels, averaging nearly 1,900 tonnes p.a. since 2000/01.

Estimates of instantaneous total mortality rates based on catch curve analyses ranged between 1.0 and 1.5, but were confounded by the northwards movement of fish through time. Estimates of natural mortality (range 0.35 to 0.5) were also uncertain. Yield per recruit, spawning biomass per recruit and spawning potential ratio analyses suggested that current levels of fishing mortality are sustainable.

A cultural study undertaken within indigenous communities on the south coast of NSW found that Australian salmon had a long history of customary importance, primarily as a staple food. An improved understanding of the indigenous values and cultural uses of Australian salmon should result in better consultation and incorporation of indigenous needs and interests in the management of this species.

KEYWORDS:

Eastern Australian salmon, *Arripis trutta*, fishery, stock structure, age, growth, reproduction, diet, management.

1. INTRODUCTION

1.1. Background

Eastern Australian salmon are important to commercial, recreational and indigenous fishers and their management has been the focus of considerable debate during the past 10 years. This debate suggests that the species may be under-utilized and anecdotal information indicates that the population size and distribution has expanded considerably during the past few years (Green 2005). The commercial fisheries for this species are currently limited to bait for lobster and fish traps and a small domestic market for human consumption. There is, however, the potential for a very large export market for this species to be developed (most likely to China: Wilson & McCallum 2001) and the possibility that the stock may be more heavily exploited in the future.

A national workshop to determine research priorities for the genus *Arripis* was held in Adelaide in 1995, and highlighted the almost total lack of information available on which to manage this species. Research priorities recommended included studies on basic biology, population structure, movements, recruitment and models of yield per recruit. Unfortunately, no research on eastern Australian salmon was subsequently funded and more than ten years after the initial national workshop, there existed no further information on which to base improved management of this species.

The current study was initiated because of concerns about management of Australian salmon in New South Wales (NSW). Management of this species has been contentious and there was a strong push for appropriate biological research to be done. In 2001, Australian salmon were declared a recreational only target species north of Barrenjoey Headland in NSW, with commercial fishers being limited to a 100kg a day bycatch limit. This closure, in combination with an apparent increase in abundance of salmon on the north coast of NSW, was unpopular with commercial and some recreational fishers. Fishers claimed that: (i) the closure was unfair and denied them the opportunity to catch salmon for sale, particularly if a lucrative export market was to be developed, and; (ii) that large schools of salmon were eating vast quantities of other fish species including baitfish (such as garfish and pilchards) and juveniles of other commercially important species (such as whiting). In response to these management concerns the NSW Recreational Saltwater Fishing Trust Expenditure Committee (NSW RFSTEC) committed funding to research the biology and fisheries for Australian salmon in NSW. This initial funding by the NSW RFSTEC was used in developing an application to FRDC to broaden the scope of the research and resulted in FRDC Project No. 2006/018 "Australian salmon (*Arripis trutta*): Population structure, reproduction, diet and composition of commercial and recreational catches in NSW".

While Project No. 2006/018 was generated by the need for information on the biology and fishery for Australian salmon to enable improved management in NSW, it was recognized by the FRDC that the issue of managing eastern Australian salmon had been of concern nationally since the 1995 workshop held in Adelaide. This workshop acknowledged the need for management arrangements for such species that range across state jurisdictions. Therefore, when funding the Project 2006/018 the FRDC included a critical milestone that stated if preliminary results indicated eastern Australian salmon in south-eastern (S.E.) Australia to be a single stock, that an application would be developed in collaboration with the Tasmanian and Victorian fisheries agencies with the objective of developing a model of management for species that are distributed across state jurisdictions. A preliminary assessment of stock structure was provided to the FRDC in October 2007 as a part of a milestone report for Project No. 2006/018. This report suggested that based on analysis of: i) historical tag/recapture data, ii) otolith microchemistry and physical morphometrics and iii) size and age structures, that eastern Australian salmon should be considered as a single management unit throughout its distribution. As a result, an expansion of Project No. 2006/018 was developed through discussions with the FRDC and scientists and managers from the fisheries management agencies in NSW, Victoria and Tasmania. This became Project No. 2008/056.

1.2. Need

Anecdotal reports suggest that the eastern Australian salmon stock has increased substantially in recent times and is believed to be under-utilized. Despite this, management of this species in NSW has been contentious, and is restricted by a lack of knowledge on biology and population dynamics. Specifically, managers require information that will assist their decision making concerning: (i) the status of the stock; (ii) potential expansion of the commercial fishery; (iii) impacts of resource allocation, and; (iv) ecosystem effects of salmon population expansion.

There was a lack of information on the sizes and ages of salmon being harvested and little knowledge of their biology. Research on age and growth in the 1970s was based on scales, which have since been shown to be inaccurate (Eggleston 1975). Studies on reproduction have been limited to the timing of spawning in southern parts of their distribution. Results from Project No. 2006/018 will provide the necessary information on the composition of landings, age, growth, reproduction, movements and diet to enable informed management of the salmon resource in NSW.

The outcomes from Project No. 2006/018 include improved knowledge and management of Australian salmon and directly addresses the FRDC R&D program "Natural Resources Sustainability" and the strategic challenge to "Improve the sustainability of natural resources supporting wild-catch and aquaculture". At the NSW state level, this project satisfies three priority areas of research listed under the key document "Planning strategic research, aquaculture and aquatic conservation in New South Wales, 2004–2009." These are: (i) to examine the predatory impacts of Australian salmon on other commercially important fish species; (ii) information on age and growth of recreationally important species, and; (iii) development of stock assessments for target species in the ocean hauling fishery.

Greater collaboration between jurisdictions that share common fish stocks is desirable because it should improve the way in which such fisheries are managed. Eastern Australian salmon have previously been identified for use as a case study when developing co-operative management arrangements between jurisdictions. This desire is reflected in the FRDC's Research & Development Plan 2005–10 under the strategic challenge of "Natural Resources Sustainability". The specific goal is to "Develop and implement management frameworks that facilitate co-management, market focus, independent accreditation and cost efficiency".

There are few concerns for the sustainability of eastern Australian salmon fishing under current harvest levels in Tasmania, Victoria and NSW; however the potential for increased markets, both domestically and overseas, is high. The historical model of eastern Australian salmon life-history suggests that all spawning occurs in the coastal waters of mainland Australia, eggs and larvae are then distributed southwards into Tasmanian waters where they recruit as juveniles before migrating back to mainland waters upon attaining sexual maturity. It is imperative that hypotheses examining the veracity of this model be tested because, if this model is correct, cross-jurisdictional management will be complicated since each state will target fish during different stages of their life-history.

A decision framework for cross-jurisdictional management was developed by MacDonald (2003) and outlined the information required to facilitate collaborative management and biological sustainability. Requisite information from each state included time series of catch and effort, current sizes and ages in landings, the ratio of eastern to western Australian salmon species in landings, and an understanding of reproductive characteristics including recruitment patterns, population dynamics and spawning migrations. Such information is needed if a cross-jurisdictional management model is to be developed and further research is required in Tasmanian and Victorian waters to complement that done in NSW.

1.3. Objectives

Project No. 2006/018

(1) Determine whether eastern Australian salmon comprise a single stock in S.E. Australia.

(2) Describe the catch composition of eastern Australian salmon taken by commercial and recreational fishers in NSW, including spatial patterns in sizes and ages.

(3) Describe the reproductive biology of eastern Australian salmon in NSW, including their size/age at maturity and where and when they spawn.

(4) Model growth (using otolith derived estimates of size-at-age) of eastern Australian salmon.

(5) Develop yield per recruit and spawner-biomass per recruit models at present levels of fishing mortality.

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(8) Describe the totemic and cultural significance of Australian salmon to the Aboriginal people of NSW.

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(4) Document the proportion of eastern and western Australian salmon in Bass Strait and Tasmanian waters.

(5) Use eastern Australian salmon as a case study in developing a model of co-operative multi-jurisdictional management of shared-stock fisheries to ensure global harvest sustainability.

The 5th objective of Project No. 2008/056 was deferred by FRDC to another FRDC funded study to be done as part of a national harvest strategy. This national harvest Strategy is being done through the Australian Fisheries Management Forum (AFMF) and will use the data collected during the present study when using eastern Australian salmon as a case study. Nevertheless, we have addressed this objective in terms of cross-jurisdictional monitoring and management of eastern Australian salmon in Chapter 9.

2. FISHERIES

OBJECTIVES ADDRESSED

This chapter addresses objective 2 of the original Project No. 2006/018 to "Describe the catch composition of eastern Australian salmon taken by commercial and recreational fishers in NSW, including spatial patterns in sizes and ages" and objectives 1 and 2 of the project expansion to "Collate existing information on eastern Australian salmon" and to "Describe the recreational and commercial catch of eastern Australian salmon".

2.1. Introduction

Eastern Australian salmon have a long history of importance to the commercial, recreational and indigenous fishers of south-eastern (S.E.) Australia. There is a long history of exploitation in New South Wales (NSW), Victoria and Tasmania with records of large catches being taken by seine net as far back as 1789 (Appendix 3). Eastern Australian salmon are not renowned for their eating qualities and the commercial fisheries for them have been high volume-low price operations. Only a relatively minor proportion of the catch has historically been sold for human consumption, with the majority of the catch being sold for rock lobster and fish trap bait. Despite this, there have been investigations into the potential for exporting Australian salmon overseas. In fact, the FRDC have funded two studies to specifically examine the potential for product development and export opportunities for Australian salmon (FRDC Project No. 95/142 and Wilson & McCallum 2001). These studies concluded that quality control was an issue and while Australian salmon rated very poorly in tasting trials, there was interest in evaluating the species for canning. In fact, a major market for eastern Australian salmon was historically through the Heinz cannery in Eden in southern NSW. The cannery processed roughly 1000 t of Australian salmon annually, but closed in June 1999. No export markets have developed for eastern Australian salmon and the commercial fisheries currently supply only local markets.

The fisheries for Australian salmon in each state are currently similar in that they are very popular targets of recreational fishers and also support substantial commercial fisheries. Commercially, each state supports a small number of large vessels that are equipped to capture and store large quantities of Australian salmon. These larger vessels land the majority of the catch, while a large number of smaller operations catch the species more as part of their diversified fishing businesses.

Eastern Australian salmon is an inshore species and the fisheries that exploit salmon are under the jurisdiction of each state. This chapter therefore describes the current state of knowledge of the fisheries by state.

2.2. Materials and methods

Information on the fisheries for eastern Australian salmon was obtained from historical records within each state management agency, commercial catch reports and sampling done during the present study. Information on the sizes and ages in landings was obtained through the sampling described in Chapter 3 (Age & Growth).

2.3. Results

2.3.1. *The NSW fishery*

In NSW eastern Australian salmon are harvested as part of the share-managed commercial fisheries and also the recreational fishery. The commercial fisheries are managed through general input controls that relate to gear and relevant fishing endorsements, while the recreational fishery is managed through a bag limit of 5 Australian salmon per person in possession with no minimum legal length. A closure prohibiting the taking of Australian salmon by netting methods in NSW waters north of Barrenjoey Headland was implemented in August 2001; however since April 2006 commercial fishers who are endorsed to fish in the Ocean Hauling Fishery have been permitted to take up to 2 t of Australian salmon north of Barrenjoey Headland for personal bait use, with a management review trigger limit of 100 t/yr. Australian salmon achieve relatively low market prices in NSW with the majority being sold for rock lobster and fish trap bait. The small quantities of Australian salmon sold through the Sydney Fish Markets average less than $1.50/kg (unpublished data).

2.3.1.1. Landings

Currently, the majority of the eastern Australian salmon commercial harvest is taken from NSW waters (Fig. 2.1). Prior to the 1990s the majority of the eastern Australian salmon commercial harvest was taken from Tasmanian waters. Annual Australian salmon catches in NSW waters since the 1980s have ranged between 200 and 1,500 t, averaging ~800 t/yr (Fig. 2.1). Historically, most of the commercial catch has been taken from the south coast of NSW; however substantial quantities were taken on the north coast during the mid 1990s (Fig. 2.2).

Landings have increased during recent years and almost the entire commercial catch is taken in the Ocean Hauling Fishery. The main methods of commercial capture are purse seining (~ 44% of the total catch since 2000/01) and beach hauling (~ 52% of the total catch since 2000/01) (Fig. 2.3). Prior to the mid 1990s most landings were taken by beach hauling. Landings occur year round, however average monthly landings are greater during the warmer months (Fig 2.4).

Australian salmon are considered an important recreational sportfish in NSW. The National Recreational and Indigenous Fishing Survey (Henry *et al.* 2003) indicated that recreational fishers harvested approximately 111,000 (~ 220 tonnes) Australian salmon annually in NSW waters. In addition, approximately 34% of Australian salmon caught by recreational fishers around Australia were released; however there are no specific estimates of release rates in NSW.

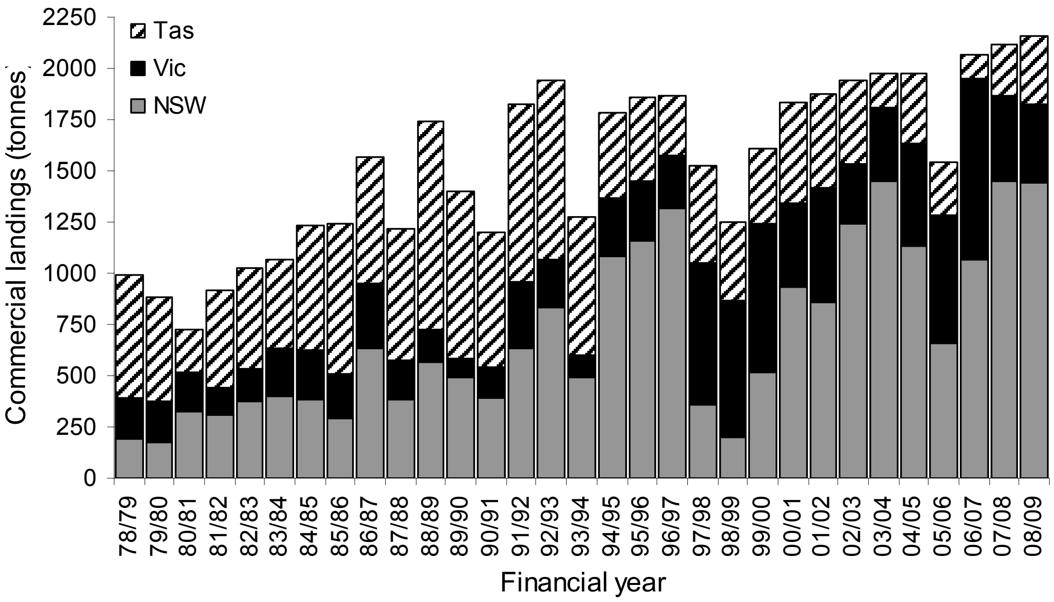


Figure 2.1. Reported commercial landings of eastern Australian salmon from each state since 1978/79.

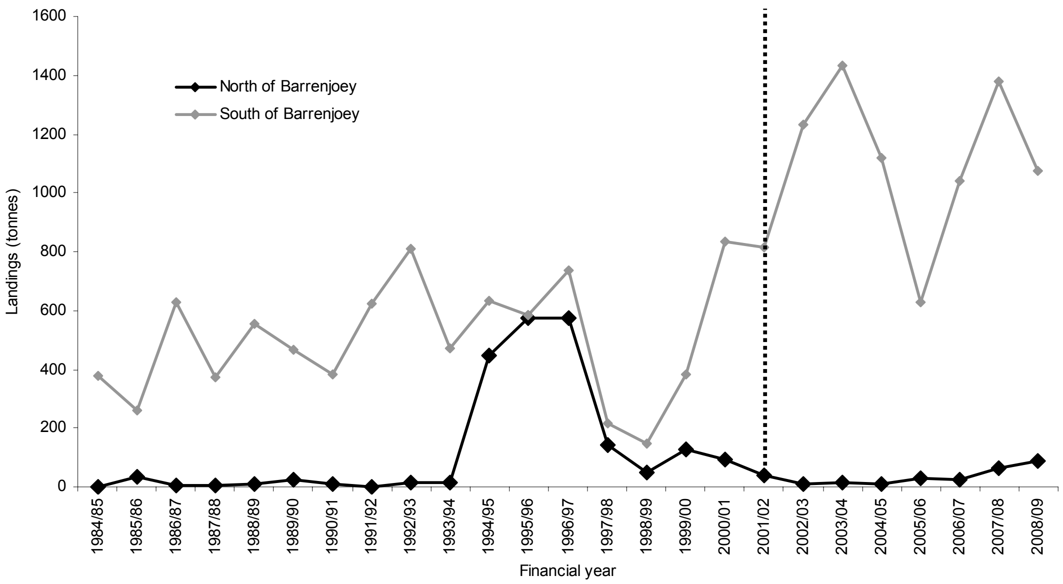


Figure 2.2. Reported commercial catch of Australian salmon in NSW waters north and south of Barrenjoey headland 1984/85 to 2008/09. The dotted line indicates the imposition of the commercial netting closure north of Barrenjoey headland in 2001.

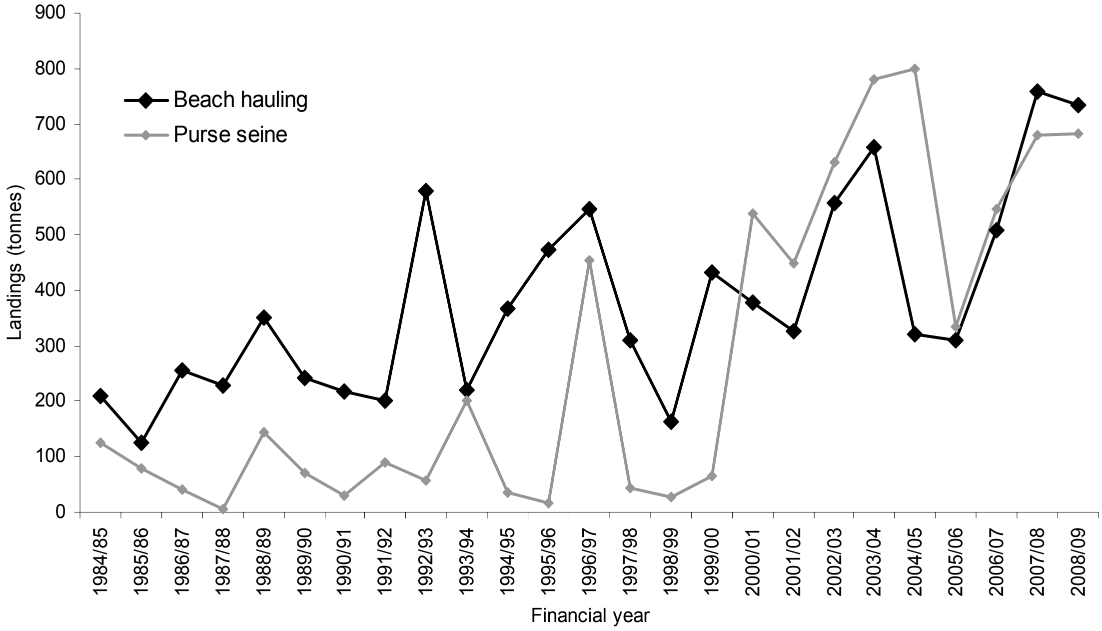


Figure 2.3. Reported commercial catch of Australian salmon in NSW waters by major fishing gear type 1984/85 to 2008/09.

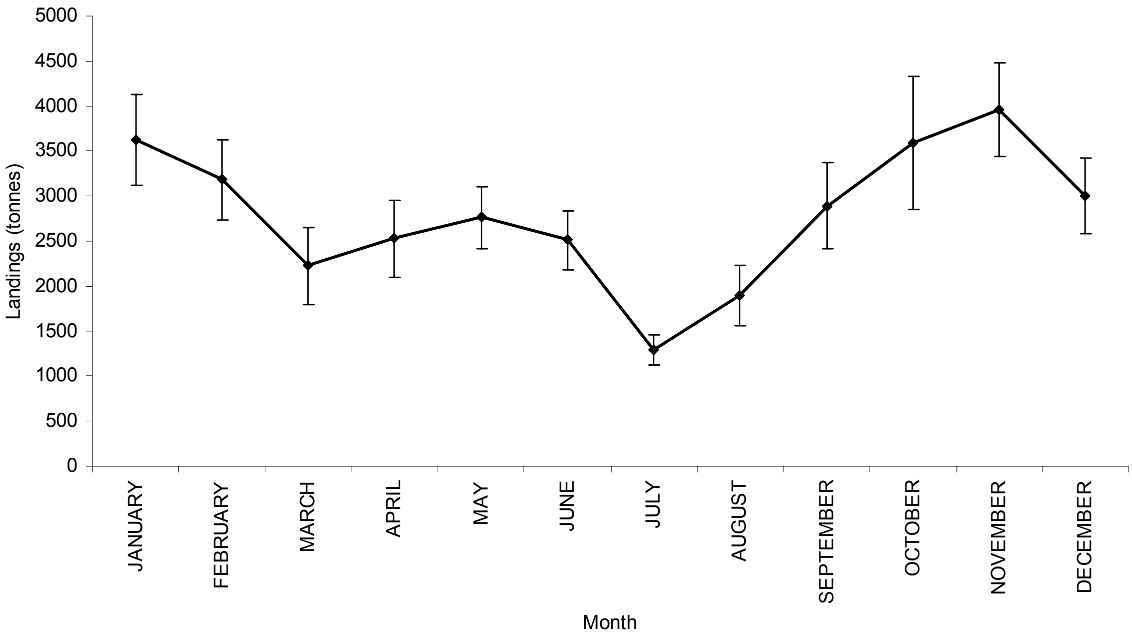


Figure 2.4. Reported average (± S.E.) commercial catch of Australian salmon by month in NSW waters 1984/85 to 2008/09.

2.3.1.2. Length composition

The lengths of 2,077 eastern Australian salmon were measured from commercial landings in NSW between 2006 and 2009. Australian salmon from catches south of Sydney were generally between 35 and 60 cm fork length (FL) and were on average larger than those sampled in Victoria or Tasmania (Figs 2.5, 2.7, 2.17). The length frequency distribution of salmon sampled from northern NSW exhibited multiple modes with the most abundant mode being substantially larger than those observed from more southern areas (Fig. 2.5).

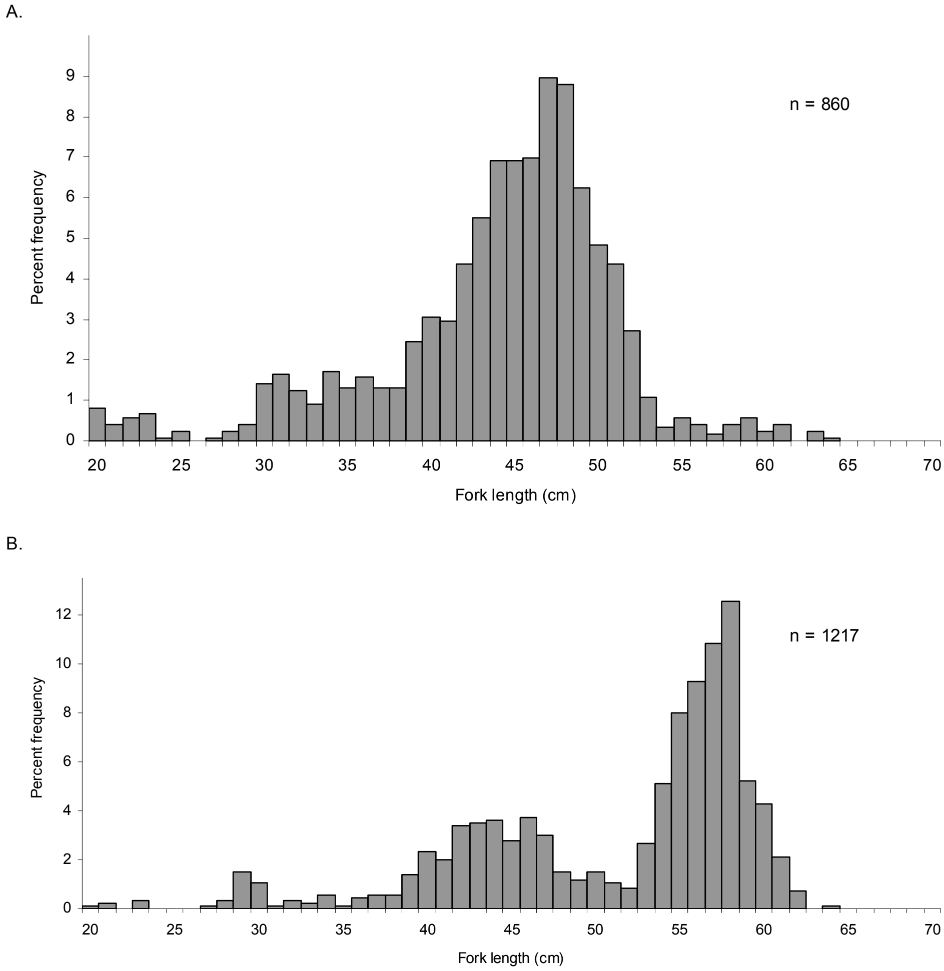


Figure 2.5. Length frequency distributions of eastern Australian salmon captured by commercial fishing in New South Wales during 2006 to 2009. A. Southern NSW; B. Northern NSW.

2.3.1.3. Age composition

The age composition of eastern Australian salmon sampled from commercial landings in NSW ranged between 0 and 12 years (Fig. 2.6). Salmon from southern NSW were typically between 2 and 5 years old, whereas a considerable percentage (~ 54%) of fish from northern NSW were aged 7 years and older (Fig. 2.6C). The most abundant age class in southern NSW was 5+ years in 2006/07, 2008/09 and overall (Fig. 2.6A). 2 and 3+ year old fish were also highly abundant in 2007/08 (Fig. 2.6A). In northern NSW, there was some evidence of a strong year class progressing from age 7 in 2006/07, to age 8 in 2007/08 and age 9 in 2008/09 (Fig. 2.6B).

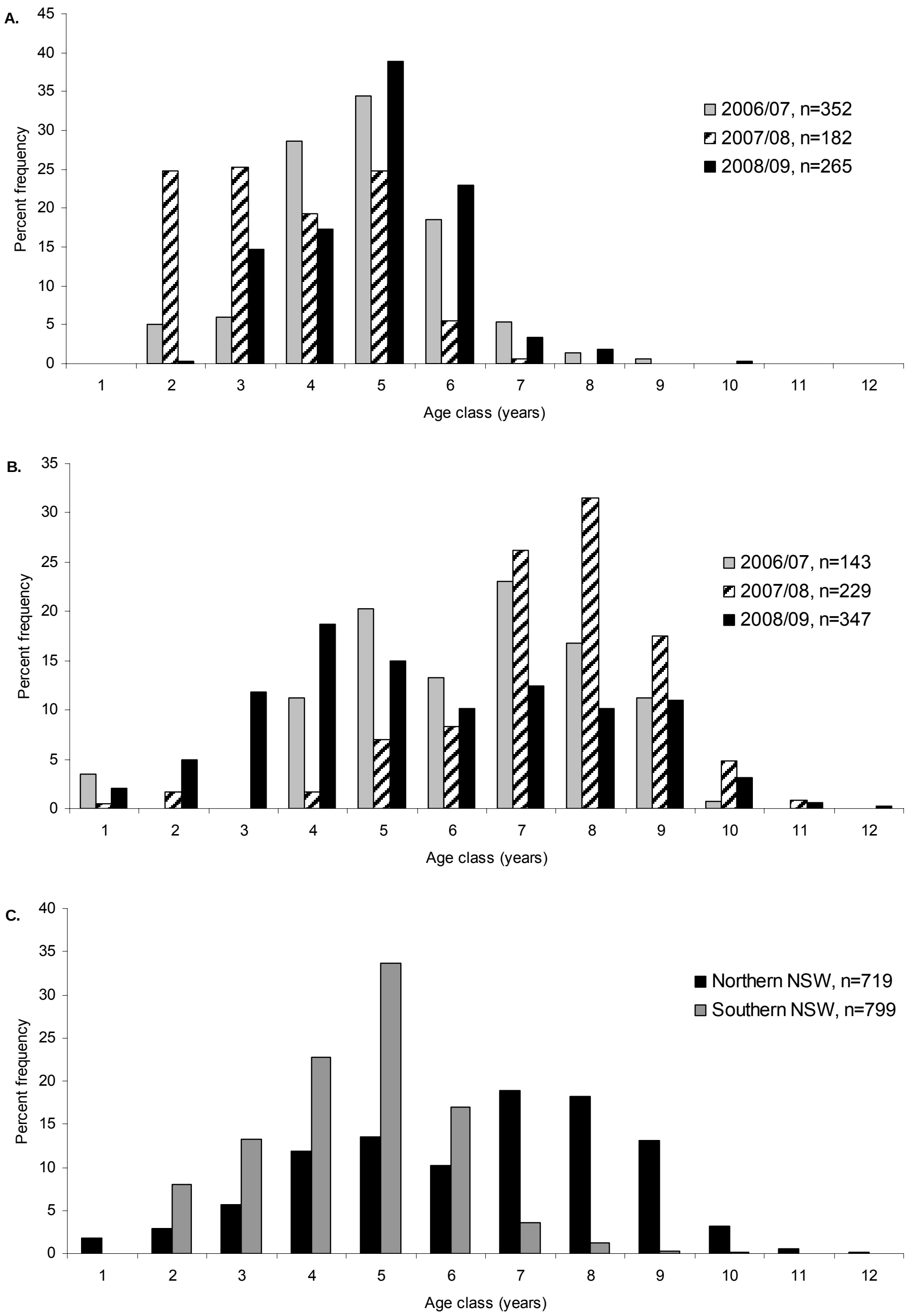


Figure 2.6. Age compositions of eastern Australian salmon sampled from commercial landings in southern and northern New South Wales 2006/07, 2007/08 and 2008/09. A. southern NSW; B. northern NSW; C. both regions pooled across years.

2.3.2. The Victorian fishery

In Victoria, Australian salmon are harvested both in open coastal waters and in bays and inlets as part of several defined multi-species commercial finfish fisheries, and also by recreational fishing. The commercial fisheries are managed using input controls (limited entry licensing, gear restrictions, closed areas/seasons), while the recreational fishery is managed using gear restrictions and the application of individual catch limits (daily bag limit and possession limit in, on or next to fishing waters of 20 Australian salmon and/or Australian herring per person). A legal minimum size of 21 cm total length (TL) applies to both commercial and recreational take of Australian salmon. Australian salmon achieve relatively low market prices in Victoria with the majority of the commercial catch being sold for bait or pet food. The small quantities of Australian salmon sold through the Melbourne Fish Market have averaged less than $2.00/kg (unpublished data).

2.3.2.1. Landings

Victorian commercial and recreational catches consist of a mixture of eastern Australian salmon (*A. trutta*) and western Australian salmon (*A. truttaceus*). The two species are morphologically similar and are not identified separately in commercial catches. For the purposes of this report past research and anecdotal evidence on species distribution has been used to estimate the total eastern Australian salmon commercial catch using the following criteria:

- Catches east of 146^o E (Gippsland coast/inlets/estuaries) are assumed to be 100% eastern Australian salmon;
- Catches between 144^o E and 146^o E (central Victorian coast/bays/inlets) are assumed to be a mixture of 30% eastern Australian salmon & 70% western Australian salmon;
- Catches west of 144^o E (western Victorian coast) are assumed to be 100% western Australian salmon; and
- Catches from unidentified Victorian waters are assigned as 50% eastern Australian salmon and 50% western Australian salmon.

Commercial landings of eastern Australian salmon from Victorian waters have fluctuated between ~ 90 and ~ 900 t/yr since 1978/79 (Fig. 2.1). Prior to the mid 1990s landings were generally less than 300 t/yr and were taken primarily using haul seine nets (also known as beach seines and estuary seines). A significant proportion of these catches (~ 20% – 80%) were taken from bays and inlets (particularly Port Phillip Bay and Corner Inlet).

Since the mid 1990s landings of eastern Australian salmon from Victorian waters have increased substantially to an average of ~ 550 t/yr and a peak of just under 900 t in 2006/07. Much of this increase is attributable to increased purse seine and haul seine catches from Gippsland coastal waters. Since 1997/98 Victorian landings have contributed ~ 20% of the total eastern Australian salmon commercial catch from S.E. Australian waters.

Australian salmon are a major target species for both boat-based and shore-based recreational fishers in bays, inlets and coastal waters of Victoria. The National Recreational and Indigenous Fishing Survey (Henry *et al.* 2003) estimated that in 2000/01 recreational fishers harvested approximately 540,000 Australian salmon from Victorian waters with an estimated weight of ~ 270 t. Approximately 34% of Australian salmon caught by recreational fishers around Australia were released; however there were no specific estimates of release rates for Australian salmon in Victoria. Examination of the regional distribution of the recreational catch using the species distribution criteria listed above indicated that eastern Australian salmon made up an estimated 35 – 40% of the 2000/01 total Victorian recreational salmon catch.

2.3.2.2. Length composition

The lengths of eastern Australian salmon were measured from 6 commercial catches taken from east Gippsland coastal waters and landed in Lakes Entrance. The length distribution had 3 distinct modes with the largest mode (being ~ 40 to 50 cm FL) being larger than the majority of fish sampled from Tasmanian commercial catches (Figs 2.7 & 2.17).

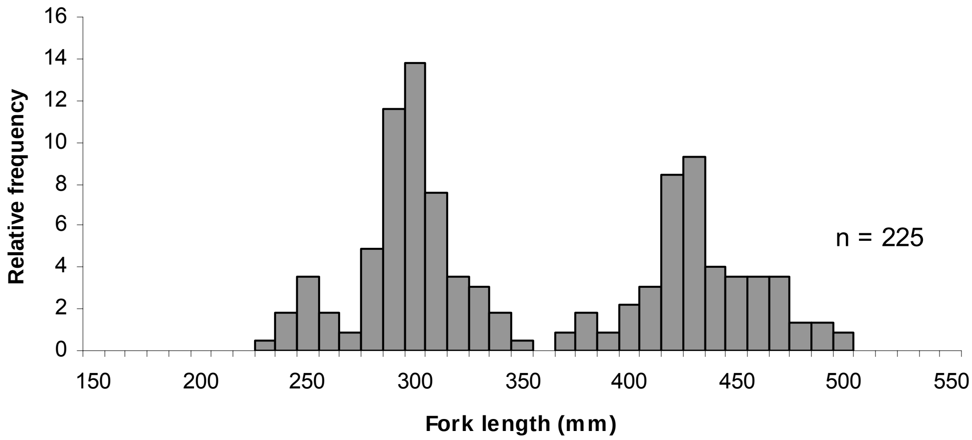


Figure 2.7. Length frequency distribution of eastern Australian salmon captured by commercial fishing in east Gippsland coastal waters, Victoria during 2008/09.

2.3.2.3. Age composition

Eastern Australian salmon sampled from commercial catches in Victorian coastal waters were typically between 1 and 6 years old (Fig. 2.8). The most abundant age classes reflect the modes in the length frequency distributions at approximately 30 cm FL (2 years old) and 40 to 50 cm FL (4 years old) (Fig. 2.7). No data were obtained on the age composition of salmon from Victorian bays and inlets.

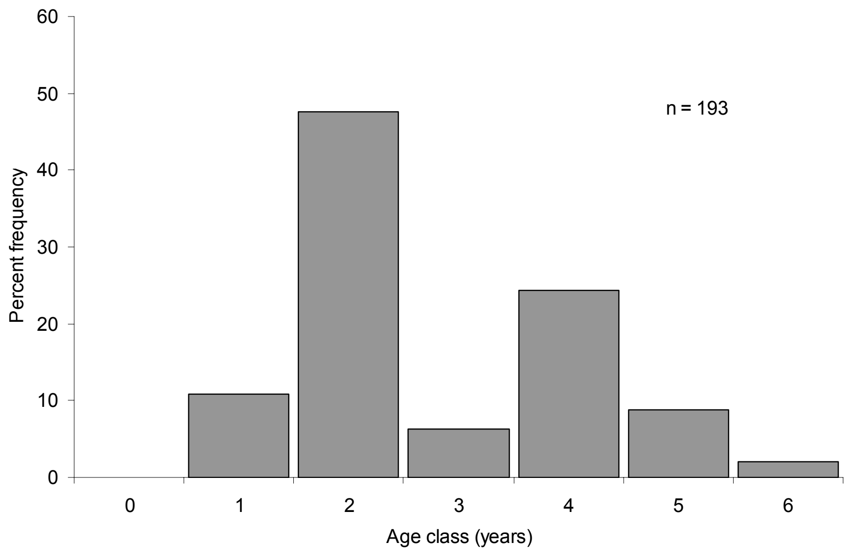


Figure 2.8. Age composition of eastern Australian salmon sampled from commercial landings in Victorian coastal waters. *n* = number of fish aged.

2.3.3. The Tasmanian fishery

Australian salmon is one of many species managed under the umbrella of the Tasmanian Scalefish Fishery (TSF). The TSF is largely an input controlled commercial fishery, with limited entry and gear restrictions being the major management tools used to restrict catch and effort; however, area closures and catch limits are also used. A Fishing Licence (Class Scalefish) has four general licence categories: Scalefish A, B, C and Rock Lobster that specify the quantity of gear that can be used. In addition, specific gear and species licences are used to provide access to and limit fishing effort on certain species. Gear licences exist for beach seines, the major gear type used to take Australian salmon, and a species licence also exists for Australian salmon called a Fishing Licence (Australian salmon).

Holders of a Fishing Licence (Class Scalefish) are permitted to harvest Australian salmon using their associated gear entitlements, but they are restricted to a maximum of 500 kg on board their vessel at any one time. Holders of a Fishing Licence (Australian salmon) are not bound by trip limits, but area closures apply and only eight licences have been issued.

Whilst the fishery is largely input controlled a total catch limit set at 120% of the average annual catch between 1996/97 and 2006/07 of 435 t applies. If the catch limit is reached during a fishing year, a review of the fishery will be undertaken to determine if further management action is required.

The recreational Australian salmon fishery in Tasmania is largely managed by two key output controls; a legal minimum size limit of 200 mm TL and a possession limit of 15. Recreational fishers are permitted to use a variety of gear types including rod and line, beach seines and gillnets, with recreational licences required to use a beach seine or gillnet. There are no restrictions on the number of recreational licences issued in any given year.

Australian salmon have had a long history of exploitation in Tasmania, with large-scale commercial fishing occurring since at least 1958. Participation in the commercial fishery is comprised of two sectors; a small number of large vessels specifically equipped to capture and store large quantities of Australian salmon, and a large number of small vessels which target the species on an opportunistic basis as part of a diversified fishing operation. In more recent years vessels typically greater than 20 m in length have taken most of the commercial catch, with one company operating up to three vessels and accounting for 85% of landed catch during the period 1995/96 to 2008/09. The most important fishing areas are along the north coast, including the Bass Strait islands, with smaller catches often taken in the south and east of the state (Figs. 2.9 and 2.10).

Beach seining accounts for the majority of catch, however, purse seining and gillnetting are often used by the smaller operators. Large-scale beach seining involves deploying a net around a school of Australian salmon using a small boat and then hauling the net into the shallows, forcing the fish into a cod-end which is transferred to the mother ship and the catch brailed into holding tanks. Spotter planes are typically used to locate the schools and direct fishers in the placement of nets.

Commercially caught Australian salmon are frozen whole and sold as rock lobster bait with production levels linked, to a large extent, to market demand. Some Australian salmon are sold fresh for human consumption and in past have been canned for pet food.

Australian salmon is also an import recreational species in Tasmania, taken mainly by line fishing methods. Australian salmon is the second most commonly captured fish species by recreational fishers in Tasmania (Lyle 2005, Lyle *et al.* 2009).

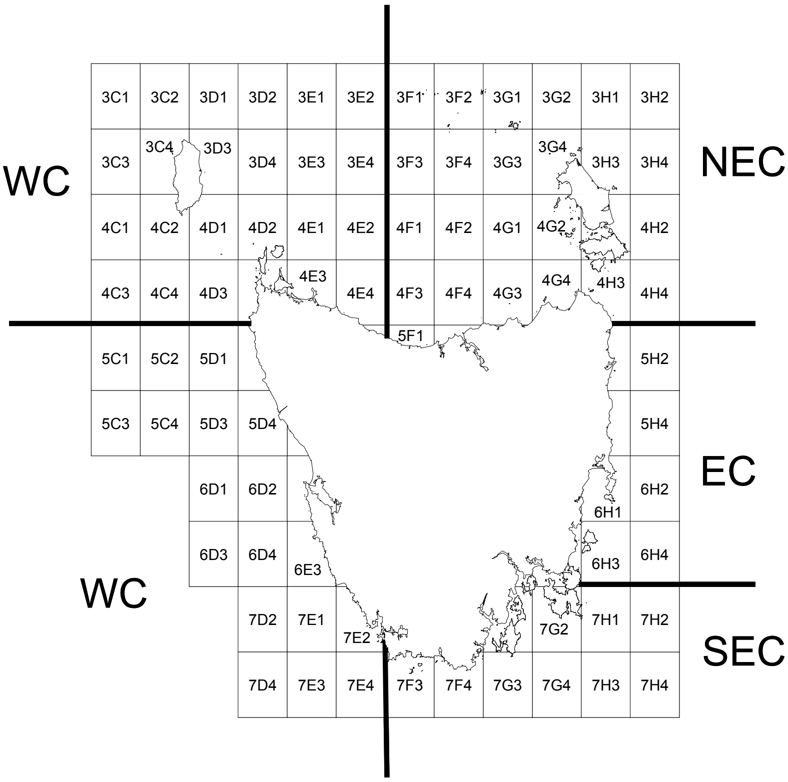


Figure 2.9. Map of Tasmania with 30 nm fishing blocks and the assessment regions. SEC is south-east coast, EC is east coast, NEC is north-east coast, NWC is north-west coast, and WC is west coast.

2.3.3.1. Landings

The commercial landings of Australian salmon in Tasmania peaked in 1974/75 at 1,464 t and have averaged ~ 530 t/yr since that time (Fig. 2.1). Over the last decade, however, landings have fluctuated between 280 and 350 t while in 2006/07 just 115 t were landed, the lowest catch recorded in the history of the fishery in Tasmania.

Beach seines have accounted for the majority of the commercial catches (~ 92%) taken since 1995/96, with the remainder captured as by-product in gillnet and modified purse seine fisheries (Fig. 2.10a). The bulk of these catches have been taken by a small number of large-scale operators. Prior to 1998/99 most catches were concentrated in the north-east but since then catches have been more evenly spread between the north-east and north-west (Fig. 2.10a).

Beach seine effort has gradually declined since the late 1990s and in 2008/09 effort was at its lowest recorded level (Fig. 2.10b). Beach seine catch rates, based on catch per shot and daily catches, remained constant up until 2006/07 after which they increased markedly and in 2008/09 were over five times greater than 1995/96 levels (Fig. 2.10c).

There is little evidence of seasonality in catches although they are generally lowest between August and October (Fig. 2.11). Since 1995/96 catches averaged ~ 28 t/month with peaks at ~ 48 t in January and July (Fig. 2.12). The highest recorded monthly catch of 195 t was recorded in July 1997. Until the late 1990s catches were generally higher during the summer and winter months whereas recently there has been a shift towards catches being more concentrated between spring and autumn (Fig. 2.11).

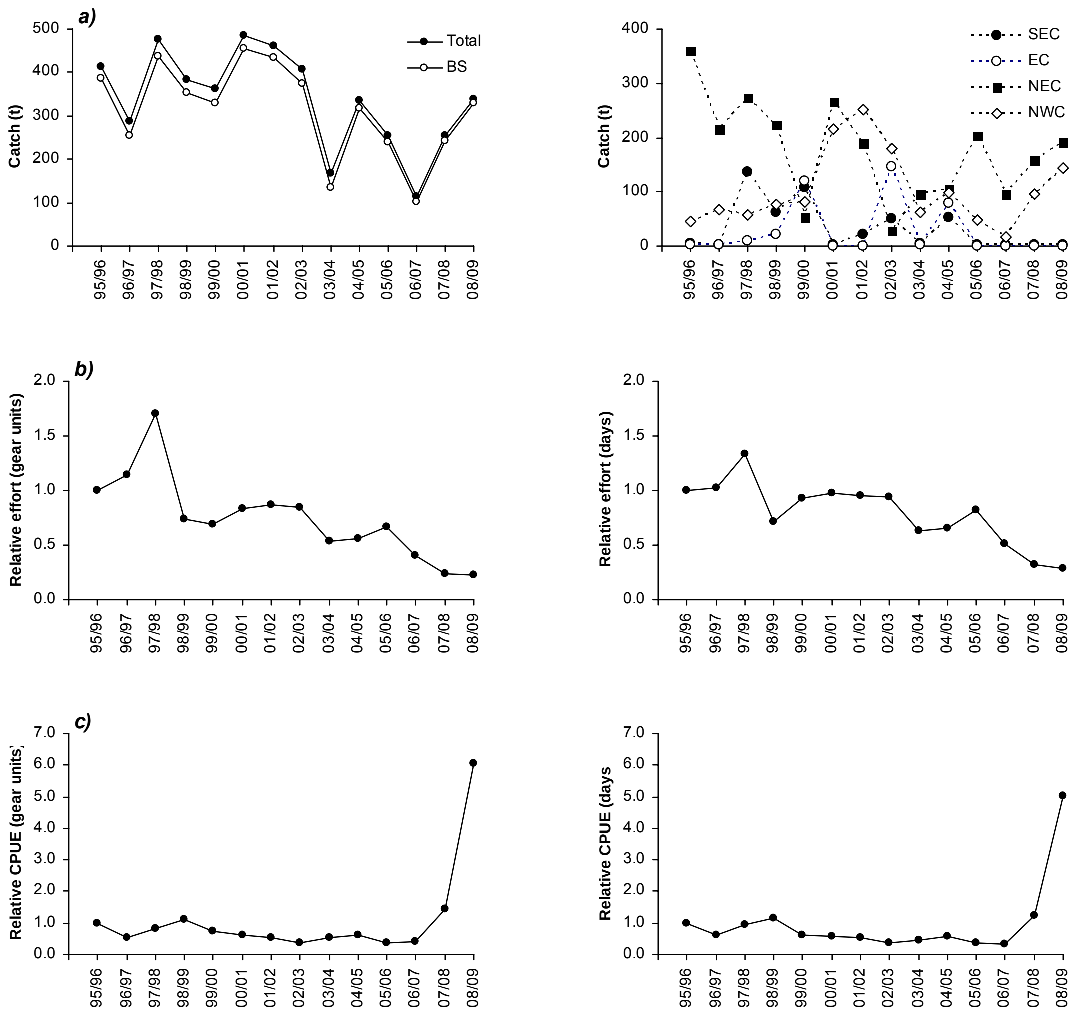


Figure 2.10. a) Annual catch (tonnes) of Australian salmon by method (left) and region (right) since 1995/96 in Tasmanian waters; b) effort by method based on gear units (left) and by days fished (right) relative to 1995/96; and c) catch per unit effort (CPUE) based on weight per gear unit (left) and weight per day fished (right) relative to 1995/96. BS is beach seine; SEC is south-east coast, EC is east coat, NEC is north-east coast, and NWC is north-west coast.

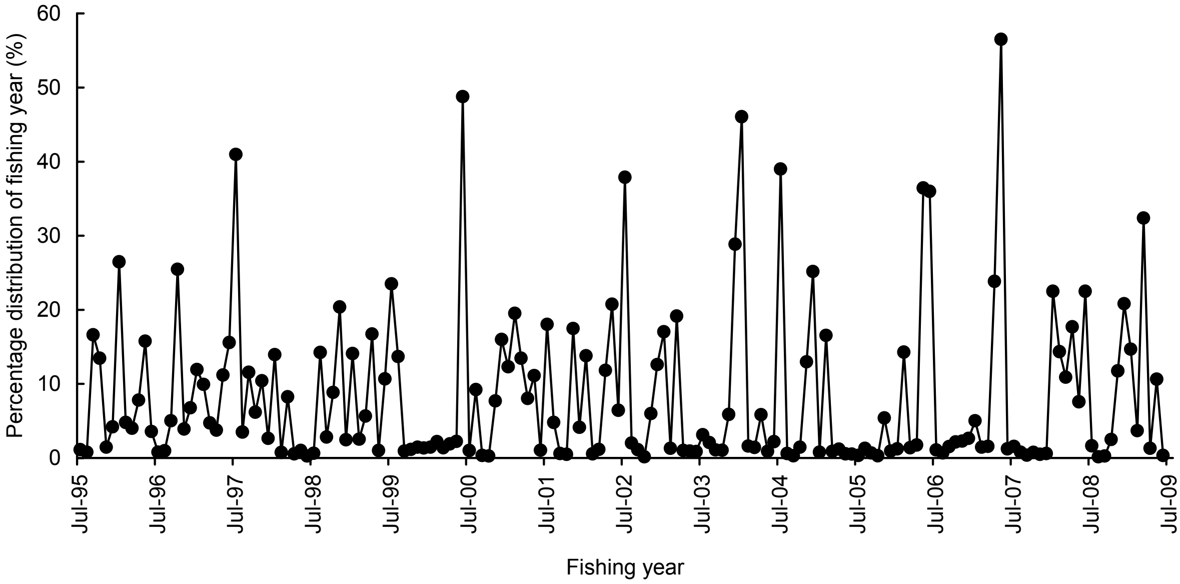


Figure 2.11. Monthly catch distributions (as proportion of the total catch within the fishing year) of Australian salmon in Tasmania between 1995/96 and 2008/09.

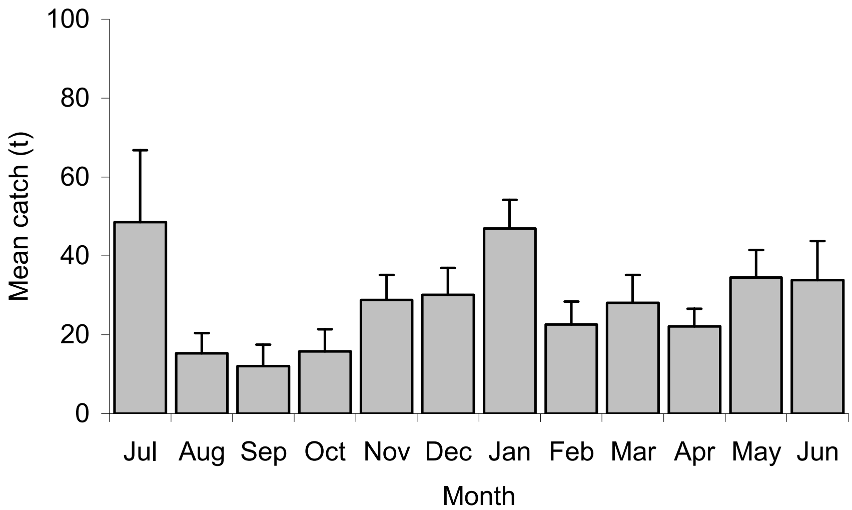


Figure 2.12. Mean monthly catch (tonnes) of Australian salmon from Tasmania for the period 1995/96 to 2008/09. Error bars are standard error.

A recently completed state-wide survey of recreational fishing provided an estimate of the recreational catch of Australian salmon in Tasmania for the 12 month period December 2007 to November 2008 of 188,227 (S.E. ± 21,280) fish, of which 110,312 (± 14,373) were harvested (Lyle *et al.* 2009). This represented approximately 48 t, which compared with the commercial harvest of 300 t for the corresponding period. Australian salmon were the second most commonly harvested finfish species in Tasmania. Key characteristics of the recreational fishery are summarised in Fig. 2.13.

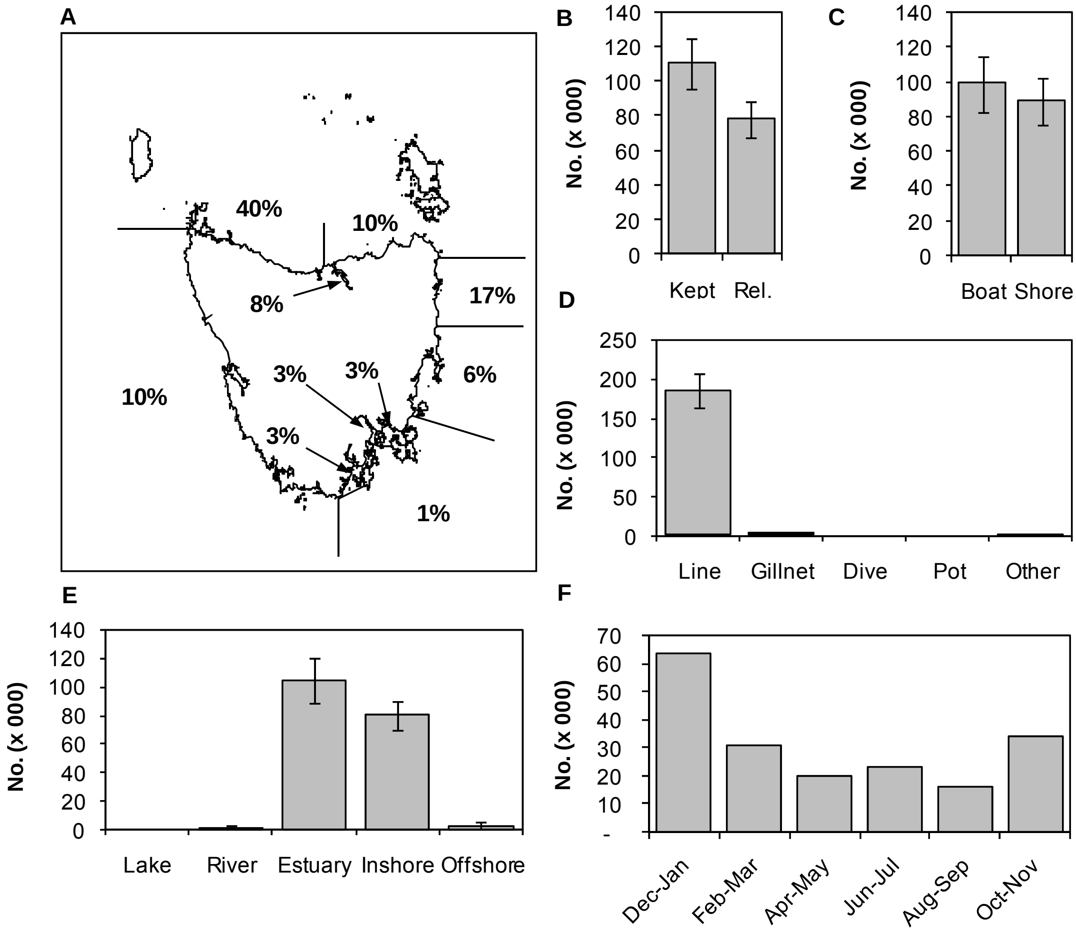


Figure 2.13. Characteristics of the recreational fishery for Australian salmon in Tasmania during 2007/08: A) proportion (%) of the total catch (numbers) by fishing region; B) total numbers kept and released; C) total catch (numbers) by boat and shore based fishing activities; D) total catch (numbers) by fishing method; E) total catch (numbers) by water body fished; and F) seasonality in the catch (numbers). Error bars represent one standard error. (modified from Lyle *et al.* 2009).

2.3.3.2. Length composition

Commercial catch sampling: 1979/80 – 1995/96

The majority of the Australian salmon taken by the Tasmanian commercial fishery between 1979/80 and 1995/96ranged between 300 and 450 mm FL; individuals > 500 mm FL were rare (Fig. 2.14). Length distributions were mainly single or bi-modal, with modes between 300 – 350 mm FL and 400 – 450 mm FL. Individuals smaller than ~ 300 mm FL were rare in most years apart from 1980/81, 1986/87 and 1994/95, when individuals in the 250 – 300 mm FL size range were captured in moderate numbers.

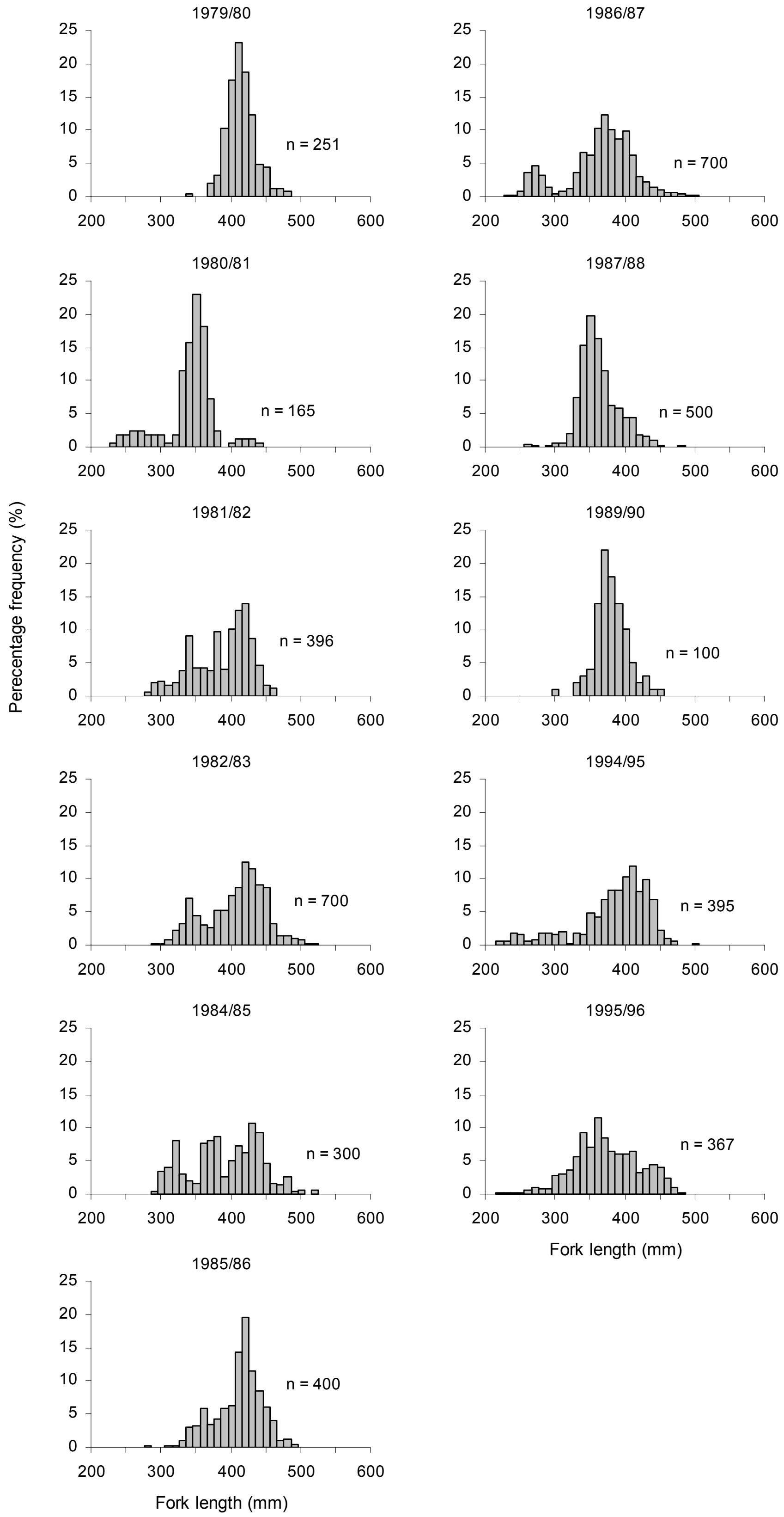


Figure 2.14. Length frequency distributions of Australian salmon captured by commercial fishing between 1979/80 and 1995/96. Frequencies are by 10 mm size classes (fork length, rounded down to the nearest size class), within fishing seasons (July–June). *n* = total number of individuals measured.

Samples combined across years indicated that in most months at least two modes were distinguishable (Fig. 2.15). Captures of Australian salmon < 300 mm FL were rare in all months apart from April, during which time fish in 250 – 300 mm size range were relatively common.

Some evidence of modal progression between months which could be linked to growth was apparent. For example in January a mode of around 300 mm FL can be seen to progress at approximately 10 – 20 mm FL per month up until August where it reached 370 to 380 mm FL. Beyond August this 'cohort' becomes somewhat obscured amongst the larger size classes however it is likely this cohort is observed as a 400 mm FL mode from September through to December.

Australian salmon captured from Bass Strait were typically larger than those from the east (EC) and south-east (SEC) coasts with fish from the central Bass Strait (CBS) on average smaller than those from the north-east coast (NEC) (Fig. 2.16). For example, ~ 85% of Australian salmon from NEC were > 400 mm FL whereas only ~ 47% from CBS, 22% from EC and 9% from SEC fell into this category. Individuals < 300 mm FL were uncommon in most regions with the exception of catches from the EC which were represented by a cohort ranging between 250 to 300 mm FL.

In most regions length frequencies were characterised by multiple modes, the exception being the NEC sample which consisted of a single mode around 430 mm FL. Landings from the SEC typically centred around two modes at 350 and 400 mm FL whereas those from the CBS and EC consisted of three modes with peaks at 325, 375, and 425, and 275, 350, and 420 mm FL, respectively.

Commercial catch sampling: 2008 – 2010

During the present study a wide range of sizes were represented in the commercial catches of eastern Australian salmon, with the catch weighted size distribution for the period October 2008 to January 2010 skewed towards fish larger than ~ 350 mm FL, with a peak at 440 mm FL but few fish larger than 470 mm FL (Fig. 2.17). Regionally, catches from the NEC were dominated by fish > 400 mm FL (~ 60% of catch) and centred around one main mode of 440 mm FL (Fig. 2.18). The majority of the fish sampled from the NWC were < 400 mm FL (~ 80%), with a dominant mode at 310 mm FL. A single commercial catch was sampled from SEC and was comprised of fish < 250 mm FL, with a peak at 210 mm FL.

Due to the sporadic nature of the fishery in Tasmania there was insufficient data to examine seasonality in size composition, noting that the majority of the large landings made during the study period were sampled.

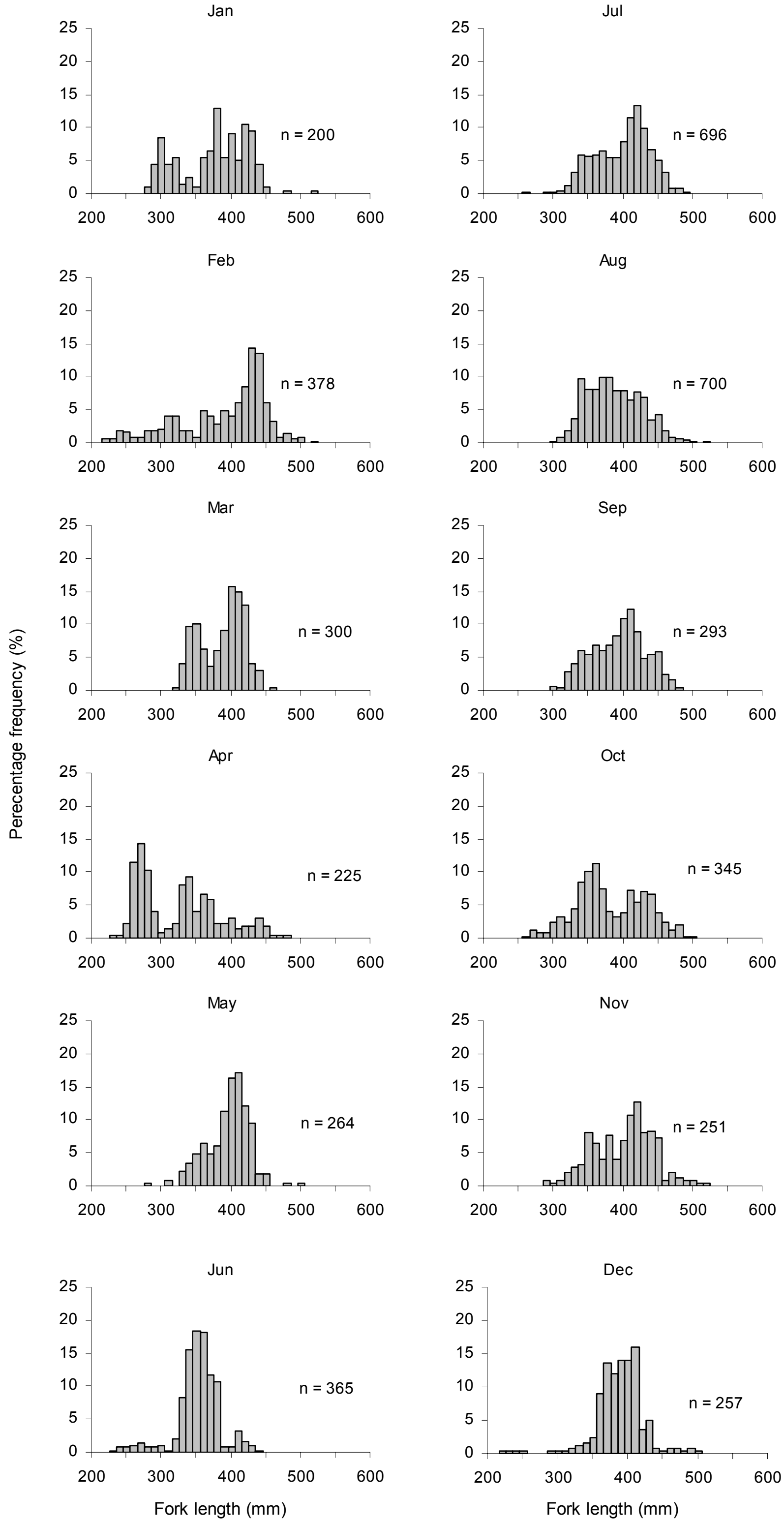


Figure 2.15. Length frequency distributions of Australian salmon by calendar month. Frequencies are by 10 mm size classes (fork length, rounded down to the nearest size class), pooled across fishing seasons 1979/80 to 1995/96. *n* = total number of individuals measured.

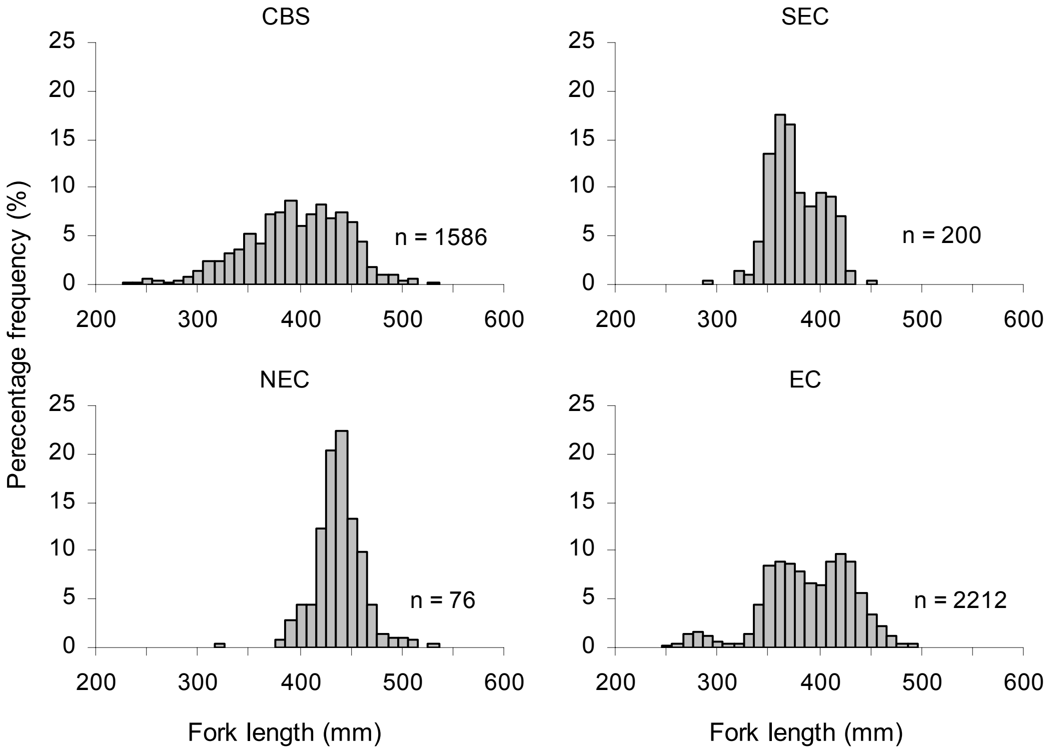


Figure 2.16. Regional length frequency distributions of Australian salmon based on commercial catch sampling. CBS is central Bass Strait, NEC is north-east coast, SEC is south-east coast, and EC is east coast. CBS comprise samples from the north-west coast (NWC) as well as NEC, a consequence of being unable to separate the data into regions used in current fishery assessments. Frequencies are by 10 mm size classes (fork length, rounded down to the nearest size class), pooled across fishing seasons 1979/80 to 1995/96. *n* = total number of individuals measured.

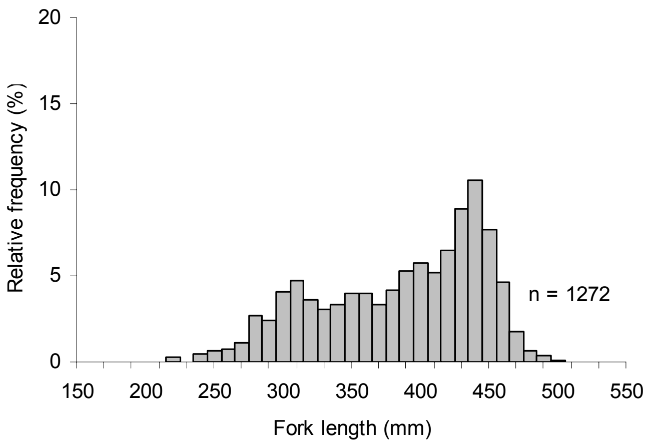


Figure 2.17. Length frequency distribution of eastern Australian salmon captured by commercial fishing in Tasmanian waters between October 2008 and January 2010. Distributions have been catch weighted. *n* = total number of individuals measured.

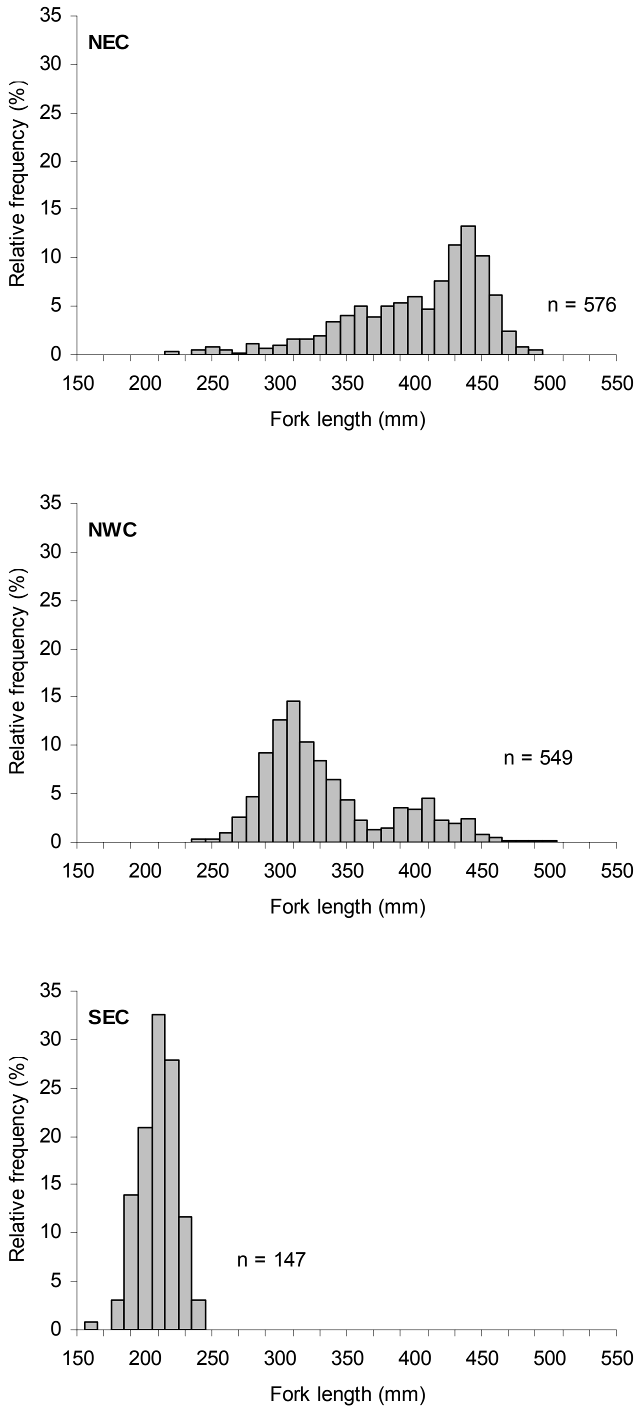


Figure 2.18. Length frequency distributions of eastern Australian salmon captured by commercial fishing in each Tasmanian region. NEC is north-east coast, NWC is north-west coast and SEC is south-east coast. Distributions have been catch weighted. *n* = total number of individuals measured.

Recreational fishers in Tasmania take more or less the full size range of Australian salmon (Fig. 2.19), however, the majority (80% of catch) are < 330 mm FL and come from estuaries and other inshore waters.

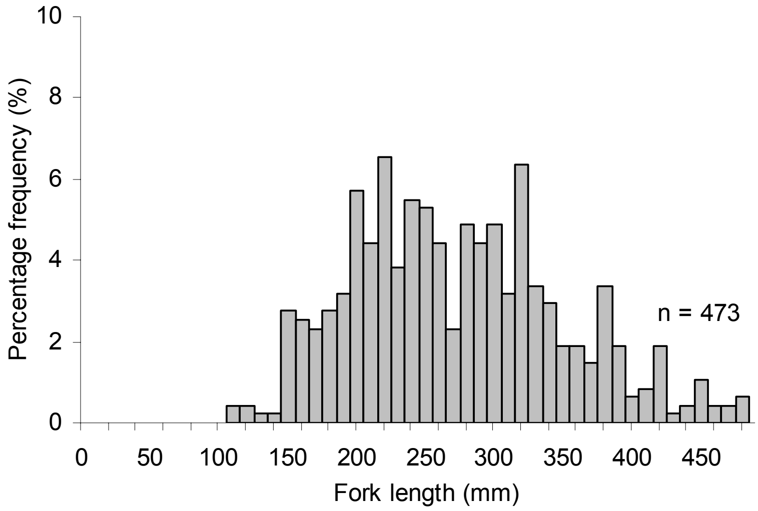


Figure 2.19. Length frequency distribution of Australian salmon captured by recreational research anglers in 2008/09 (includes released and retained fish). *n* = number of fish measured.

2.3.3.3. Age composition

The age structure of Tasmanian landings of eastern Australian salmon during the study period was dominated by 2+ to 4+ year olds, with lower numbers of 5+ and 6+ years olds also taken (Fig. 2.20). Catches from the NWC were comprised mainly of 2+ to 3+ year olds, NEC were mainly 3+ to 4+ year olds, and in the SEC only 1+ to 2+ year old individuals were represented (Fig. 2.21).

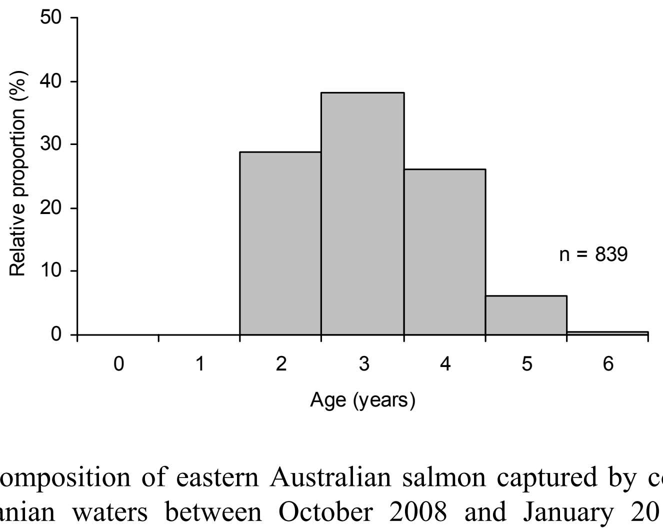


Figure 2.20. Age composition of eastern Australian salmon captured by commercial fishing in Tasmanian waters between October 2008 and January 2010. *n* = number of individuals aged.

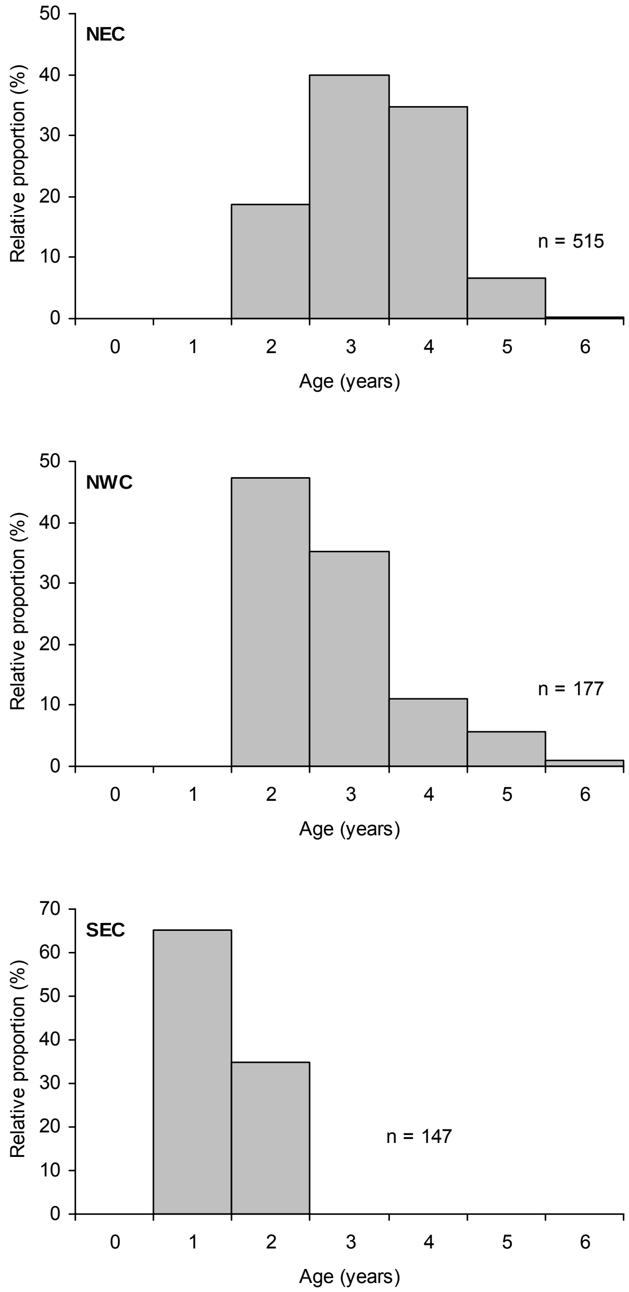


Figure 2.21. Age distributions of eastern Australian salmon captured by commercial fishing in each Tasmanian region. NEC is north-east coast, NWC is north-west coast and SEC is south-east coast. *n* = number of individuals aged.

2.3.3.4. Species mixing

Tasmanian commercial catches were dominated (94% by number of those sampled) by eastern Australian salmon. In the main fishing grounds off the NEC and NWC catches were comprised almost exclusively (99%) of eastern Australian salmon; most of the western Australian salmon (*A. truttaceus*) captured in these regions were 2 – 3 year olds. By contrast, western Australian salmon accounted for one third of the catch sampled from the SEC and were mostly 1 – 2 year olds.

2.4. Discussion

The fisheries for eastern Australian salmon in NSW, Victoria and Tasmania are similar in being relatively high volume, low market price commercial net operations as well as being important recreational fishing targets. Each state's fisheries are, however, different in the life-history stage that they exploit. The sampling done during the present study has confirmed that eastern Australian salmon in Tasmanian waters are mainly juveniles, prior to the hypothesized 1-way migration northwards where maturity occurs (Stanley & Malcolm 1977, Stanley 1978). As such, the Tasmanian fisheries exploit generally small (< 45 cm FL) and young (2 to 4 years old) fish. Monitoring since the late 1970s has shown this to be consistent through time and is also reported in Nicholls (1973). The Victorian fisheries for eastern Australian salmon were not comprehensively monitored during the present study; but the observations for catches from open coastal waters were consistent with previous studies and showed that fish aged 2 to 5 years old predominate (Stanley 1978). Catches from Victorian bays and inlets were not monitored, but are likely to consist of younger, smaller fish. Australian salmon in southern NSW are generally from 3 to 7 years old (also reported in Malcolm 1966c and Stanley 1978) and generally range in size from 30 to 55 cm FL. The commercial fishery in northern NSW generally lands salmon from 3 to 10 years old, with much of the catch being greater than 55 cm FL.

Total commercial Australian salmon landings for NSW, Victoria and Tasmania were reported to be around 2,000 t/yr during the early 1940s and again between the mid 1950s and 1960s, peaking at 3000 t in 1956/57 (Stanley 1978). However, these historical landings data included both the eastern and western species. Therefore, it is possible that the current commercial harvest of eastern Australian salmon is at historically high levels, averaging nearly 1,900 t/yr since 2000/01. It is apparent that the major harvesters of salmon in each state operate large vessels, which can catch and store large quantities of fish at any time. These few fishing businesses tend to fish to market orders and may take large (> 60 t per purse-seine shot) quantities on any day. Once market requirements are satisfied these large operators may not fish for salmon again until more orders require filling. This type of fishery presents substantial problems for monitoring and assessment. The strong link between market demand and annual landings means that landings will not be a good indicator of stock status in any state (Ziegler and Lyle 2010). In addition, catch rate is unlikely to be a good indicator of abundance because of the schooling nature of Australian salmon, particularly if search time is not taken into account, as is the case in the reporting of commercial activity in each state. Catch rates in each state will also be skewed by the overwhelming contribution to the total catch of small numbers of very large catches.

The latitudinal gradient in size and age structure of eastern Australian salmon in addition to the sporadic, market driven nature of the major landings, makes representative sampling of the population difficult. Gaining representative samples in northern NSW is complicated further where the commercial fishery is limited to a by-catch allowance and a relatively small daily trip limit for some fishers to allow retention of salmon for use as bait. Good rapport with the major salmon fishers in each state is essential, as is close communication that enables sampling to be organized at times and places where large catches are expected. This strategy worked extremely well during the present study in NSW and Tasmania, where researchers have a good rapport with industry. It did not work well in Victoria, even though the major salmon harvester is extremely helpful, because co-ordination of sampling with short notice from NSW was logistically difficult and costly. Future sampling of the salmon fishery will require dedicated staff from each state to co-ordinate the work.

There appears to be capacity in each state for the commercial industries to increase production should the current domestic market expand or if new markets are developed. Any such increases in harvest would require careful monitoring to ensure sustainability. This is particularly important given the current historically high landings of this species and the complicating factor of harvesting Australian salmon at different stages of their life-history in each state. Future monitoring and assessment of the eastern Australian salmon fisheries is discussed in Chapter 9.

3. AGE AND GROWTH

OBJECTIVES ADDRESSED

This chapter addresses objective 4 of the original Project No. 2006/018 to "Model growth (using otolith derived estimates of size-at-age) of eastern Australian salmon".

3.1. Introduction

Despite the commercial and recreational importance of eastern Australian salmon in south-eastern (S.E.) Australia, few studies have investigated aspects of their age and growth in this region (Nicholls 1973, Stanley 1978), even though the growth of the species has been the subject of extensive ongoing research in New Zealand (NZ) (Eggleston 1975, Bradford 1998, Stevens & Kalish 1998, Griggs *et al.* 1998, Hartill & Walsh 2005, Armiger *et al.* 2006, Devine 2007, Hartill *et al.* 2007). The majority of information on the age and growth of eastern Australian salmon in S.E. Australia is from work done during the 1960s and 70s; very little data has been collected since that time upon which to base management of this resource which spans three state jurisdictions (New South Wales (NSW), Victoria and Tasmania).

Eastern Australian salmon is the second smallest member of the monogeneric teleost family Arripididae (Steyskal 1980) and grows to a reported maximum size of 78 cm FL (89 cm TL) and 7.4 kg in S.E. Australia (Hutchins & Swainston 1986). In NZ, eastern Australian salmon have been reported up to 79 cm FL (6.9 kg) and a maximum age 26 years (Eggleston 1977, 1978, Duffy & Petherick 1999), although fish older than 20 years are very rarely encountered (Hartill *et al.* 2004). Previous research into the age and growth of eastern Australian salmon in Australian waters has been done using scale readings (Nicholls 1973). This work estimated a maximum age of 7 years (Nicholls 1973), although a longevity of up to 10 years has since been claimed (Stanley 1980). Eastern Australian salmon in S.E. Australia were found to grow rapidly reaching ~17 cm FL after 1 year and ~28 cm FL after 2 years (Nicholls 1973). Growth rate slowed substantially after 3 years. Nicholls (1973) also found that eastern Australian salmon growth was similar in Tasmania, Victoria and NSW with pooled von Bertalanffy growth function (VBGF) parameters: L_∞ = 58.39 cm FL, t_0 = -0.14 years and k = 0.30 /year.

Similar work on eastern Australian salmon in NZ found that using scales to estimate age was unsuitable for accurately estimating the ages of individuals older than 5 years (Eggleston 1975). The use of opaque zone counts in otolith sections to age eastern Australian salmon has since been established as best practice for estimating age in this species (Stevens & Kalish 1998). These researchers also successfully validated the annual periodicity of opaque zone formation by use of a vital stain (tetracycline) to mark the otoliths of wild fish and by following known-age year classes in size frequency data through time. Nonetheless, despite using age estimates from scale readings, the growth rates reported for eastern Australian salmon in S.E. Australia compare well with those from NZ up to the ages of 6 – 7 years. In NZ, eastern Australian salmon grow slightly slower than in S.E. Australia reaching ~11 and ~23 cm FL after 1 year and 2 years respectively (Stevens & Kalish 1998, Hartill & Walsh 2005). The calculated VBGF parameters are also similar for eastern Australian salmon from Australia and NZ. The average maximum size (L_∞) estimated for eastern Australian salmon in Australia was 58.39 cm FL which is only slightly larger than the mean L_∞ estimated for eastern Australian salmon from NZ of ~55.3 cm FL. Similarly, the parameters t_0 and k for Australian fish (-0.14 years & 0.30/year, respectively) were only slightly smaller than the mean values found for NZ fish (~0.25 years & ~0.33/year, respectively).

The aim of this chapter was to provide current information on the age and growth of eastern Australian salmon in S.E. Australia using the accepted best method of counting annuli in sectioned otoliths. Specifically, we: (i) estimated length-at-age; ii) modelled growth, and; iii) validated the daily and annual deposition of opaque zones in otoliths. The age and growth of eastern Australian salmon is described and compared between states and with latitude.

3.2. Materials and methods

3.2.1. Sample collection

3.2.1.1. New South Wales

Eastern Australian salmon were sampled between November 2006 and February 2010 from coastal waters of northern NSW/southern Queensland (Kirra Beach – 28º10'S, 153º31'E to Stockton Beach – 32º49'S, 151º56'E) and southern NSW (Wattamolla Beach – 34º08'S, 151º07'E to Eden – 37º05'S, 149º56'E). Fish were collected by commercial fishers by purse seining and beach hauling. Small fish (~ < 20 cm FL) were also collected using recreational hook and line and research seining during the sampling period throughout the study region. As eastern Australian salmon is a nearshore species, all fish were captured from marine waters < 2 nm of the coast. After capture, fish were placed on ice or frozen prior to transport to the Cronulla Fisheries Research Centre to be processed. Once in the laboratory, all fish collected were measured (fork length – FL) to the nearest 0.1 cm, and weighed to the nearest g. Sex was determined by macroscopic examination of the gonads. Maturity was determined using the macroscopic characteristics of gonads outlined in Chapter 4. The sagittal otoliths were removed, dried and stored in labelled paper envelopes. After drying, each otolith was weighed (to the nearest 0.00001 g) using an electronic balance (Sartorius CP225D).

3.2.1.2. Victoria

Commercially caught eastern Australian salmon were sampled on 6 occasions between February 2007 and April 2009. These fish were sourced from Mitchelson Fisheries in Lakes Entrance and were caught by the method of purse seine. In addition, small (< 20 cm FL) eastern Australian salmon were obtained through the Victorian DPI Angler Diary Program and the Victorian DPI research meshing program during November and December 2008. These Victorian samples of whole fish were freighted frozen to the Cronulla Fisheries Research Centre for processing.

3.2.1.3. Tasmania

<u>Juvenile and sub-adult sampling</u>

Biological data were collected opportunistically from commercial landings or onboard catch sampling between October 2008 and January 2010. Fish were mostly sourced from beach seine catches taken by the main commercial Australian salmon fisher operating off north western and north eastern Tasmania (12 samples), with a further two samples sourced from small-scale commercial fishing operations, one from the northwest and the other from the southeast coast. Typically 50 – 100 fish were randomly selected from each shot or landing and were either processed fresh or frozen prior to examination.

Additional fish in the 15 – 30 cm FL range were obtained from recreational fishers, these size ranges being uncommon in the commercial catch samples.

Small juvenile sample collection

Research fishing for small juvenile Australian salmon was undertaken at a range of sites around Tasmania between December 2008 and January 2010 using a small mesh beach seine. Monthly sampling was undertaken at three sites in south-east Tasmania and seasonal samples collected from 12 additional sites spread between the remaining four regions (Fig. 3.1, Table 3.1). Each site was sampled during the day (0800 – 1800 hours) using a 30 m beach seine (3 m drop, 10 mm mesh), set parallel to the shoreline and hauled to cover an area of approximately 100 m^2. Sampling was also undertaken over a 24-hour period in February 2009 with fish collected at 3-hourly intervals in order to examine diurnal feeding behaviour. At capture fish were euthanased in an anaesthetic (AQUI-S®) seawater solution (40 ml/L seawater) and held on ice until processing. On each sampling occasion multiple hauls were made until 20 – 25 fish were captured.

Australian salmon were identified to species based on gill raker counts (Gomon *et al.* 2008), measured for fork length (FL) (mm), total weight (0.1 g), gonad weight (0.01 g), and sex and macroscopic gonad condition recorded. Sagittal otoliths were removed, cleaned and stored in plastic vials for later processing.

Table 3.1. Site and habitat characteristics of beach seine sampling sites around Tasmania. Site codes are in parentheses. Maximum depth represents maximum depth sampled by the beach seine. * denotes SEC sites sampled on a monthly basis.

Site	**Region**	**Substrate**	**Exposure**	**Maximum Depth (m)**
Binalong Bay Beach (BB)	EC	Sand	High	1.5
Cockle Creek Beach (CC)	SEC	Sand	Medium	1.5
Couta Rocks (CR)	WC	Sand	Medium	1.0
Cremorne Beach (CB)*	SEC	Sand	Medium	1.0
East Beach (EB)	NEC	Sand	High	1.0
Kingston Beach (KB)	SEC	Sand	High	1.5
Little Mussleroe Bay (LM)	NEC	Sand	High	1.5
Macquarie Harbour Entrance (MH)	WC	Sand/Seagrass	Medium	1.5
Marion Bay Beach (MB)	EC	Sand	High	1.0
Nine Mile Beach (NM)	EC	Sand	High	1.0
Nutgrove Beach (NB)*	SEC	Sand/Seagrass	Medium	1.5
Peggs Beach (PB)	NWC	Sand	High	1.0
Roaring Beach (RB)*	SEC	Sand	High	1.5
Safety Cove (SC)	SEC	Sand	Medium	1.5
Wynyard Beach (WB)	NWC	Sand/seagrass	Medium	1.0

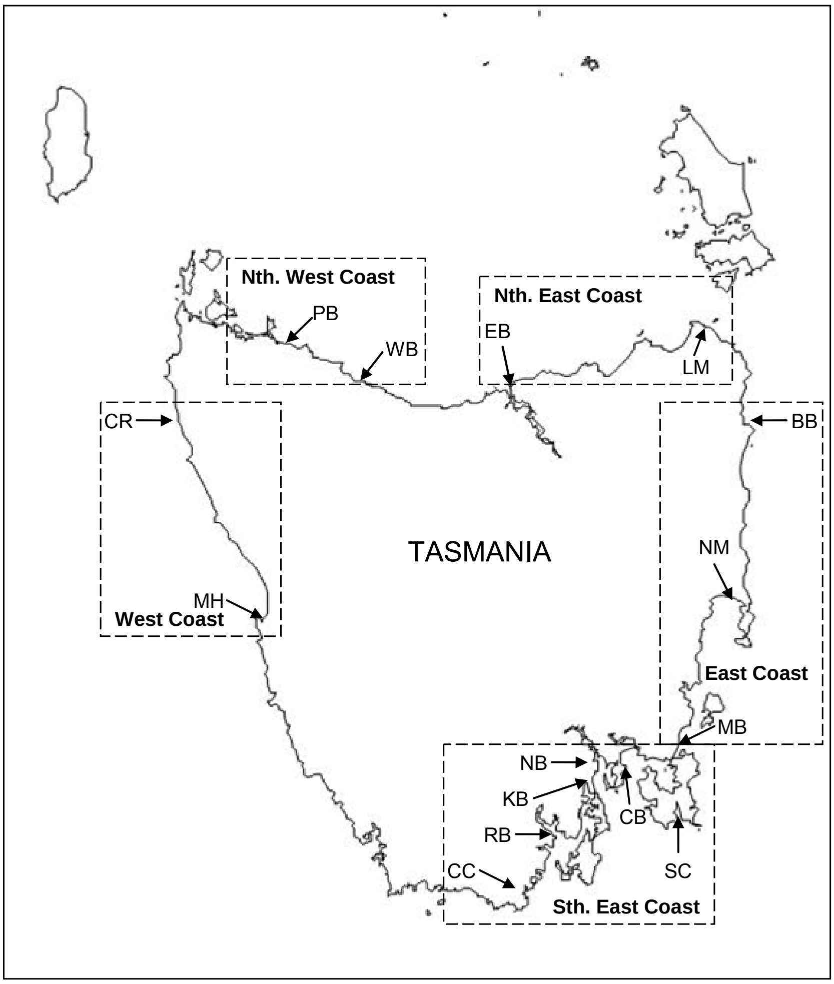


Figure 3.1. Location of beach seine sampling sites around Tasmania. Details of site codes are presented in Table 3.1.

3.2.2. Age estimation

3.2.2.1. Annual age estimation

Estimates of age of eastern Australian salmon from each state were made by examining otolith sections. Otoliths from fish collected in NSW and Victoria were processed and read at the Cronulla Fisheries Research Centre (CFRC), while otoliths from fish sampled in Tasmania were processed and read at the Tasmanian Aquaculture and Fisheries Institute (TAFI).

One of each pair of sagittae was embedded in resin, sectioned transversely through the core using a diamond lapidary saw to a thickness of ~ 250 – 300 µm and the section mounted on a glass microscope slide. The section was then viewed using a compound microscope with reflected light against a black background at magnification of ×2 or ×4 at the CFRC laboratory and using a stereomicroscope at ×20 magnification with transmitted light at the TAFI laboratory. Opaque zones visible in the otolith sections were counted, and measurements were made from the core to the centre of each opaque zone and to the otolith edge. All measurements were made along the ventral edge of the sulcus (Fig. 3.2) using a microscope mounted video camera interfaced with a computer running image analysis software.

A universal birth date of 1 January was assigned to eastern Australian salmon (based on the middle of the spawning season: October–March; Chapter 4). The final age estimate for each fish was made by counting the number of opaque zones plus the proportion of the year between the universal birth date and the date of capture.

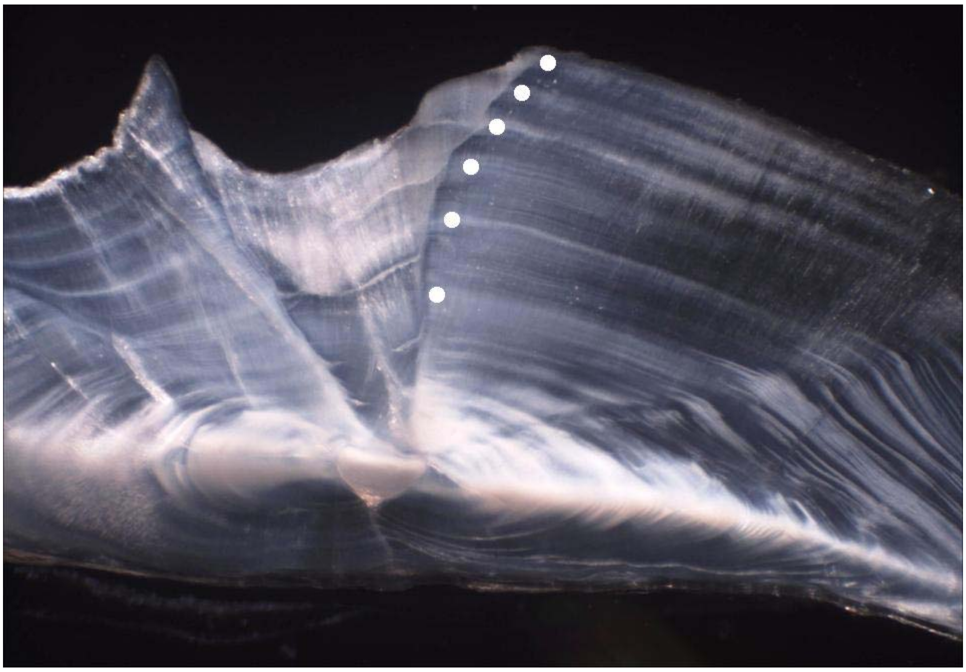


Figure 3.2. Section of an eastern Australian salmon otolith showing 6 opaque zones counted along the ventral edge of the sulcus.

3.2.2.2. Daily age estimation

Tasmania

All otoliths from fish < 15 cm (n = 2184) were initially examined whole under a stereomicroscope to assess the presence of annual banding. Where annual bands were evident or if the reader was unsure, these otoliths were sectioned and aged using the protocol described for adults. Those otoliths which clearly displayed no annual banding were deemed as 0+ years old and used to estimate daily age. Due to the large sample size and time involved in preparing otoliths for daily age estimates, only 10 otoliths from 0+ individuals collected from each location in each month or season were randomly selected for this purpose.

Otoliths were embedded distal side down on a glass slide with thermoplastic resin (Crystalbond^{TM}) and ground to a thin section using 1200-grit wet and dry paper. Otoliths were ground from the anterior edge to the primordium, flipped over onto the ground facet and the posterior edge ground until a thin section was achieved encompassing the primordium. Both facets were polished using alumina powder wetted into a paste and spread over felt polishing cloth. Otolith microstructure was examined under a Leica DM LB2 compound microscope at ×200 to ×400 magnification using transmitted light. Daily age was determined by counting the number of increments along the ventral axis from the primordium to the otolith edge. Otolith radius was measured to the nearest 1 µm along the same axis using image analysis software (Lieca Application Suite v3). Otoliths were read twice by the primary reader and the mean increment counts used where there were < 10 days between readings. Otoliths that were cracked or exceeded 10 days between reads were discarded.

3.2.2.3. Back calculation of birth dates

Little is known about the exact timing of the formation of the first daily increment in the otoliths of eastern Australian salmon. Typically increment formation is dependent on the rate of embryonic development, which is influenced by environmental conditions, and can occur at either the time of hatching, yolk sac absorption or at the time of first feeding (Jones 1986). For those species from warm temperate conditions (> 20 °C) increment formation generally occurs at the time of hatching whereas in cooler climates it occurs later, at the time of yolk sac absorption or first feeding (Jones 1986). Since eastern Australian salmon spawn in temperate waters (15 to 25 °C) off eastern Australia (Stanley and Malcolm 1977; Chapter 4) and hatch ~ 40 h post-fertilisation (Stanley and Malcolm 1977) a further two days were added to the final increment count for the purpose of back calculating birth dates.

3.2.2.4. Quality control

Within reader estimates of precision were done at each ageing laboratory. In NSW a random subsample of 200 eastern Australian salmon otoliths were re-read to examine the precision of estimates of counts of opaque zones (Kimura & Anderl 2005). The coefficient of variation (CV) for the two readings for each otolith was calculated and an average across all otoliths determined using the method described in Campana (2001). In Tasmania, all otoliths (n = 839) were read twice by the primary reader, one month apart and the index of average percent error (*IAPE*) (Beamish and Fournier 1981) calculated.

Between ageing laboratory estimates of accuracy and precision were made by reading a random sample of 196 otoliths collected in NSW in both laboratories. The primary readers in each laboratory were Jerom Stocks (NSW) and Jaime McAllister (Tasmania). *IAPE* and age bias plots were calculated as indicators of ageing accuracy and precision.

3.2.3. Age validation

3.2.3.1. Marginal increment analysis

The annual periodicity of formation of opaque zones in the otoliths of eastern Australian salmon has been previously validated for fish > 1 year old in NZ (Stevens & Kalish 1998). Marginal increment analyses (MIAs) were nonetheless used to confirm the periodicity and timing of opaque zone appearance in otoliths of wild eastern Australian salmon sampled during the study from S.E. Australian waters. The marginal increment (MI) was defined as follows: for fish with no opaque zones as the distance (mm) from the core to the otolith edge along the ventral edge of the sulcus; for fish with 1 opaque zone as the distance from the opaque zone to the otolith edge as a proportion of the first completed increment, and; for fish with 2 or more opaque zones as the distance from the most recently completed opaque zone to the otolith edge as a proportion of the last completed increment.

3.2.3.2. Validation of the first opaque zone

As the periodicity and timing of the formation of the first opaque zone had not been validated, two methods were used to accomplish this: i) using a vital stain (tetracycline) to mark the otoliths of captive eastern Australian salmon, and; ii), counting daily increments in 0+ year old eastern Australian salmon from the wild.

Tetracycline Marking

Sixteen small (~ < 15 cm FL) juvenile eastern Australian salmon were collected from Twofold Bay (37º06'S, 149º55'E) on 12 February 2009 using a small mesh beach seine. These fish were transported in an aerated 100 L bin to the aquarium facility at the CFRC where they were kept in a 1000 L flow through seawater tank. These fish were allowed to acclimate to captivity for ~ 2 months before being injected with tetracycline hydrochloride (Engemycin 100) at a concentration of 100 mg/kg to stain their otoliths on 15 April 2009. Fish were then sampled ~ 10 months after marking (1 February 2010) to examine their otolith growth subsequent to the tetracycline mark. The otoliths from all fish were examined after the experiment was terminated. Otoliths were sectioned as described above. Otolith sections were viewed with a compound microscope and incident ultraviolet light in a darkened room. When a fluorescing tetracycline band was identified, its position in relation to the core and the otolith edge was measured using the microscope, camera and computer setup described above. The section was then examined under reflected white light and measurements from the core to the centre of each opaque zone and to the otolith edge recorded. The distances from the otolith core to the tetracycline mark, to any identified opaque zones, and to the otolith edge, were then compared.

Daily increments

To validate the timing of first annual increment formation in eastern Australian salmon in NSW, one of each sagittal otolith from 30 small fish ~ < 18 cm FL were polished down using 9 µm lapping film followed by 0.05 µm alumina powder until the microincrements representing daily growth were visible. The microincrements were then counted along the ventral edge of the sulcus using a compound microscope with transmitted light at magnification of ×10.

3.2.3.3. Daily age validation

Small juvenile eastern Australian salmon (4.9 to 6.0 cm FL; n = 45) were obtained from Cremorne Beach in south-east Tasmania on 27 January 2010 using the research sampling method described in Section 3.2.1.3. The fish were placed in a 200 L container filled with seawater and transported to the TAFI aquarium facility where they were transferred to a 300 L holding tank connected to recirculating seawater and exposed to ambient light and temperature cycles. The fish were held in the holding tank for two days to acclimatise before being immersed in a 500 mg/L solution of oxytetracycline (OTC) (2.5 mL/L Ilium Oxytet-200 solution of 500 mg/mL OTC as the base) for 22 hours. After immersion the fish were removed from the OTC solution and returned to their original holding tank. The fish were fed a combination of amphipods and mysids daily (approximately 50 to 100 per fish) in all phases of the experiment. At intervals of 6, 14, 19, and 25 days post exposure to OTC sub-samples of fish were euthanased and otoliths extracted. Otoliths were stored in darkness to avoid photo-deterioration of the OTC (Cermeño *et al.* 2003). Otoliths were prepared in the same manner as described in section 3.2.2.2 and were examined using a Leica I3 fluorescence filter combination (blue excitation range 450 to 490 nm, emission 515 nm) to visualise the margin of fluorescence created by exposure to OTC.

3.2.4. Growth

Growth was modelled by fitting the von Bertalanffy growth function (VBGF) to the size-at-age data from all states combined. The data used included all of the annual age counts plus the daily age estimates. The VBGF used was:

$$L_t = L_\infty \, [1\text{-e-}^{k}(^{t\text{-}to})],$$

where L_t is length at age t (cm), L_∞ is the asymptotic length (cm), k is the rate at which the curve approaches L_∞ (yr^{-1}), t is age (yr), and t_0 is the theoretical age of the fish when it has no length (yr).

Statistical comparisons of the growth curves between male and female fish were made using the analysis of residual sums of squares (ARSS) method (Chen *et al.* 1992). Growth curves were fitted to size-at-age data for each sex including data from all immature fish in both data sets. We also fitted a VBGF to all data combined to generate a general growth curve for eastern Australian salmon in S.E. Australia.

Juvenile growth was examined using the daily size-at-age estimates from each state. The timing of juvenile recruitment and juvenile growth in Tasmanian waters was also estimated through the monthly length frequency data obtained during the small mesh beach seine sampling.

3.3. Results

3.3.1. Sample collection

Otoliths were collected from 2,037 eastern Australian salmon caught in NSW waters. These comprised 800 fish collected from northern NSW (NNSW) between November 2006 and October 2009 and 1,237 fish collected from southern NSW (SNSW) between November 2006 and February 2010.

A total of 193 eastern Australian salmon were sampled from the commercial fishery in Victoria between February 2007 and April 2009. In addition, 35 small (9 to 19 cm FL) eastern Australian salmon were obtained through the Victorian DPI Angler Diary Program during November and December 2008. A further 48 small (9 to 21 cm FL) salmon were also obtained through Victorian DPI research meshing during December 2008.

In Tasmania, ages were assigned to a total of 3,138 eastern Australian salmon sampled between October 2008 and June 2009. Of these, 2,184 were from small juveniles < 15 cm FL caught using small mesh seine research sampling and 839 were sampled from the commercial fishery.

3.3.2. Age estimation

Annual age estimates were made on 5,245 eastern Australian salmon. A distinct pattern of alternating narrow opaque and wider translucent zones in sectioned eastern Australian salmon otoliths was clearly discernable and opaque zones were easily counted when viewed under reflected light (Fig. 3.2). The core was always a dense opaque region, followed by a wider translucent region and then a very distinct opaque band, which was scored as the first annulus (Fig. 3.2).

Daily age estimates were made on 449 small eastern Australian salmon, 370 in the TAFI laboratory and 79 in the CFRC laboratory. Of the 79 examined in the CFRC laboratory, 30 were sampled from NSW, 42 from Tasmania and 7 from Victoria. Of the 370 otoliths prepared at TAFI, 92% were read successfully, the rest were discarded due to a discrepancy of more than 10 days between reads or due to over-polishing or cracking which made increments difficult to interpret. Increments in undamaged otoliths were exceptionally clear and were characterised by two formation patterns which distinguished the core region from the outer margin. Typically the core region consisted of 10 – 15 narrow increments surrounding the primordium followed by broad, more opaque increments which continued towards the otolith edge, but became increasingly merged in the outer otolith margin after approximately 100 days (Fig. 3.3). The point of transition was clear in very few otolith sections (n = 20) and its significance is uncertain.

Figure 3.3. Cross section of a sagittal otolith of 101 day-old eastern Australian salmon (FL = 55 mm). Arrow indicates growth check assumed to be associated with larval settlement. Scale bar = 100 µm.

3.3.3. Quality control

The clear and unambiguous appearance of sectioned eastern Australian salmon otoliths was reflected by a high precision when re-reading subsamples in both ageing laboratories. In NSW the mean CV after re-reading 200 otoliths was 0.03, while in Tasmania the *IAPE* after re-reading 200 otoliths was 2.09. The *IAPE* in NSW was calculated as 3.16.

The between ageing laboratory comparisons resulted in 78% of estimates between readers being in agreement, with 97% of estimates being within one year of each other. The age bias plot showed age differences were consistent across year classes, with a slight tendency for the primary reader in Tasmania to under estimate ages in older (9 and 10 year old) individuals (Fig. 3.4). Given the very low sample sizes in the reference collection in these age classes (eight 9 year olds and three 10 year olds), together with the fact that no fish older than 6 years were sampled in Tasmania, we are confident that no bias existed between ageing laboratories.

3.3.4. Age validation

3.3.4.1. Marginal increment analysis

The marginal increment data from each state was similar and pooled for analysis. Small sample sizes for some age classes in some months precluded analysing the monthly marginal increment data separately for each age class. The age classes were therefore pooled into months across all years and split into ages 2 to 4 and 5 to 12 for analysis.

The monthly marginal increments for eastern Australian salmon with both 2 to 4 opaque zones and 5 to 12 opaque zones showed considerable variation each month but with a seasonal pattern of higher values during late spring/winter, peaking in September (Fig. 3.5). Mean marginal increment values started declining in October with the minima occurring in March for both age groups. This pattern suggests that opaque zone formation was completed in most fish by March. Since, irrespective of the number of opaque zones in the otolith, the mean monthly marginal increment rose and declined only once during the year (Fig. 3.5), it was concluded that a single opaque zone is laid down annually and therefore, the number of opaque zones could be used to estimate age.

3.3.4.2. Validation of the first opaque zone

Tetracycline Marking

Of the 16 juvenile eastern Australian salmon injected with tetracycline on 15 April 2009 and kept in captivity in NSW, two died on 17 April, one on 6 August and the remaining 13 fish were sacrificed on 1 February 2010, 292 days after injection. The tetracycline mark was easily identified as a thin fluorescing band when otolith sections were viewed under ultraviolet light (Fig. 3.6). The mark was visible in the otolith sections of 15 out of the 16 fish that had been injected (94%). All fish had a single opaque zone before they were injected and at the end of the experiment, the 13 remaining fish had formed their second opaque zone. At the cessation of the experiment, the fish had reached an average size of 24.80 ± 0.56 cm FL. The tetracycline mark appeared approximately midway between the two opaque zones in these fish (Figs 3.6 & 3.7). This indicates that the first annulus was formed before mid-April when the fish were injected. The single fish that died in August (113 days post injection) had not yet formed a second ring suggesting that the second annulus was formed sometime after August but before the completion of the experiment some 179 days later in February.

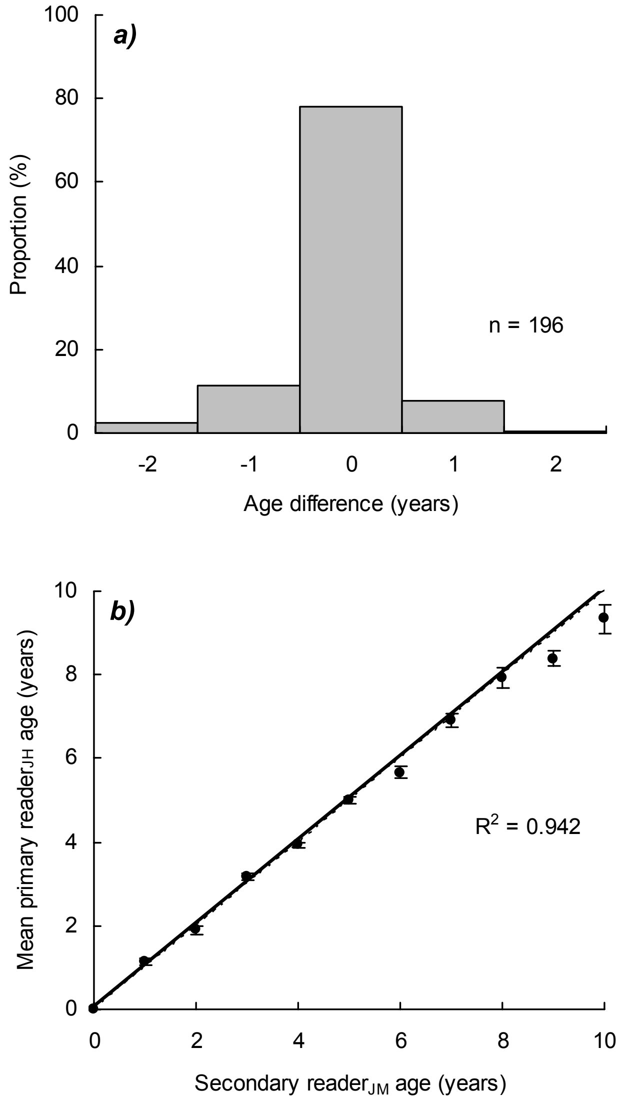


Figure 3.4. Precision of age estimates between ageing laboratories showing a) distribution of age differences, and b) correlation of age estimates. Error bars are ± S.E.

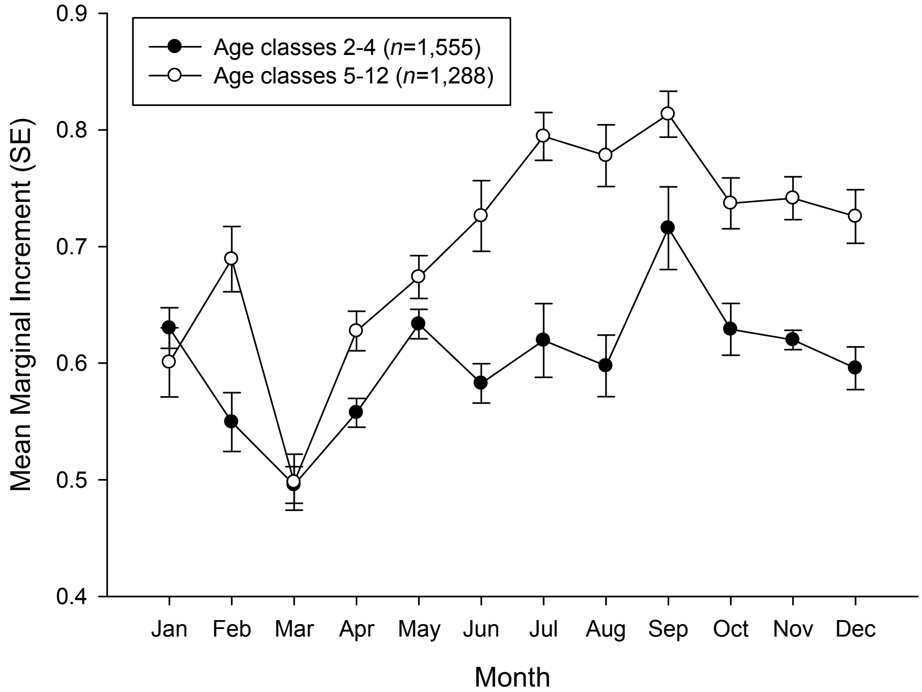


Figure 3.5. The mean monthly marginal increment values (± S.E.) for eastern Australian salmon from all states and years. The data have been split into fish aged 2 to 4 years (●) and 5 to 12 years (○).

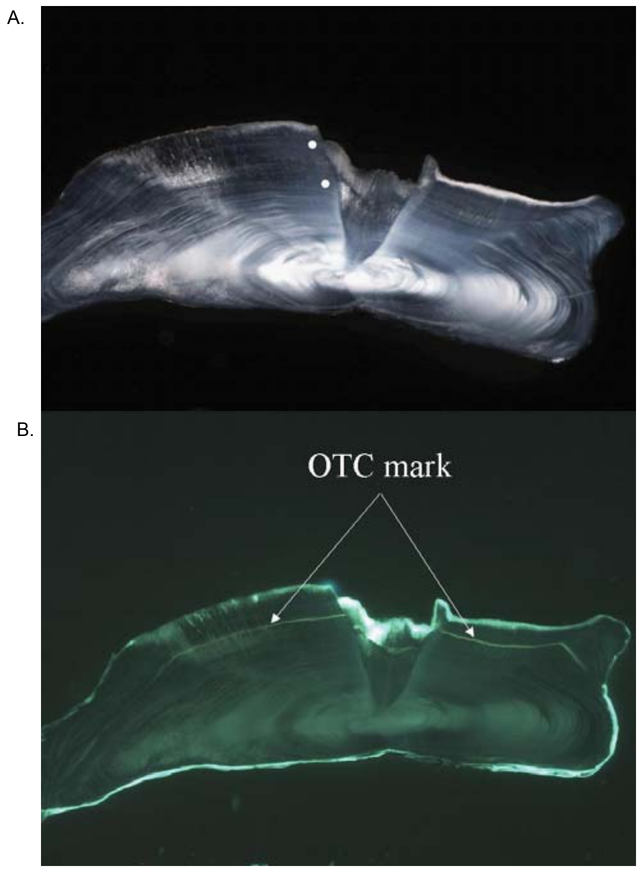


Figure 3.6. Section through an eastern Australian salmon otolith that was marked with tetracycline (OTC) on the 15th April 2009 and killed on the 1st February 2010. A. Under reflected light with annuli marked by white dots, B. Under ultraviolet light.

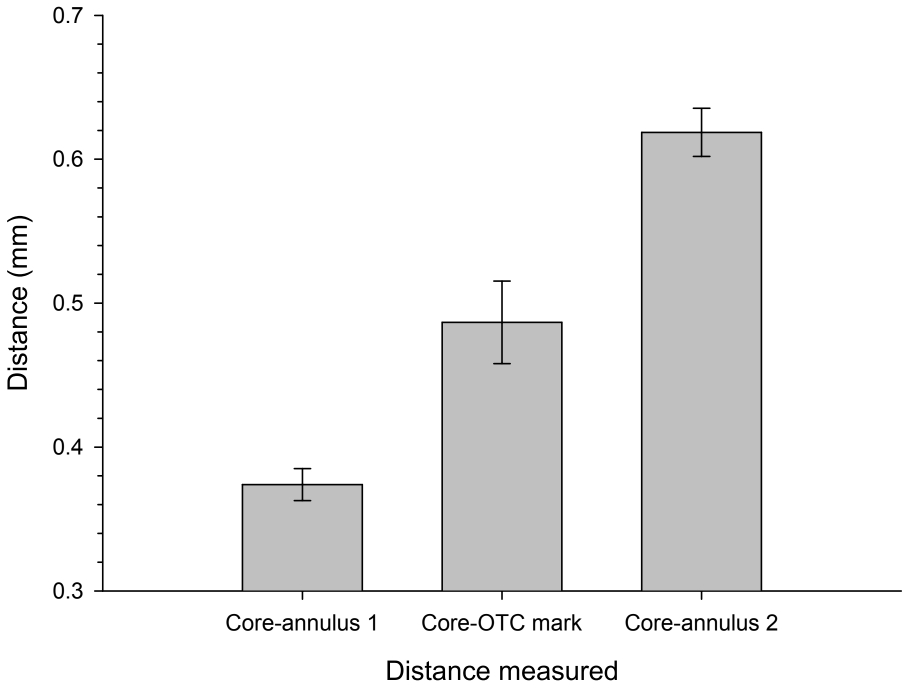


Figure 3.7. Mean distances from the otolith core to the annuli and tetracycline mark (OTC).

Daily increments

Daily increment counts of the otoliths of 30 small fish (4.7 to 17.7 cm FL) sampled from NSW waters were used to validate both the position and timing of first annulus formation. The number of daily increments counted ranged from 47 to 329. Otoliths classified as having an opaque margin (n = 12) had an average of 261 ± 14 daily increments (range 190 to 329) counted in their sections and otoliths classified as having a narrow translucent margin (n = 9) (i.e., newly completed 1st annulus) had an average of 283 ± 11 daily increments counted (range 223 to 324). The data indicated that the 1st annulus is generally completed in fish from NSW at ~ 12 cm FL.

3.3.4.3. Daily age validation

OTC treatment resulted in the mortality of seven fish in the Tasmanian study, with the remainder (n = 38) surviving through to the completion of the experiment. All treated otoliths showed a clear fluorescent band which was also visible as an apparent stress check under normal transmitted light (Fig. 3.8), although four otoliths were discarded due to cracking during processing. Of the remaining 34 individuals successfully aged, 20 had post-OTC increment counts equal to the expected number of daily increments, while 10 displayed one less post-OTC increment (Fig. 3.9). One individual had an increment count of two less and another three less than the number of days post exposure. The remaining two individuals had one increment more than expected. Regression analysis showed there was no significant difference between post OTC increment counts and expected daily increments ($F_{1,32}$ = 2094.71, P < 0.01).

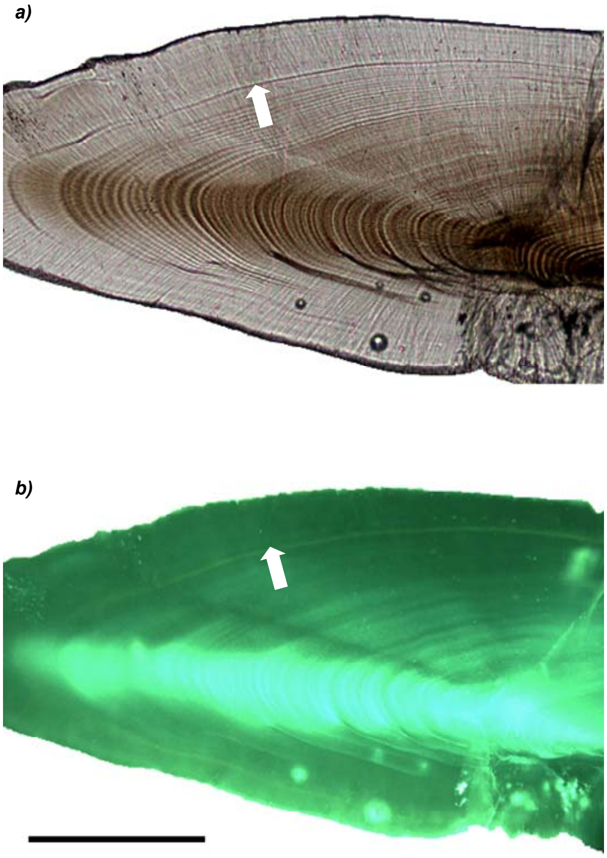


Figure 3.8. Oxytetracycline (OTC) mark in the margin of an eastern Australian salmon sagittal otolith used for validation of the daily deposition of increments. Arrows indicate outer margin of fluorescing material due to OTC. (*a*) Check mark seen in otolith under transmitted normal light coincides with OTC mark seen under fluorescent light (*b*). Scale bar: 200 µm.

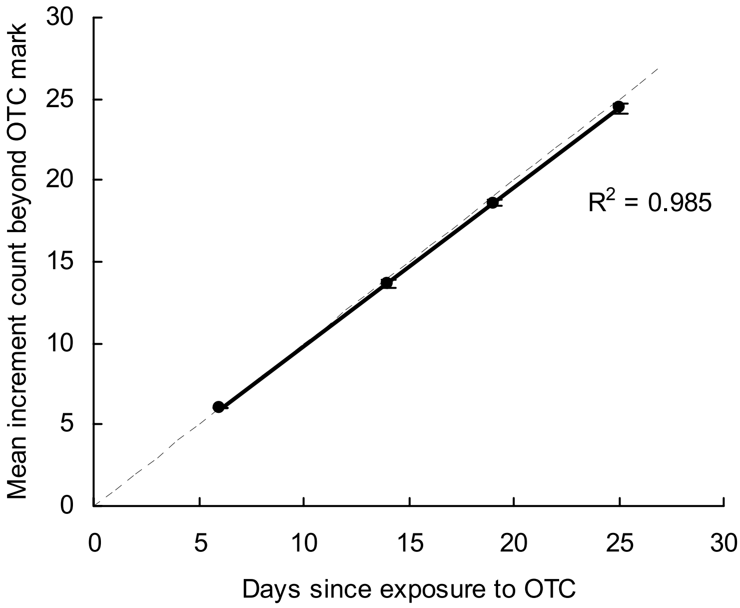


Figure 3.9. Relationship between increments observed in sagittal otoliths of eastern Australian salmon otoliths and the number of days lapsed since exposure to oxytetracycline (OTC). Broken line represents equal number of days. Error bars are ± S.E.

3.3.5. Growth

Growth was modelled by fitting VBGFs to the size-at-age data. The analyses were done based on final ages (i.e., the number of opaque zones plus the proportion of the year after 1st January that the fish was sampled), except for fish without any opaque zones. Fish with no opaque zones were omitted from the analyses and only those fish that had daily ages estimated used to represent growth in fish < 1 year old.

The VBGFs fitted to female and male size-at-age data were significantly different (ARSS, $F_{3,2984}$ = 16.6, P < 0.001; Fig. 3.10), with females being larger on average than males in the older age classes.

Plots of size-at-age of eastern Australian salmon from each state indicated differences in the distribution of sizes for any given age class (Fig. 3.11) with fish from NSW being generally larger for their age than fish from either Tasmania or Victoria after about 3 years of age. These differences are likely to be driven by the life-history of eastern Australian salmon with fish moving northwards through time (see Chapter 6).

The daily size-at-age data for juvenile eastern Australian salmon, pooled across states, indicated that growth was variable but roughly linear (FL = 0.0361*age + 2.3793, R^2 = 0.78) for the first ~ 300 days (Fig. 3.12). Almost all fish smaller than 10 cm FL were sampled from Tasmanian waters, whereas the larger fish > 10 cm FL were sampled from Victorian and NSW waters.

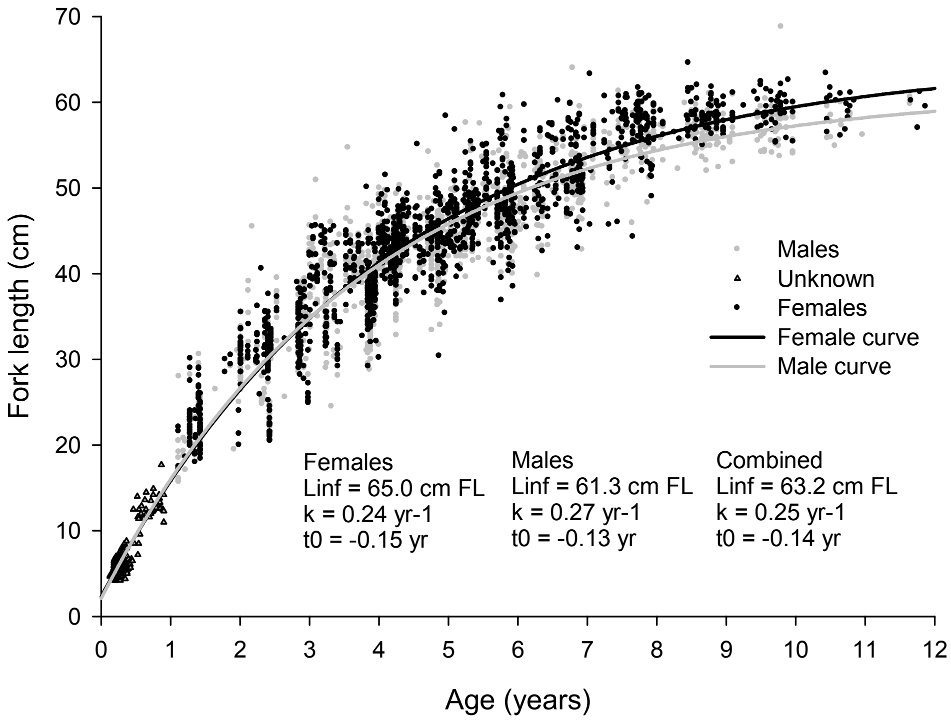


Figure 3.10. Size-at-age data for eastern Australian salmon with fitted von Bertalanffy growth functions.

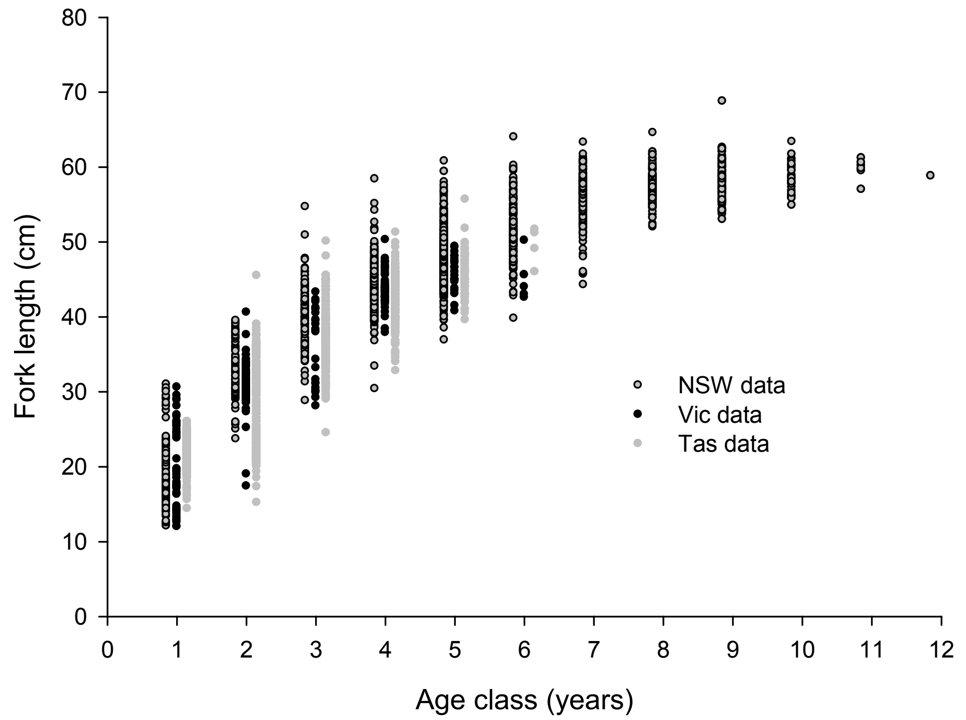


Figure 3.11. Size-at-age data for eastern Australian salmon from each state. Note the age classes for different states have been offset for clarity.

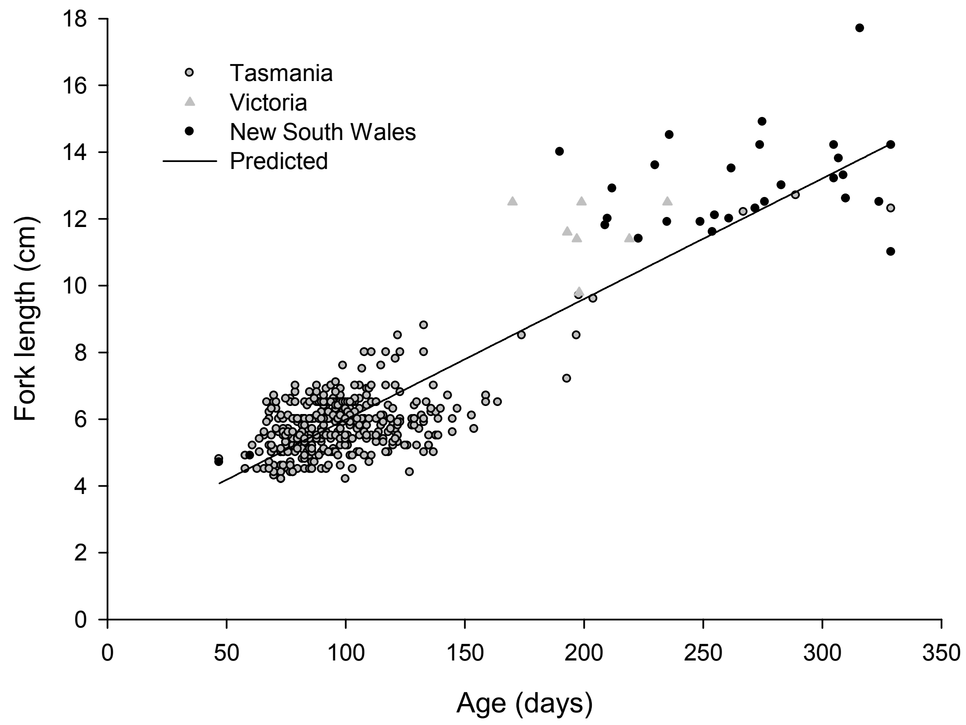


Figure 3.12. Daily size-at-age data for eastern Australian salmon from each state.

Research beach seine samples from Tasmania were dominated by individuals ranging between 40 and 150 mm FL. Seasonal length compositions clearly revealed two distinct cohorts during summer in most regions; comprising newly recruited individuals of around 40 mm FL (0+) and a second cohort of larger individuals ranging between 100 and 150 mm FL (presumably 1+) which remained present until autumn (Fig. 3.13). Monthly and seasonal length frequencies provided evidence of modal progression of the 0+ cohort which can be linked to growth. For example, the cohort of new recruits at around 40 mm FL in January 2009 could be tracked through to January the following year at which stage it had grown in size to approximately 100 – 150 mm FL (Fig. 3.14).

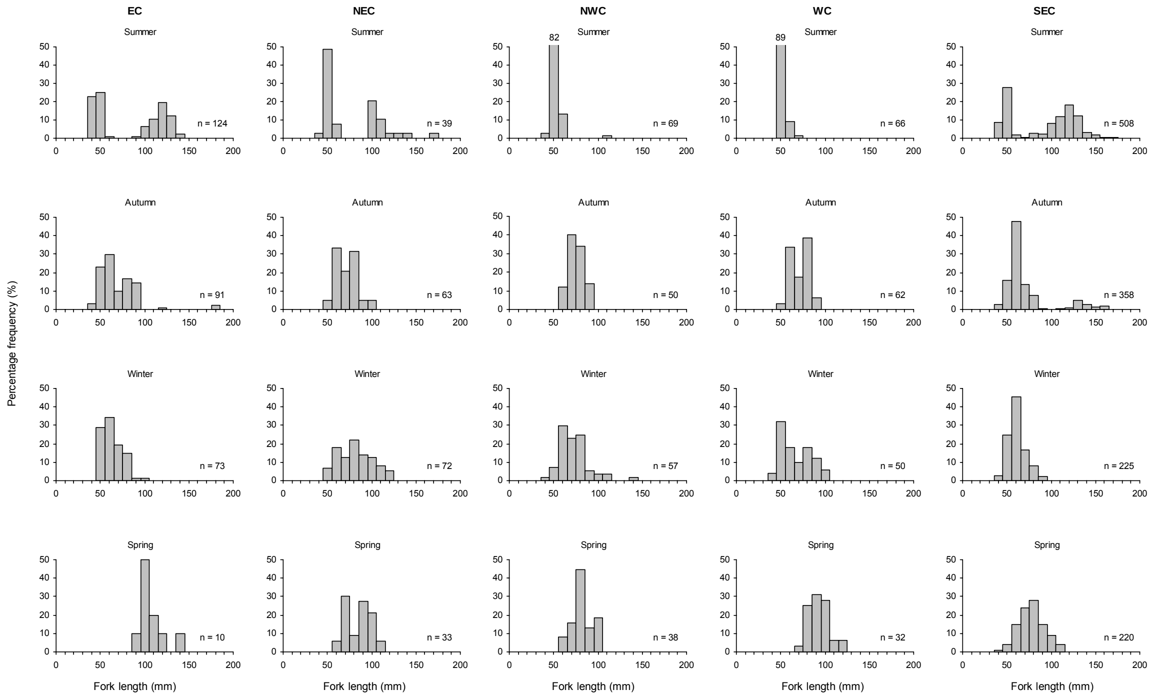


Figure 3.13. Seasonal length frequency distributions of eastern Australian salmon captured in research beach seining from each Tasmanian region between January 2009 and January 2010. EC is east coast, NEC is north-east coast, NWC is north-west coast, and WC is west coast. n = number of fish measured.

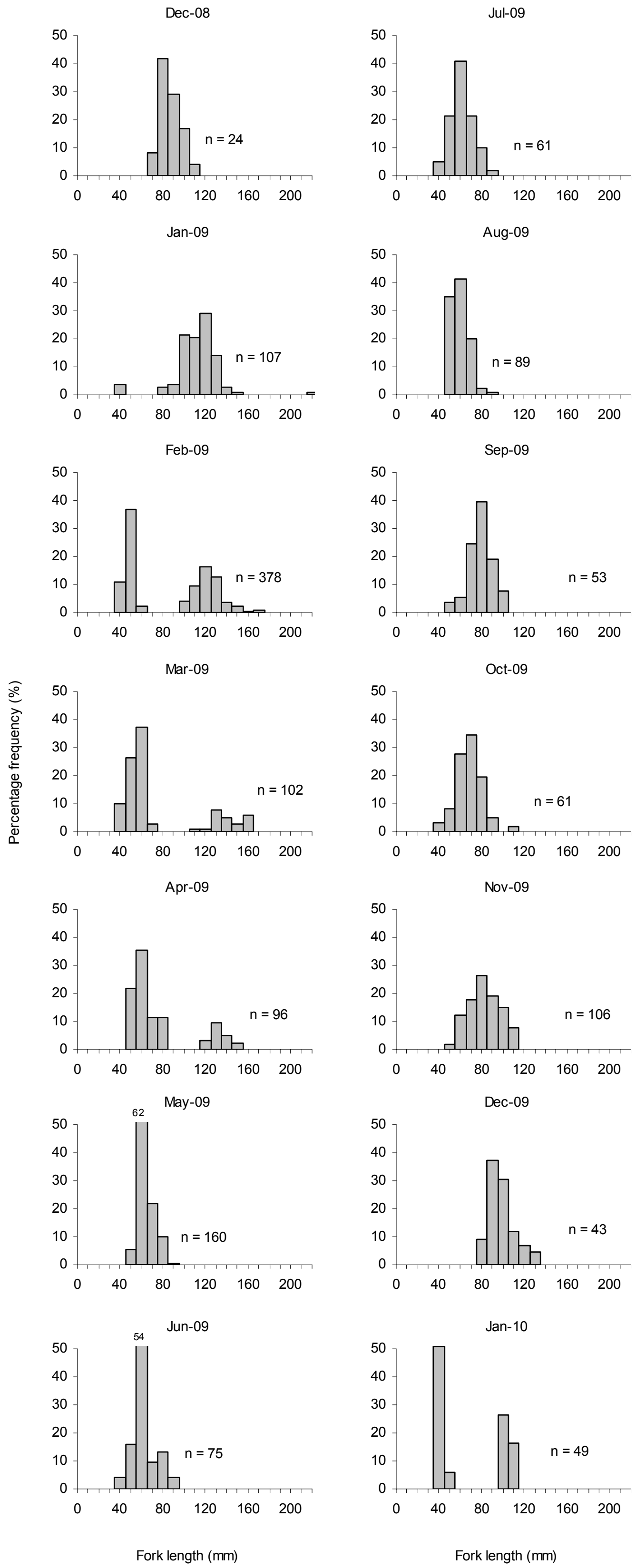


Figure 3.14. Monthly length frequency distributions of eastern Australian salmon captured in research beach seining from the SEC region. *n* = number of fish measured.

3.4. Discussion

This study has demonstrated that the growth increments observed in the otoliths of small juvenile eastern Australian salmon form daily. The strong correlation between the numbers of increments formed after the fluorescent marker created by tetracycline treatment and number of days elapsed between treatment and sacrifice supports the use of juvenile otoliths to estimate daily age. The formation of the 1st annulus in otoliths was validated using both a vital stain and by daily age estimation. Tetracycline marking of captive fish in NSW suggested that the first annulus was formed well before April, when the fish were injected with tetracycline. Given that the tetracycline mark was approximately half way between the two opaque zones in these fish at the completion of the experiment, and based on approximately linear otolith growth through time, then the 1st annulus was likely formed ~6 months before tetracycline marking (i.e., October). This estimate of an October 1st annulus formation is supported by the daily age analyses. Daily age estimates suggest that the first annulus in NSW begins to form on average, ~261 days after hatching and is completed after ~283 days. If the universal birthday is taken to be January 1st (Chapter 4) this means that the 1st annulus begins forming on average around mid-September and is completed, on average, by mid October. This is also supported by the reported timing of first annulus formation in the scales of eastern Australian salmon during October (Nicholls 1973).

The marginal increment analyses indicate that opaque zones in eastern Australian salmon after age 1 are also formed annually. There were no obvious differences between fish sampled from Tasmania, Victoria and NSW and opaque zones were judged to be completed in most fish by March. Despite extensive age and growth work done on this species in NZ waters, the period of opaque zone formation has not been estimated there (Stevens & Kalish 1998, Hartill & Walsh 2005). Marginal increment analyses of eastern Australian salmon from NZ have to date proven unsuccessful, however age validation using tetracycline injection and the progression of juvenile length frequencies has confirmed that one annulus is formed each year in fish from one to 14 years of age in NZ waters (Stevens & Kalish 1998, Bradford 1998).

Juvenile eastern Australian salmon attain an average size of approximately 15.9 cm FL after their first twelve months of growth according to the VBGF fitted to the combined size-at-age data, and approximately 15.5 cm FL after 365 days according to the linear growth estimated from the daily size-at-age data. These estimates of size-at-age after 1 year were slightly larger, but still similar to, the length frequency distributions observed in research sampling in Tasmania, with individuals ranging in size between 10 and 15 cm FL after approximately 12 months (January/February). The growth estimates of juveniles from Tasmanian waters may have been slightly lower than those estimated from the combined data from each state because of colder waters in that state. In fact, when only the Tasmanian daily size-at-age data is examined, a linear relationship between FL and age predicts that fish attain approximately 12 cm FL after 365 days, very similar to that observed in the research sampling. These findings are similar to those previously reported in Tasmanian waters, based on modelling and tracking monthly length modes (Nicholls 1973). Growth estimates, also based on length frequency distributions, reported for populations in New Zealand waters suggest that individuals reach approximately 130 – 150 mm FL in their first year (Stevens & Kalish 1998, Ministry of Fisheries 2008).

The growth of eastern Australian salmon in the present study was well described by the VBGF. The VBGF produced a value for t_0 of -0.14 which is close to 0 years and a value of L_∞ (62.3 cm FL) within ± 5% of the largest fish collected (L_{max} = 64.6 cm FL) (Froese & Binohlan 2000). Initial growth was rapid, with fish attaining on average ~ 16 cm FL after one year and ~ 26.5 cm FL after 2 years. This initial rate of growth is in very close agreement with that previously estimated for this species in S.E. Australia of ~ 17.2 and 27.8 cm FL after one and two years respectively, despite the historical use of scale readings for estimation of age (Nicholls 1973).

The VBGF parameters for eastern Australian salmon estimated in the present study were similar to those previously reported for this species from S.E. Australia; the parameters t_0 (-0.14 years) and k (0.25 year^{-1}) were similar to those estimated by Nicholls (1973) of -0.14 years and 0.30 year^{-1}, respectively. The estimated L_∞ of 63.2 cm FL in the present study was slightly larger than that reported by Nicholls of 58.4 cm FL. The reason for this discrepancy in estimated growth of the same population of fish may lie in the use of different structures to estimate age. Counts of opaque zones in otolith sections were used to estimate age in the present study whereas scale readings were used previously. The use of scales to estimate age has previously been shown to underestimate the ages of older fish (e.g., *Seriola lalandi*: Gillanders *et al.* 1999, eastern Australian salmon: Eggleston 1975). Eggleston (1975) found that scales were unsuitable for accurately estimating the ages of eastern Australian salmon older than 5 years in NZ. As a result, the oldest eastern Australian salmon previously recorded in S.E. Australia was estimated to be only 7 years old (Nicholls 1973). It is not surprising therefore, that the L_∞ estimated using scales is smaller than that using otolith sections. Nonetheless, the growth of eastern Australian salmon in S.E. Australia appears to be consistent, at least up to age 5, despite being modelled on two occasions 40 years apart and estimated using ring counts in very different hard structures.

The VBGF parameters in the present study were also comparable to those for populations of eastern Australian salmon from NZ waters, estimated using validated annulus counts in sectioned otoliths. Average t_0 = 0.25 years (range -0.26 to 0.60), average k = 0.33 year^{-1} (0.23 to 0.43) and average L_∞ = 55.3 cm FL (53.5 to 60.3) (Stevens & Kalish 1998, Hartill & Walsh 2005) suggesting slower initial growth and lower average maximum sizes than for this species in S.E. Australia.

Growth of the sexes was similar up to ~ 5 years of age, after which females were on average larger than males at all subsequent ages. A similar trend has been reported for eastern Australian salmon in NZ waters (Bradford 1998, Hartill & Walsh 2005).

The life-history of eastern Australian salmon, with fish tending to move northwards as they grow older, complicates analysis of variation in growth rates with latitude. However, the size-at-age data indicated substantial differences in growth rates with latitude, with fish from NSW being generally larger at any given age than fish from Victoria and Tasmania. This was evident in both the annual and daily size-at-age estimates. Previous growth modelling work using the VBGF undertaken by Nicholls (1973) also found some regional differences in growth between fish sampled from NSW, Victoria and Tasmania. Fish from NSW were reported to grow faster initially than those from Victoria and Tasmania (Nicholls 1973). Growth of eastern Australian salmon in NZ waters has also been shown to vary significantly by region with fish from the South Island growing slower initially than fish collected from the North Island (Stevens & Kalish 1998, Hartill & Walsh 2005). These observed differences in growth at different latitudes are likely the result of differences in ambient water temperatures and its influence on metabolism. In S.E. Australia, annual mean coastal SSTs for northern NSW (~21 to 23.5ºC), southern NSW (~18 to 21ºC), Victoria (~15.5 to 18ºC) and Tasmania (~14 to 16ºC) vary substantially (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Similarly in NZ, coastal waters around the North Island are warmer (~14.5 to 18.5ºC) than those of the northern South Island (~14 to 15ºC), the southernmost area where eastern Australian salmon are found. The observed differences in growth rates with latitude emphasize the importance of sampling fish across their full distributions when attempting to model growth for a species. Growth curves based only on eastern Australian salmon from the southern states will not model growth of older fish well. Similarly, growth modelled only on fish from NSW is unlikely to be representative of the growth of the younger age classes which are less common in that part of the species range.

The largest fish recorded in the present study was a 64.6 cm FL female fish sampled from Eden in southern NSW. This was considerably smaller than the maximum reported size in both Australia (78 cm FL: Hutchins & Swainston 1986) and NZ (79 cm FL: Duffy & Petherick 1999). The oldest fish collected in the present study was estimated to be 12 years old. Prior to this, the maximum age recorded for the species in Australian waters was 7 years (Nicholls 1973), although a longevity of up to 10 years was claimed by Stanley (1980). Nonetheless, even a maximum age of 12 years is considerably less than the maximum recorded age of 26 years for fish from NZ (Eggleston 1977, 1978), where small numbers of 15 to 23 year old individuals do occur in commercial catches (particularly around the northern South Island) (Bradford 1998, Stevens & Kalish 1998). Given that eastern Australian salmon in NZ achieve considerably greater longevities than in Australia, and the fact that no individuals close to their maximum reported size were sampled in the current project, it is probable that the maximum age for the species in Australia exceeds that of the oldest fish sampled in this study.

4. REPRODUCTION

OBJECTIVES ADDRESSED

This chapter addresses objective 3 of the original Project No. 2006/018 to "Describe the reproductive biology of eastern Australian salmon in NSW, including their size/age at maturity and where and when they spawn".

4.1. Introduction

The majority of information on the reproductive biology of eastern Australian salmon in S.E. Australia is from work done in the 1960s and 70s; very little data has been collected since that time upon which to base management of this resource which spans three state jurisdictions (NSW, Victoria and Tasmania).

Previous research into the reproductive biology of eastern Australian salmon indicated that spawning occurred from September–October to March–April between Lakes Entrance in eastern Victoria and Bermagui in southern NSW (Malcolm 1966a, Stanley & Malcolm 1977). These authors also noted some latitudinal variation in spawning periods with spawning commencing in the Bermagui area earlier (November) than further south in the Eden or Lakes Entrance areas (December–January). No evidence of spawning was found in fish collected from Tasmanian waters. The onset of sexual maturity has been reported to occur in both sexes at 39 cm FL in both S.E. Australia (Stanley & Malcolm 1977) and NZ (Hartill & Walsh 2005), which was suggested to be at approximately the end of the fourth year of life (Nicholls 1973, Stanley 1980, Hartill & Walsh 2005).

Eastern Australian salmon have been reported to be fractional (partial) spawners, where only a portion of the eggs present in the ovary are ripe at any given time (Stanley & Malcolm 1977), with females possessing ripe ovaries for 4 – 6 weeks during which time many batches of eggs are spawned on multiple occasions (Stanley 1980). The other members of the genus *Arripis* present in the waters of WA, the Australian herring and western Australian salmon have also been shown to be multiple batch spawners with asynchronous oocyte development (Malcolm 1960, Fairclough *et al.* 2000). The batch fecundity of female eastern Australian salmon has not been examined in S.E. Australian waters, but in NZ has been estimated at 60,000 – 750,000 eggs per large female fish (Hartill & Walsh, 2005).

Eastern Australian salmon exhibit strong spatial age and size specific population structuring in S.E. Australia, whereby young fish (0 to 2 years old) are found predominantly in Tasmania and Victoria and older (> 4 years), larger fish predominate in NSW (Nicholls 1973, Stanley 1978, Chapter 2). This distribution is hypothesized to be partly driven by a size/age specific migration pattern where a one-way migration of juveniles from Tasmania across Bass Strait occurs with the onset of sexual maturity at 39 cm FL/~ 4 years old (Stanley & Malcolm 1977, Stanley 1980). This distribution of adults and juveniles provides strong evidence of a southward movement of early life-history phases from NSW and Victoria to Tasmania (Malcolm 1966a,c), and it has been suggested that the southward moving Eastern Australian Current (EAC) is important in the advection of larvae from spawning grounds off NSW into nursery areas in Tasmania and along the S.E. coast of Victoria (Nicholls 1973, Stanley & Malcolm 1977, Kailola *et al.* 1993). The relative contribution of spawning by large old fish in NSW waters to sustaining the population of eastern Australian salmon in Tasmania and eastern Victoria may therefore be substantial.

The aim of the present chapter was therefore to redress the paucity of available reproductive information for eastern Australian salmon by examining the following aspects of reproduction in NSW, Victoria and Tasmania: i) reproductive seasonality and the geographical extent of spawning by analysis of gonadosomatic indices (GSIs) and macroscopic gonad stages, ii) microscopic development of ovarian and testicular tissue by histological analysis, iii) size and age at sexual maturity, iv) sex ratios, v) batch fecundity, and vi) reproductive mode by analysis of oocyte size frequencies.

4.2. Materials and methods

4.2.1. Sample collection and processing

Reproductive condition was assessed using the fish sampled for biological analysis (see Chapter 3). Fish were measured (fork length – FL) to the nearest 0.1 cm, and weighed to the nearest g. Gonads were removed, weighed to the nearest 0.01 g and sex determined by macroscopic examination of the gonads. The sex ratios in catches from northern NSW, southern NSW, Victoria and Tasmania, as well as from beach haul and purse seine catches were calculated and compared using χ^2 tests.

4.2.2. Timing of reproduction

The timing of reproductive activity was determined by examining changes in gonadal condition through time. Gonadal development was assessed using gonadosomatic indices (GSIs) and a macroscopic staging schedule. GSIs were calculated as gonad weight as a percentage of the gonad-free body weight. Immature (Stage 1) fish were excluded from GSI calculations. Reproductive stages were assigned according to the developmental criteria based on size, colour, vascularisation, and visibility of oocytes or spermatozoa outlined in Tables 4.1 & 4.2.

Estimates of daily age for newly recruited fish from Tasmanian waters were used to back-calculate their spawning dates. These daily age estimates were from the work described in section 3.2.2.2.

4.2.3. Gonad histology

Gonads from five female and five male fish of each macroscopic reproductive stage collected (total n = 30 for each sex) were fixed in a solution of 10% formaldehyde, 5% glacial acetic acid, 1% anhydrous calcium chloride and 84% seawater (FAACC) for one week, before being transferred to 70% alcohol for storage.

Gonad tissue samples were dissected from fixed specimens, placed within plastic cassettes and preserved until processing in an automated tissue processor (Thermo Scientific Excelsior ES. Waltham, MA, USA) on an extended cycle of 32 h (graded ethanol series, 13 h total; 3 x xylene, 6.5 h total; 3 x paraffin wax, 12 h total; all steps under vacuum). The tissues were then embedded in paraffin wax (Paraplast™, McCormick Scientific, St. Louis, MO), sectioned at 5 µm thickness on a rotary microtome and dried at 45ºC overnight. Sections were deparaffinised in xylene (2 changes, 15 mins each) and rehydrated through a graded series of ethanols to tap water prior to staining in Harris' Haematoxylin (Lomb Scientific, Taren Point, NSW, Australia) for 3 mins. Sections were then rinsed in water, differentiated in acidified alcohol, blued using Scott's Blueing solution and stained in alcoholic eosin (2 changes, 45 s each; Lomb Scientific, Taren Point, NSW, Australia). Slides were finally dehydrated through a graded series of ethanols, cleared in citrosolve (Labtech, Riverstone, NSW, Australia) and coverslipped using DPX mountant (BDH, Poole, UK).

These gonads were then examined using the microscope and camera setup described in Chapter 3 in order to describe the internal microscopic characteristics of each macroscopic reproductive stage (Tables 4.1 & 4.2).

Table 4.1. The macroscopic and microscopic characteristics of each stage in the development of eastern Australian salmon ovaries.

Stage	Macroscopic Characteristics	Microscopic Characteristics
1. Immature	Determination of sex extremely difficult. Fine, translucent, jelly-like and tubular in cross section.	Previtellogenic primary growth (perinucleolar and chromatin nucleolar) oocytes arranged in folded ovigerous lamellae. Ovarian wall thick.
2. Developing/Resting	Reddish-brown in colour, translucent and jelly-like. No oocytes visible through ovary wall.	Mainly primary growth oocytes, but also some larger primary cortical alveolar oocytes developing.
2/3. Maturing	Yellow-orange in colour, small oocytes visible through ovary wall gives ovary a grainy appearance. Capillaries visible in ovary wall.	Some primary oocytes remain, but a large proportion of oocytes are vitellogenic secondary (yolk granule) oocytes. Ovarian wall thinning.
3. Ripe	Yellow-orange in colour, vitellogenic oocytes clearly visible through ovary wall, but no hydrated oocytes. Extensive vascularisation of ovary wall.	Mainly full yolk granule oocytes. Some developing yolk granule oocytes and primary oocytes are also present. Ovarian wall thin.
4. Running ripe	Hydrated oocytes visible through ovary wall throughout ovary, oviduct full of hydrated ova and shed through genital pore with gentle pressure on abdomen. Same length as Stage 3, but much more massive occupying most of the visceral cavity.	Hydrated oocytes occupy most of the ovary. A few yolk granule and primary oocytes are also present. Ovarian wall very thin.
5. Spent	Flaccid, rubbery and bloodshot, particularly towards posterior end.	Similar to Stage 2 (developing/resting) ovary- mainly primary growth oocytes along with some remnant yolk granule oocytes undergoing atresia. Ovarian wall very thick.

Table 4.2. The macroscopic and microscopic characteristics of each stage in the development of eastern Australian salmon testes.

Stage	Macroscopic Characteristics	Microscopic Characteristics
1. Immature	Determination of sex extremely difficult. Cream in colour, thin and strap-like in cross section.	Mainly early spermatogonia, a few cysts containing spermatocytes and spermatids developing.
2. Developing/Resting	Cream-brown in colour, strap-like, tough and leathery (not translucent and jelly-like).	Mainly spermatocytes and spermatids, but some spermatozoa in seminiferous tubules.
2/3. Maturing	Cream-white in colour, becoming soft and lobular. Much larger than Stage 2 testes.	Spermatocytes and spermatids throughout testicular tissue, spermatozoa beginning to accumulate in seminiferous tubules and sperm duct.
3. Ripe	Pinkish-white in colour, soft and easily ruptured, no milt expelled with pressure on abdomen. Much larger than Stage 2/3.	Spermatocytes and spermatids present in tissue around outside half of testis lobule, spermatozoa present in seminiferous tubules and sperm duct.
4. Running ripe	Pinkish-white in colour, copious milt easily expelled with gentle pressure on abdomen. Very soft and difficult to remove without rupturing. Same length as Stage 3 but much more massive occupying most of the visceral cavity.	As for Stage 3 above, but amount of spermatozoa present in seminiferous tubules and sperm duct increased.
5. Spent	Brownish, rubbery and bloodshot, particularly towards posterior end. Small amount of residual milt may be expelled with pressure on abdomen.	Some residual spermatozoa remain in lobular lumen, fewer cysts containing spermatocytes and spermatids than in Stage 3 or 4. Sertoli cells absorbing spermatozoa sometimes visible.

4.2.4. Size and age at maturity

The sizes at sexual maturity for both sexes were estimated using the macroscopic staging of gonads described above. Fish collected during the peak spawning season in both northern and southern NSW (November to March inclusive) were classified as being immature if the gonads were reproductively inactive (Stages 1 or 2). If, during the overlapping spawning seasons for each region, the gonads were reproductively active (Stages 3 to 5), the fish was classified as being mature.

A logistic regression model was used to test the effect of 4 variables and interactions between these factors on the binary variable 'maturity' (Y_i) of individual salmon (i.e., either mature or immature). These variables were: length, sex, age and location.

The models were:

$$\text{logit}(Y_i) = a + b^*\text{length}_i + c^*\ \text{location}_i + d^*\ \text{sex}_i + \epsilon_i$$

$$\text{logit}(Y_i) = a + b^*\text{age}_i + c^*\ \text{location}_i + d^*\ \text{sex}_i + \epsilon_i$$

where a, b, c and d are constants.

The model was calculated using the freeware statistical package "R" (R Development Core Team 2006). General linear models predicting maturity using the above variables were fitted within "R" using the glm (family = binomial) function. The significance of each variable to the model was tested using the null hypothesis that they were significantly different from 0 using partial z-tests. Variables that were non-significant were removed and a reduced model refitted. The influence of each variable on the reduced model was assessed using the *drop1()* function within "R". This function calculates an Akaike Information Criteria (AIC) value for the reduced model and for the model without each variable. Variables with the greatest corresponding AIC value influence the model the most. Data were pooled based on the results of the logistic regression analyses and logistic curves fitted to estimate the size L_{50}) and age (A_{50}) at 50% maturity.

4.2.5. Fecundity

Ovaries from running ripe (Stage 4) female fish were removed and fixed in FAACC for one week, before being transferred to 70% alcohol for storage. The entire ovary was weighed to the nearest 0.0001 g and a random subsample of ovarian tissue was then taken from the ovary. The subsample was weighed to the nearest 0.0001 g, the eggs separated from one another by immersing the plastic storage jar containing the subsample in an ultrasonic cleaning bath (FXP4, Ultrasonics Australia Pty Ltd), and poured into a glass petri dish. Oocytes within each subsample were scanned using a flatbed scanner (CanoScan 8600F) and then counted and diameters calculated using the image analysis software ImageJ (version 1.38l). Initially, 3 replicate subsamples were taken from each of the anterior, centre and posterior of the ovary in order to examine any potential influence of subsampling location on oocyte counts. This was done for 6 randomly selected running ripe fish and analysis of variance (ANOVA) was used to examine for differences in oocyte counts per gram of ovary between subsamples taken from different parts of the ovary. Three replicate subsamples were then taken from each ovary so that each batch fecundity (BF) estimate had an associated standard error. The largest size class of eggs from a running ripe female fish representing a single batch of hydrated eggs was used to calculate the number of eggs shed during one spawning event. The sampled number of hydrated eggs was multiplied by the sub-sample fraction to estimate the BF for each fish.

4.2.6. Oocyte size frequency

To examine the size frequency distributions of oocytes during ovarian maturation, an ovarian sample representing each macroscopic reproductive stage (Table 4.1) was randomly selected. Three sub-samples of ~0.1 g each were taken from each selected sample and the diameters of all oocytes present were measured using the scanner and software setup described above.

4.3. Results

Only two fish from Tasmania were classified as being mature, a 44 cm FL female fish and a 46 cm FL male fish both sampled during January 2010 and assessed as having stage 3 gonads. The Victorian samples were dominated by small fish that were collected for juvenile work and were not considered representative of the reproductively active fish in that location. Only one fish from Victoria was assessed as being mature, a 44 cm female sampled during February 2007.

4.3.1. Sex ratios

The sexes were externally morphologically indistinguishable and sexual differentiation was only achieved through dissection and identification of ovarian or testicular tissue. There were no significant differences detected using χ^2 tests between the numbers of females and males collected from northern NSW, southern NSW, Victorian or Tasmanian waters or caught using beach haul or purse seine nets ($P > 0.05$ in each case). Overall, the number of female and male eastern Australian salmon sampled was not significantly different from a ratio of 1:1 ($\chi^2 = 0.65$, $df = 1$, $n = 2700$, $P >$ 0.05).

4.3.2. Timing of reproduction

In Tasmanian waters, mean monthly GSIs of fish staged as being > Stage 1 showed little variation through the year and remained at < 0.6% between October 2008 and January 2010. Macroscopic staging demonstrated that both sexes remained in an immature state (Stages 1 and 2) for the entire study period.

The timing and duration of elevated GSI values for both male and female eastern Australian salmon were consistent for each of the three spawning seasons sampled in NSW. For northern and southern NSW combined, peak GSI values occurred between October and March for both males and females in 2006-07, 2007-08 and 2008-09 (Fig. 4.1). Slightly elevated GSI values often occurred at the start and end of the spawning season (e.g., April 2007, September 2008 and April–May 2009) (Fig. 4.1). The highest GSI values recorded for female and males occurred early in the spawning period in November (females: 7.14 ± 0.83%, Nov 2007; males: 6.71 ± 0.45%, Nov 2006) (Fig. 4.1). During the peak spawning period (October to March), testes and ovaries increased in weight by approximately 13 and 6 times their non-spawning weights respectively.

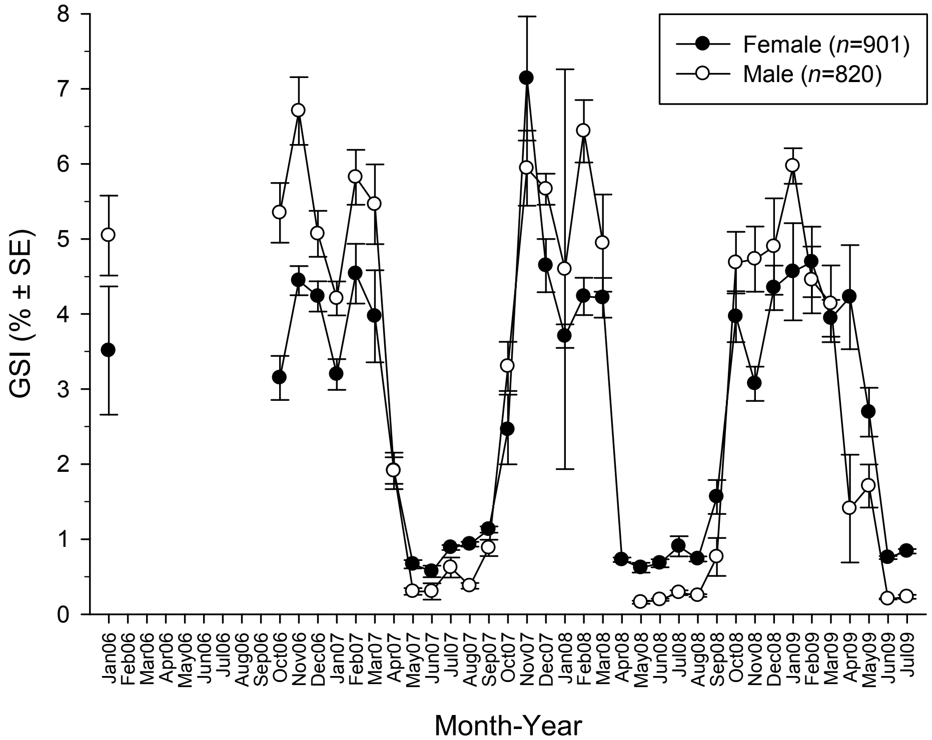


Figure 4.1. Gonadosomatic indices (mean ± S.E.) for eastern Australian salmon (> gonad Stage 1) for females (●) and males (○) collected from New South Wales between January 2006 and July 2009. *n* is sample size.

A lag in gonad development was evident between northern and southern NSW when the GSI values for females and males were averaged for each month (Figs 4.2A & B). The ovaries of eastern Australian salmon from northern NSW began to increase in size in September and peaked in October, whereas those from southern NSW did not begin this increase until October and did not reach peak size until November (Fig. 4.2A). A similar pattern occurred for males, with testicular development commencing and peak size occurring on average one month earlier in northern NSW than in southern NSW (Fig. 4.2B). At the end of the spawning season however, gonads from fish from both northern and southern NSW began to decrease in size in April and reached non-spawning minimum sizes by May (Figs 4.2A & B).

These patterns were closely mirrored by variation in macroscopic gonad staging between fish from northern and southern NSW (Figs. 4.3 & 4.4). In northern NSW, the spawning period indicated by the presence of running ripe fish occurred between October and March. During these months the average proportion of male fish with running ripe testes (63.2%) was much higher than the proportion of female fish with running ripe ovaries (18.2%) (Fig. 4.3). Fish with ripe gonads also occurred during this period, but some fish with ripe ovaries or testes also occurred before or after (in September 2007 and April–May 2009). Spent gonads also occurred during the peak spawning period, but were most common from April to May signifying the end of spawning. Some spent testes were observed through to June and July. Fish with resting/developing gonads were most common in the non-spawning months between June and August and fish with maturing gonads occurred mainly in the lead-up to and early stages of the spawning period in August–October (Fig. 4.3).

With a pattern similar to that for northern NSW, fish with running ripe gonads from southern NSW occurred from October to March (Figs 4.4). Once again the average proportion of males with running ripe testes (50.8%) was much higher than the proportion of females with running ripe ovaries (23.4%) during this period. Fish with ripe gonads primarily occurred during this peak spawning period, but again some fish with ripe gonads were evident after the peak; in April 2007 and April 2009 (Figs 4.4). Spent gonads occurred throughout the spawning period and as late as June (2009) and July (2007 & 2008). Resting/developing gonads made up the majority of fish sampled between May and September, a slightly longer period than for fish from northern NSW.

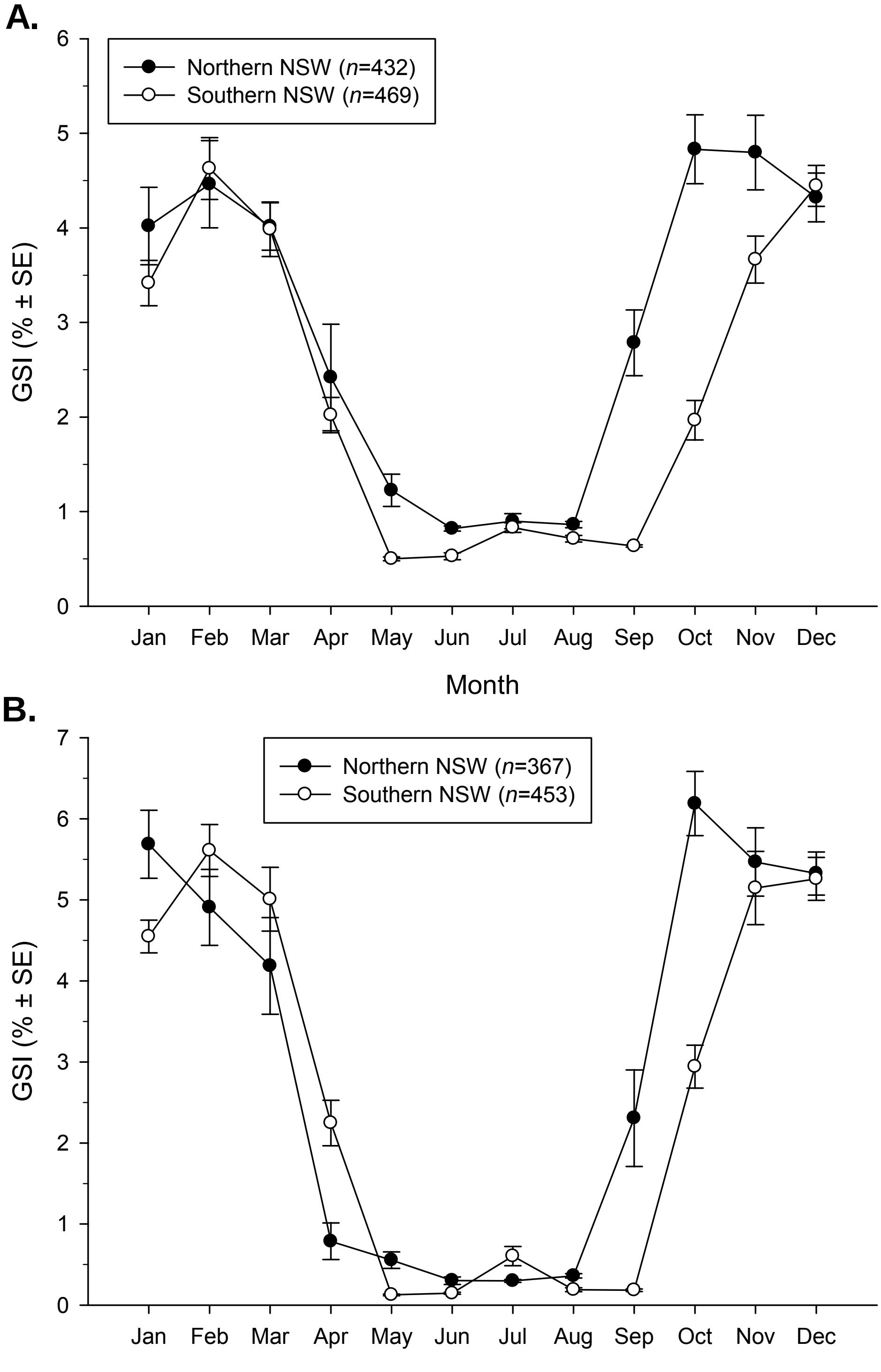


Figure 4.2. Mean monthly gonadosomatic indices (± S.E.) for A), female and B), male eastern Australian salmon collected from northern (●) and southern (○) New South Wales between January 2006 and July 2009. *n* is sample size.

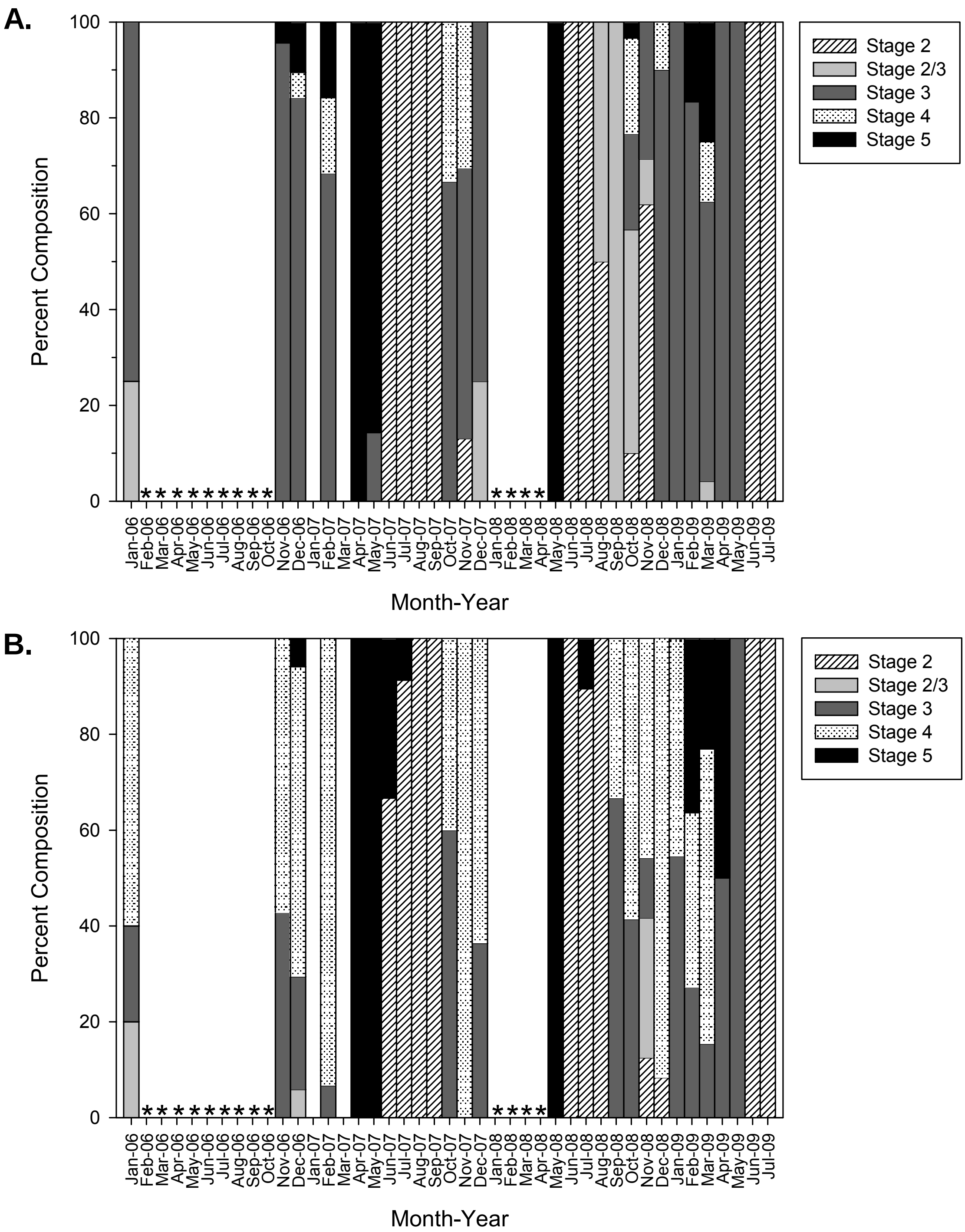


Figure 4.3. Monthly proportion of mature gonad stages for A), female and B), male eastern Australian salmon collected from northern New South Wales between January 2006 and July 2009. * indicates no data. Gonad stages are outlined in Tables 4.1 (ovaries) and 4.2 (testes).

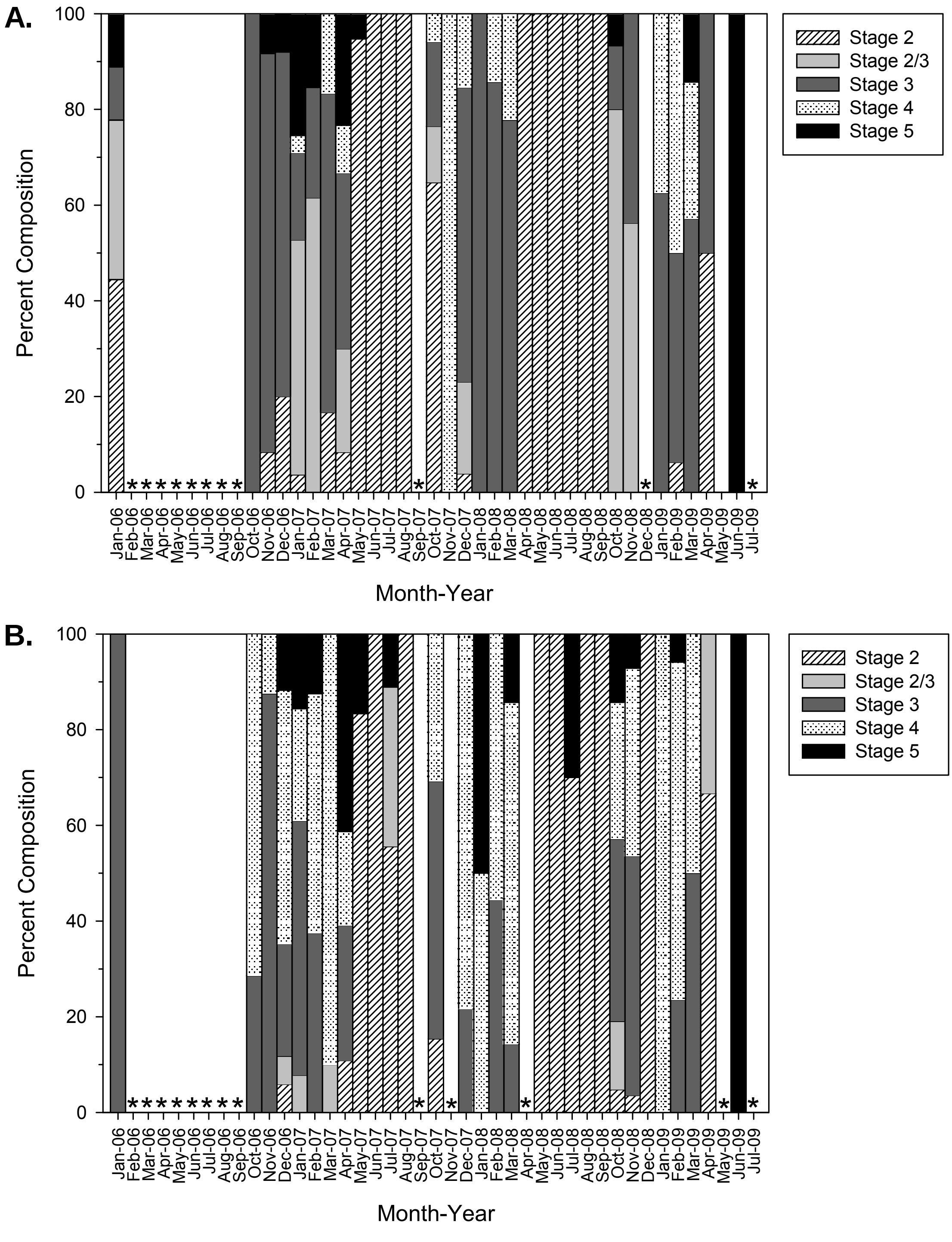


Figure 4.4. Monthly proportion of mature gonad stages for A), female and B), male eastern Australian salmon collected from southern New South Wales between January 2006 and July 2009. * indicates no data. Gonad stages are outlined in Tables 4.1 (ovaries) and 4.2 (testes).

Back calculated hatching dates

Back calculated hatching dates for 0+ eastern Australian salmon captured from Tasmanian waters implied that the spawning period was concentrated between November 2008 and March 2009, with peaks evident during November 2008 and February 2009 (Fig. 4.5). The earliest back calculated hatching dates were in late October and the latest were at the beginning of July.

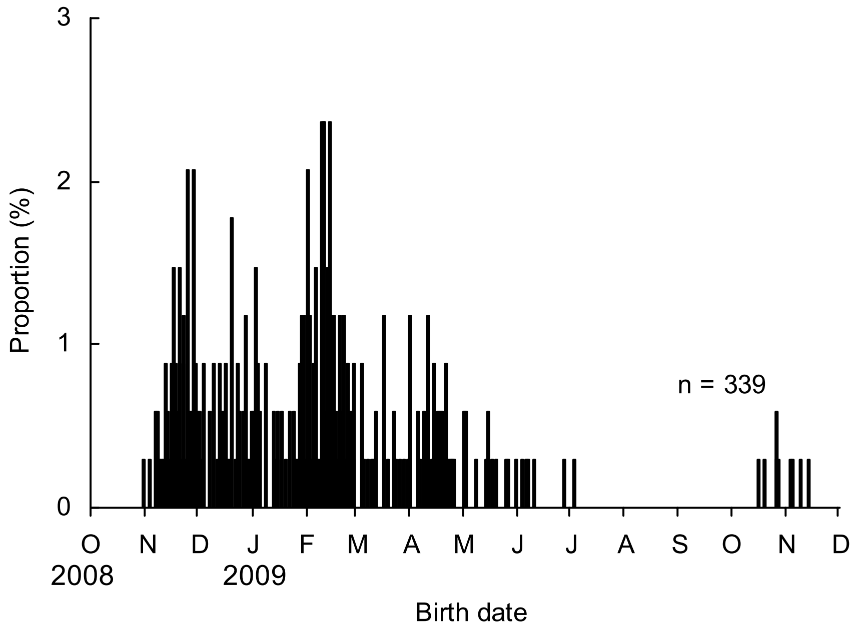


Figure 4.5. Back-calculated hatching dates for small eastern Australian salmon captured in Tasmanian waters between January 2009 and January 2010.

4.3.3. Size and age at maturity

Size and age at maturity assessments were based on 1,639 eastern Australian salmon sampled during the spawning period (November to March). Of these, 273 were from northern NSW, 689 were from southern NSW, 59 were from Victoria and 618 from Tasmania.

As a result of the lack of mature fish from Tasmanian and Victorian samples, spatial variation in size and age at maturity was restricted to southern and northern NSW and was based on individuals for which sex was determined (i.e., no indeterminate juvenile fish). In the full size-based logistic regression model, FL was the only factor which contributed significantly to the predictive power of the model (Table 4.3). As neither sex nor location (nor any of the interactions) contributed significantly to the model, these factors were removed and a reduced model was fitted containing only the factor FL. The resulting maturity ogive for NSW fish, which included small immature individuals, had an L_{50} of 31.01 ± 0.72 cm FL (Fig. 4.6).

When data from all states were combined the L_{50} was estimated to be substantially larger, at 43.3 ± 0.27 cm FL (Fig. 4.7).

Table 4.3. Parameter estimates for the full regression model describing the size at maturity of eastern Australian salmon in NSW. FL is fork length, Loc is "location" (northern or southern NSW), S.E. is standard error.

Variable	**Coefficient**	**Value**	**S.E.**	***z*-value**	***P***
Intercept	*a*	-12.32183	2.90763	-4.238	<0.001
FL	*b*	0.34524	0.07616	4.533	<0.001
Sex	*c*	–3.75869	9.1702	-0.41	0.222
Loc	*d*	4.18614	3.57166	1.172	0.230
Interactions					
FL * Sex		0.19176	0.29555	0.649	0.516
FL * Loc		-0.08928	0.09208	-0.97	0.332
Sex * Loc		5.76868	9.47072	0.609	0.542
FL * Sex * Loc		-0.22556	0.3017	-0.748	0.455

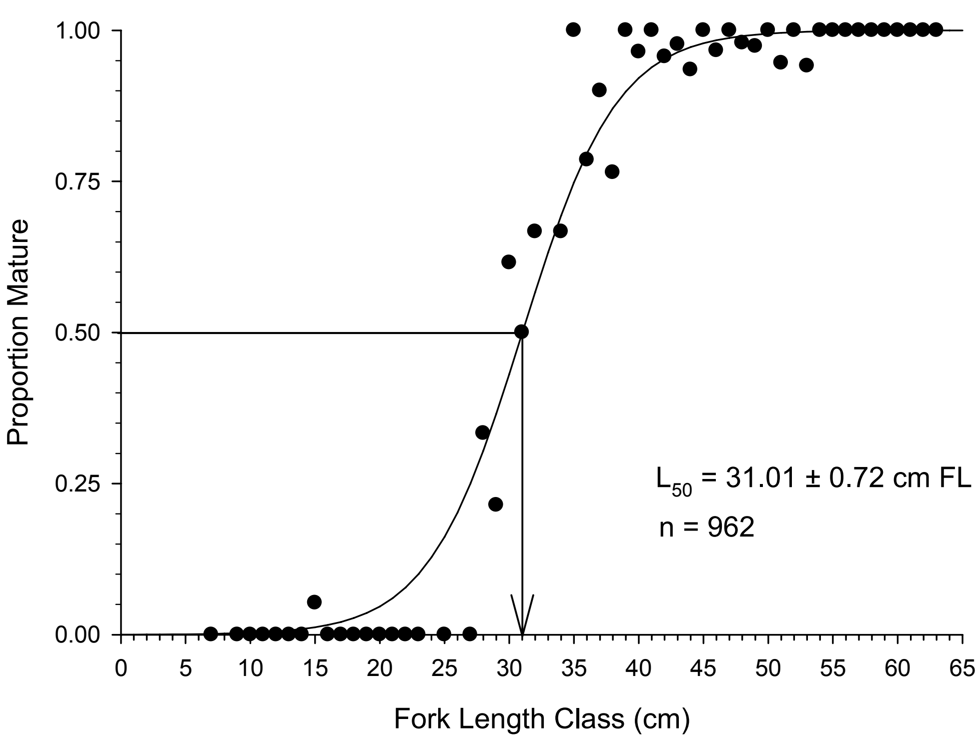


Figure 4.6. Size-related reproductive maturity data with fitted logistic curve for eastern Australian salmon collected from New South Wales waters between November and March (2006 to 2009). The arrow indicates size at 50% maturity (L_{50}). *n* is sample size.

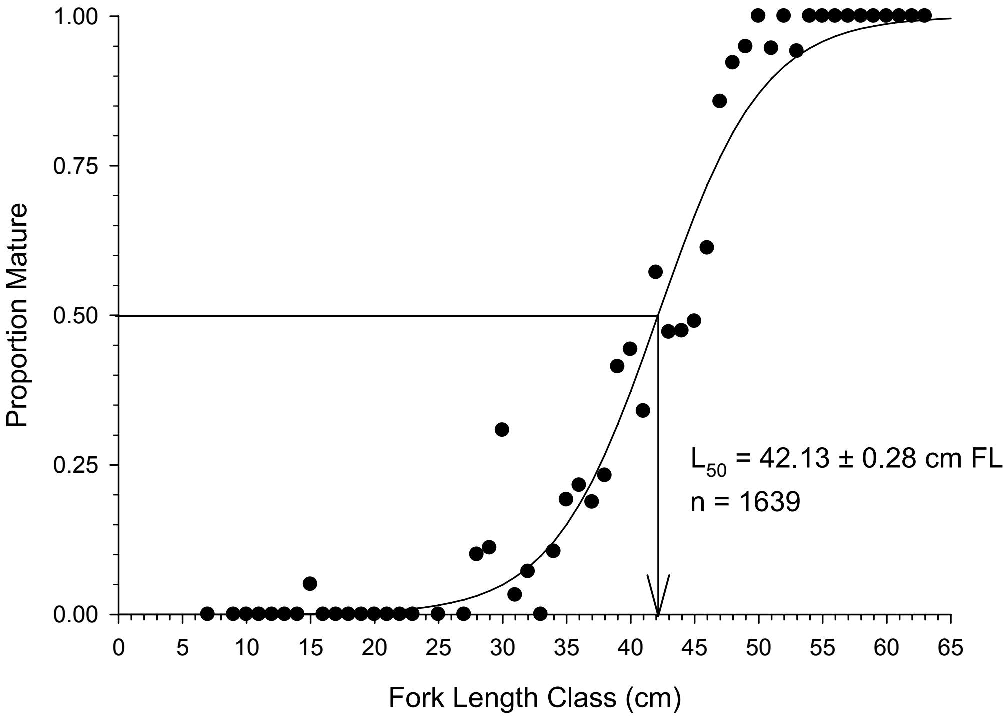


Figure 4.7. Size-related reproductive maturity data with fitted logistic curve for eastern Australian salmon collected from all states combined between November and March (2006 to 2009). The arrow indicates size at 50% maturity (L_{50}). *n* is sample size.

In the full age-based logistic regression model, age was the factor which contributed most significantly to the predictive power of the model (Table 4.4), although location was also significant at the 5% level. As the factor sex (and all interactions) did not contribute significantly to the model, this factor was removed and a reduced model was fitted containing only the factors age and location. In this reduced model only age was significant (Table 4.5).

The resulting age-based maturity ogive for fish from NSW waters, which included small immature fish, had an A_{50} of 2.19 ± 0.08 years (Fig. 4.8).

All but 2 fish sampled from Tasmania and Victoria during the spawning period were assessed as being immature and we therefore did not re-analyse the age-based maturity data from all states combined.

Table 4.4. Parameter estimates for the full regression model describing the age at maturity of eastern Australian salmon in NSW. Loc is "location" (northern or southern NSW), S.E. is standard error.

Variable	**Coefficient**	**Value**	**S.E.**	***z*-value**	***P***
Intercept	*a*	-6.5949	1.8447	-3.575	<0.001
Age	*b*	2.2018	0.5271	4.177	<0.001
Sex	*c*	3.5247	2.4425	1.443	0.149
Loc	*d*	4.2974	2.0214	2.126	0.03351
Interactions					
Age * Sex		-0.3103	0.8613	-0.36	0.71865
Age * Loc		-0.9064	0.5831	-1.554	0.12007
Sex * Loc		-3.0669	2.63	-1.166	0.24357
Age * Sex * Loc		0.2726	0.9165	0.297	0.7661

Table 4.5. Parameter estimates for the reduced regression model describing the age at maturity of eastern Australian salmon in NSW. Loc is "location" (northern or southern NSW), S.E. is standard error.

Variable	**Coefficient**	**Value**	**S.E.**	***z*-value**	***P***
Intercept	*a*	-3.8965	0.9496	-4.104	<0.001
Age	*b*	1.7134	0.3297	5.197	<0.001
Loc	*d*	1.9672	1.0442	1.884	0.0596
Age * Loc		-0.4783	0.3594	-1.331	0.1832

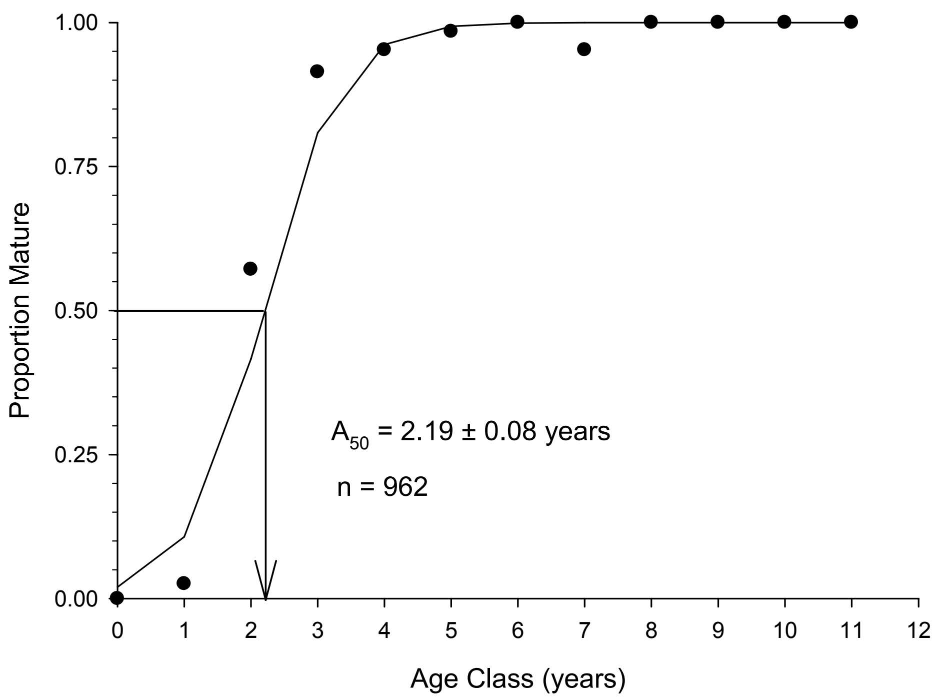


Figure 4.8. Age-related reproductive maturity data with fitted logistic curve for eastern Australian salmon collected from New South Wales between November and March (2006 to 2009). The arrow indicates age at 50% maturity (A_{50}). *n* is sample size.

4.3.4. *Fecundity*

There were no significant differences in oocyte counts per gram of ovarian tissue when sub-sampling from the anterior, centre or posterior of the ovary (ANOVA; $F_{12,53} = 1.66$, $P = 0.12$). Consequently, subsamples for estimation of fecundity were taken from any part of the ovary.

There was a significant positive correlation between BF and fish size (FL- cm) ($r = 0.74$, $P < 0.0001$), and the data were best described by the exponential relationship BF = 14,581*(exp 0.0659(FL)) ($r^2 = 0.74$, Fig. 4.9A). Mean BF was variable for all FLs and ranged from 71,279 ± 8,627 hydrated oocytes for a 32.5 cm FL fish to a maximum of 1,729,489 ± 63,627 hydrated oocytes for a 61.1 cm FL fish (Fig. 4.9A). Relative BF ranged from 97 to 466 hydrated oocytes/g body weight (mean 205 ± 13). There was also a significant positive correlation between BF and estimated age ($r = 0.78$, $P < 0.0001$) and the data were best described by the exponential relationship BF = 96,604*(exp 0.227(Age)) ($r^2 = 0.64$, Fig. 4.9B).

4.3.5. *Oocyte size frequency*

Immature eastern Australian salmon possessed a single mode of previtellogenic primary growth oocytes generally < 0.1 mm dia. (Fig. 4.10A). This distinctive mode of primary oocytes was the dominant group of oocytes present in all subsequent reproductive stages (Fig. 4.10A-F). Developing/resting ovaries contain mainly oocytes < 0.1 mm dia., but ~ 3% of visible oocytes were > 0.1 mm dia. In maturing ovaries, a large number of oocytes between 0.2 up to 0.6 mm dia. developed (Fig. 4.10C). When ovaries reached a reproductive stage of ripe, this group of oocytes had become a distinct broad mode between 0.3 and 0.7 mm dia. and made up ~ 10% of the oocytes visible in the ovary (Fig. 4.10D). In running ripe ovaries, a group of oocytes 0.7-0.9 mm dia. had developed into hydrated ova ready for spawning, however the broad mode of oocytes seen in ripe ovaries remained, albeit in reduced numbers (~ 3%, Fig. 4.10E). The size frequency distribution of running ripe ovaries was virtually continuous, but with a clear separation between the hydrated oocytes and the rest (Fig. 4.10E). No hydrated or vitellogenic oocytes remained in the ovaries of spent fish. (Fig. 4.10F).

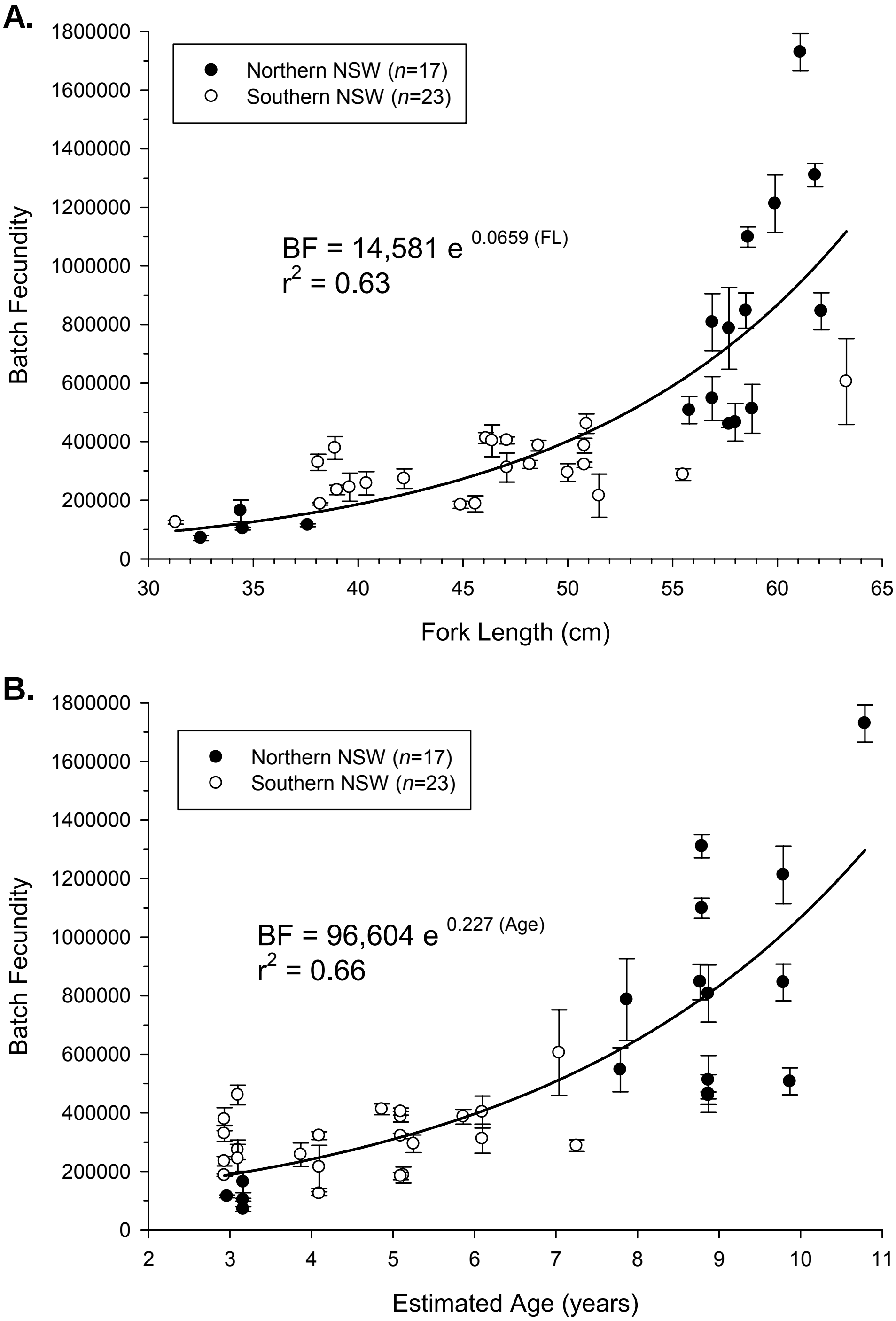


Figure 4.9. Relationships between batch fecundity (± S.E.) and A), fork length (cm); and B), estimated age (years), for eastern Australian salmon collected from northern (●) and southern (○) New South Wales between January 2006 and July 2009. *n* is sample size.

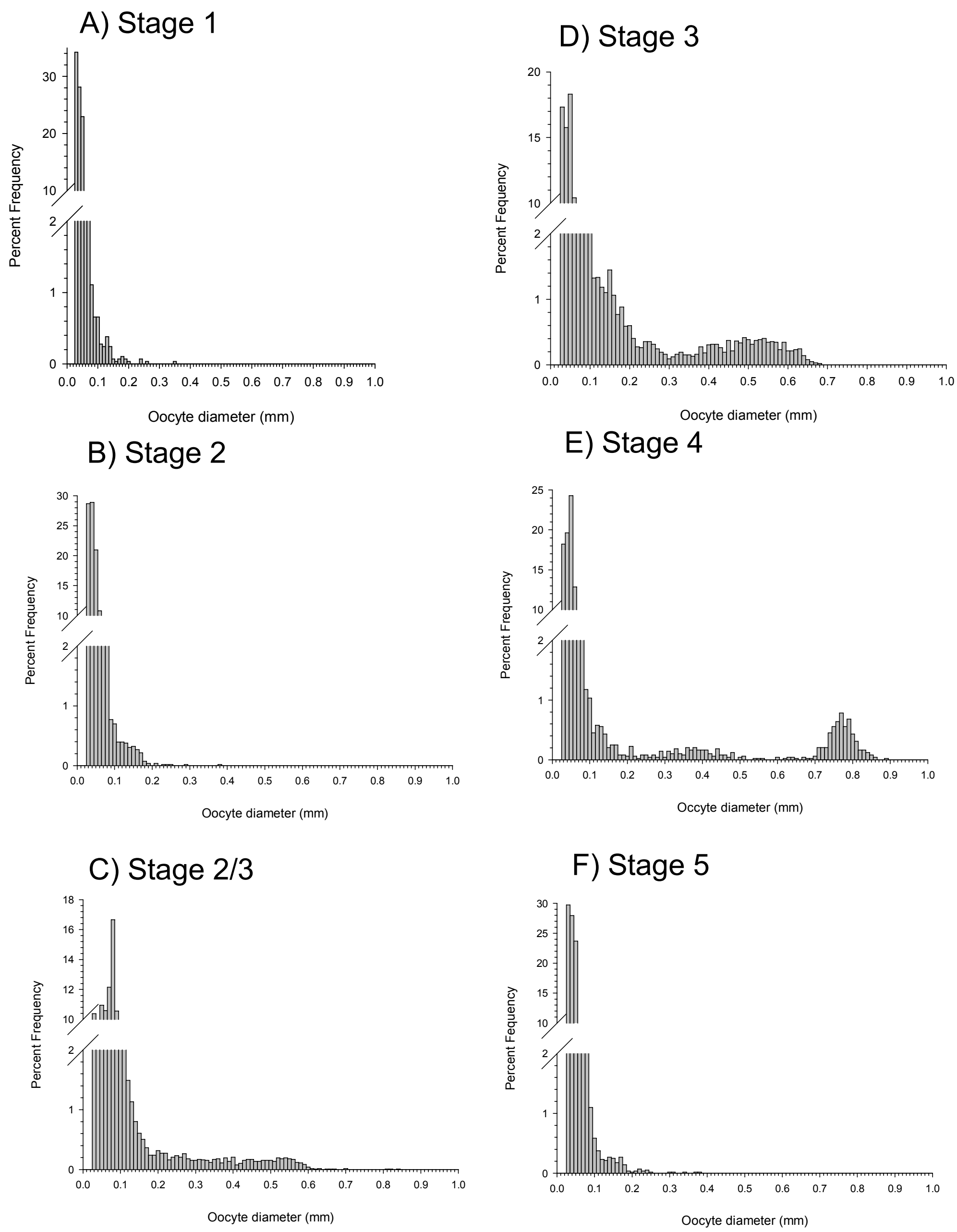
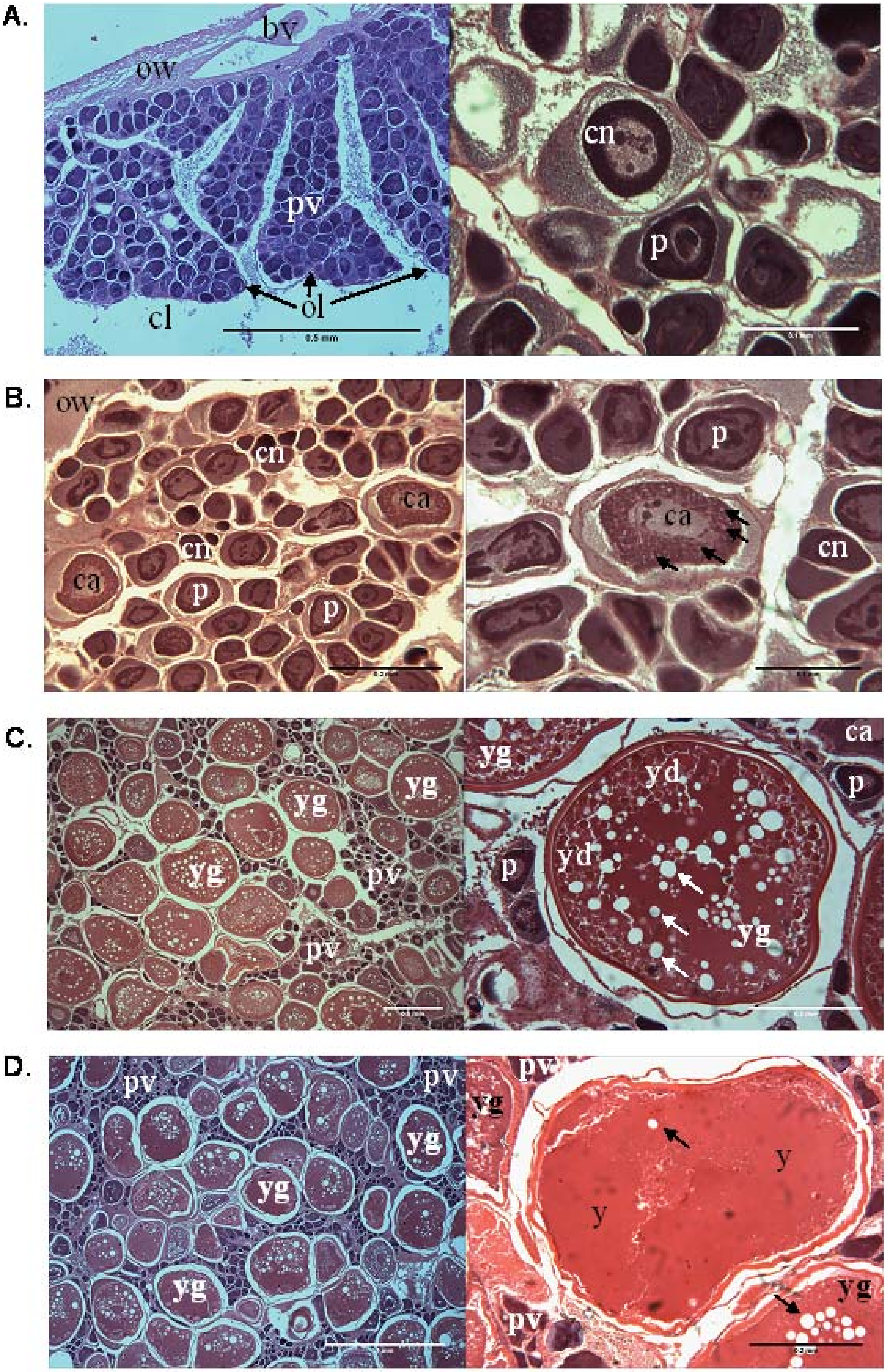


Figure 4.10. The size frequency distributions of oocytes taken from the ovary of a randomly chosen female eastern Australian salmon typical of each of the reproductive stages outlined in Table 4.1: **A)** Stage 1 (immature), **B)** Stage 2 (developing/resting), **C)** Stage 2/3 (maturing), **D)** Stage 3 (ripe), **E)** Stage 4 (running ripe) and **F)** Stage 5 (spent).

4.3.6. Gonad histology

Immature ovaries contain some oogonia and undifferentiated previtellogenic primary growth oocytes (perinucleolar and chromatin nucleolar oocytes) arranged in a series of lamellae around a central lumen with a thick ovarian wall (Fig. 4.11A). Developing/resting ovaries also contained mainly primary growth oocytes but also contained many larger oocytes where cortical alveoli (yolk granules) had begun to form (Fig. 4.11B). In maturing ovaries, the ovarian wall thinned markedly as vitellogenesis began to occur and a large proportion of oocytes were either developing or complete yolk granule oocytes (Fig. 4.11C). Some primary chromatin nucleolar oocytes also remained. Full yolk granule oocytes were predominant in ripe ovaries as well as some developing yolk granule and chromatin nucleolar oocytes (Fig. 4.11D). The majority of oocytes in running ripe ovaries had undergone final oocyte maturation (FOM) and were fully hydrated ready for spawning (Fig. 4.11E). A few yolk granule and chromatin nucleolar oocytes also occurred and the ovarian wall was extremely thin in running ripe fish. Spent ovaries did not contain any postovulatory follicles (POFs) indicative of recent spawning. Instead they were microscopically very similar to developing/resting ovaries containing mainly primary oocytes but also some remnant yolk granule oocytes undergoing atresia. The ovarian wall of spent fish was very thick (Fig. 4.11F).

The testes of immature fish contained mainly early spermatogonia along with some developing spermatogenic cysts of spermatocytes and spermatids (Fig. 4.12A). Spermatogenic cysts contained a single spermatogonium or a small group of spermatogonia and seminiferous tubules did not show a continuous lumen. Most germ cells in developing/resting testes were spermatocytes and early spermatids (round) but some spermatozoa had begun to accumulate within the seminiferous tubules (Fig. 4.12B). In maturing testes, spermatocytes, early and late (elongated) spermatids and spermatozoa were present in approximately equal proportions, however whilst spermatocytes and spermatids occurred throughout the testicular tissue, spermatozoa occurred primarily near the centre of the testes and especially in the seminiferous tubules and sperm duct (Fig. 4.12C). This accumulation of spermatozoa continued in Stage 3 (ripe) and 4 (running ripe) testes with the testicular tissue divided into two distinct parts (Fig. 4.12D & E): the innermost tissue consisting of spermatozoa filling the sperm ducts and seminiferous tubules (Fig. 4.12D & E) and the outermost consisting of tissue containing spermatids and spermatocytes (Fig. 4.12D & E). Spent testes contained substantial amounts of residual spermatozoa remaining in the lobular lumen and the amount of spermatocytes and spermatids present in the rest of the tissue was greatly reduced (Fig. 4.12F).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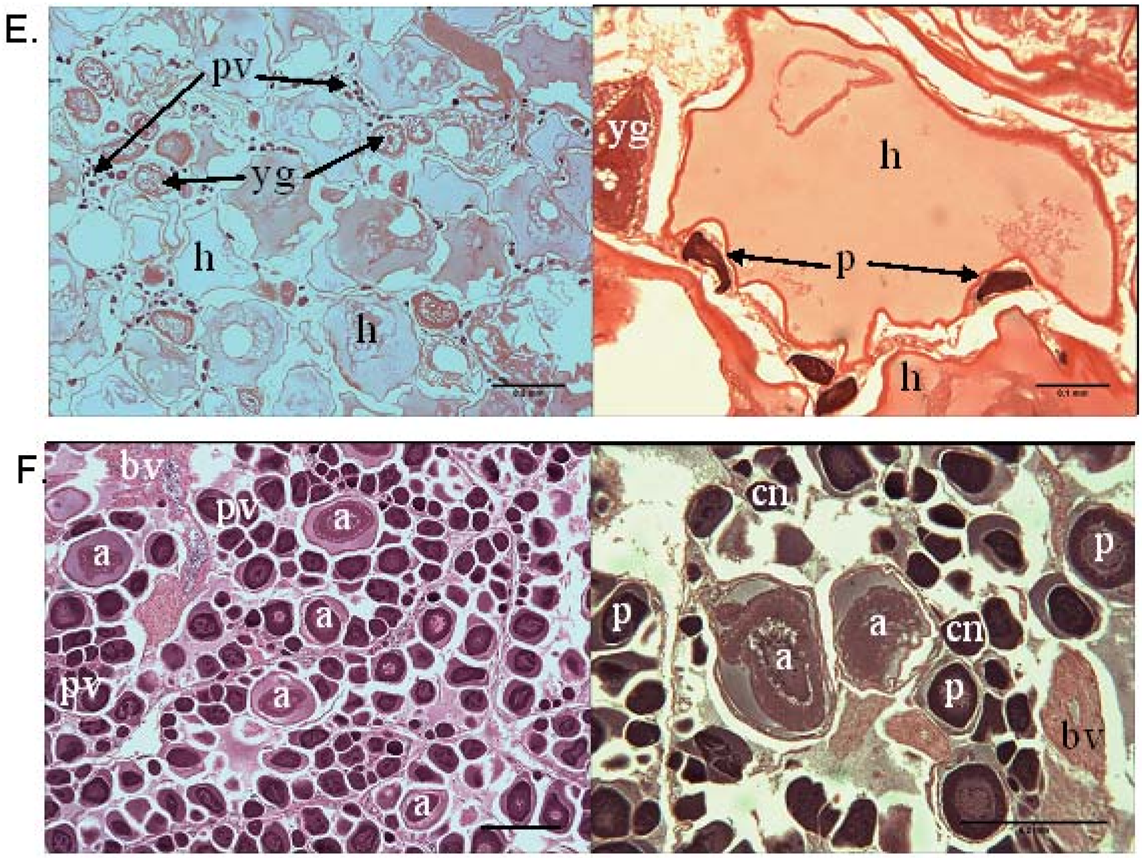
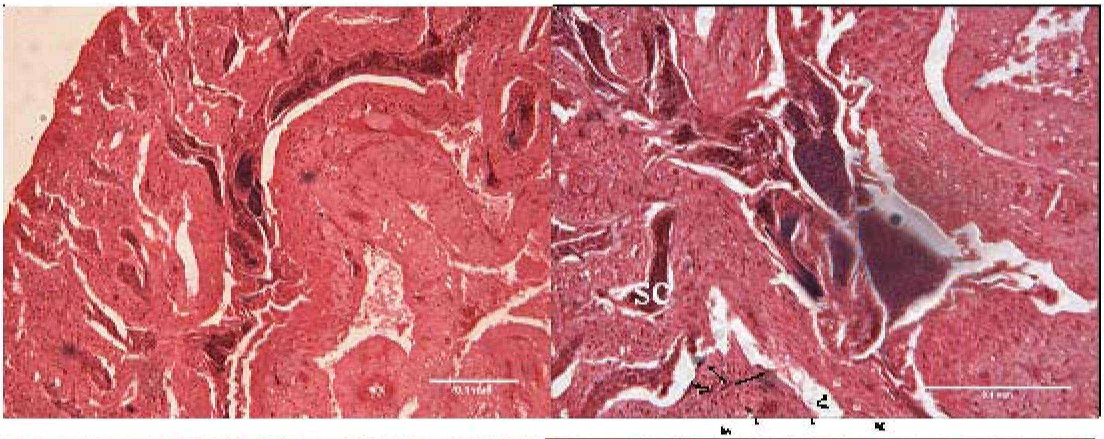


Figure 4.11. Histological sections of the development eastern Australian salmon ovarian tissue according to the criteria outlined in Table 4.1: **A)** Stage 1 ovary at x10 (left) and x40 (right) magnification showing ovigerous lamellae containing primary oocytes, **B)** Stage 2 ovary at x20 (left) and x40 (right) magnification showing development of cortical alveolar oocytes, **C)** Stage 2/3 ovary at x4 (left) and x40 (right) magnification showing developing yolk granule oocytes, **D)** Stage 3 ovary at x4 (left) and x40 (right) magnification showing mature yolk granule oocytes, **E)** Stage 4 ovary at x2 (left) and x10 (right) magnification showing fully hydrated oocytes and **F)** Stage 5 ovary at x10 (left) and x20 (right) magnification showing yolk granule oocytes undergoing atresia. Abbreviations: **a**, atretic yolk granule oocyte; **bv**, blood vessel; **ca**, cortical alveolar oocyte; **cl**, central lumen; **cn**, chromatin nucleolar oocyte; **h**, hydrated oocyte; **p**, perinucleolar oocyte; **pv**, previtellogenic oocyte; **ol**, ovigerous lamellae; **ow**, ovarian wall; **y**, fused yolk; **yd**, yolk droplet; **yg**, yolk granule oocyte. Arrows indicate cortical alveoli.

A.



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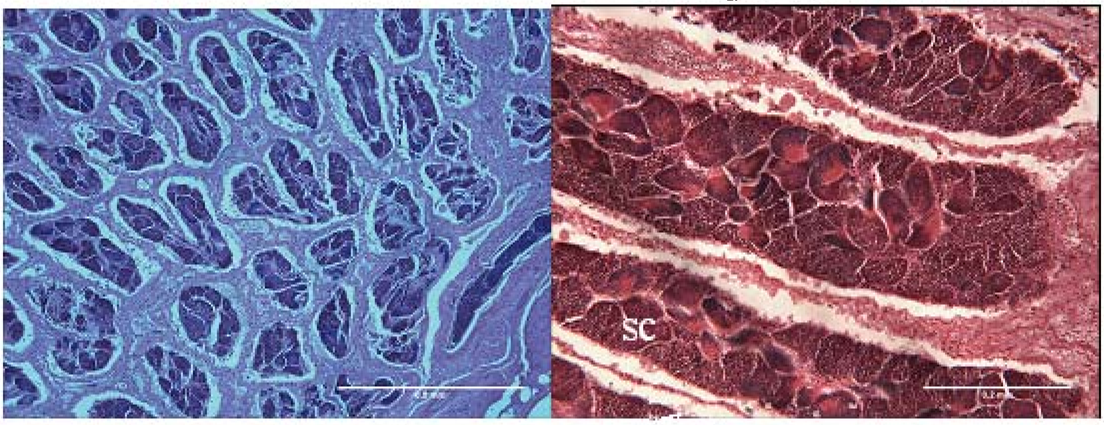
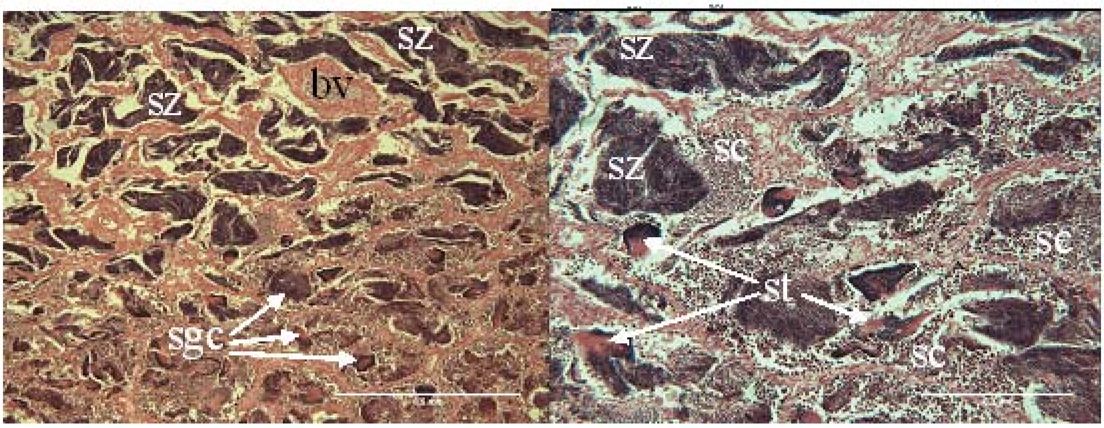
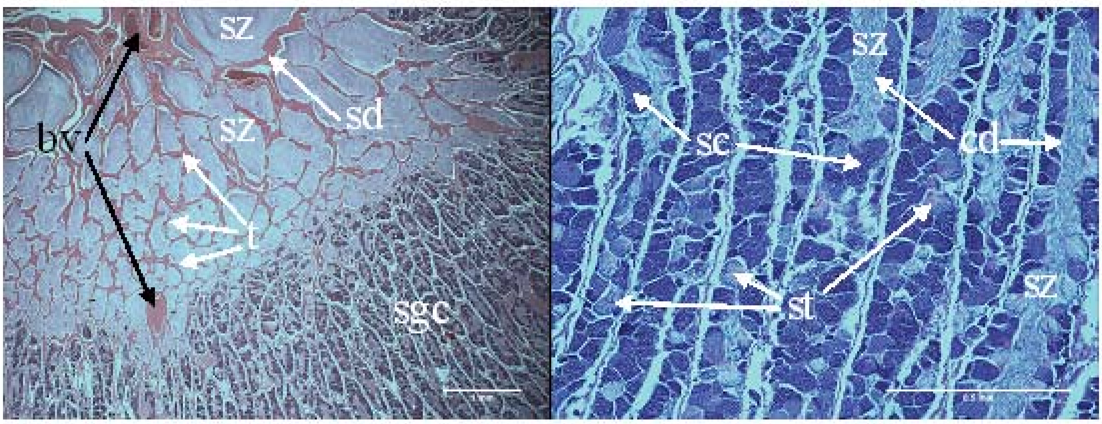


C.



D.



E.

F.

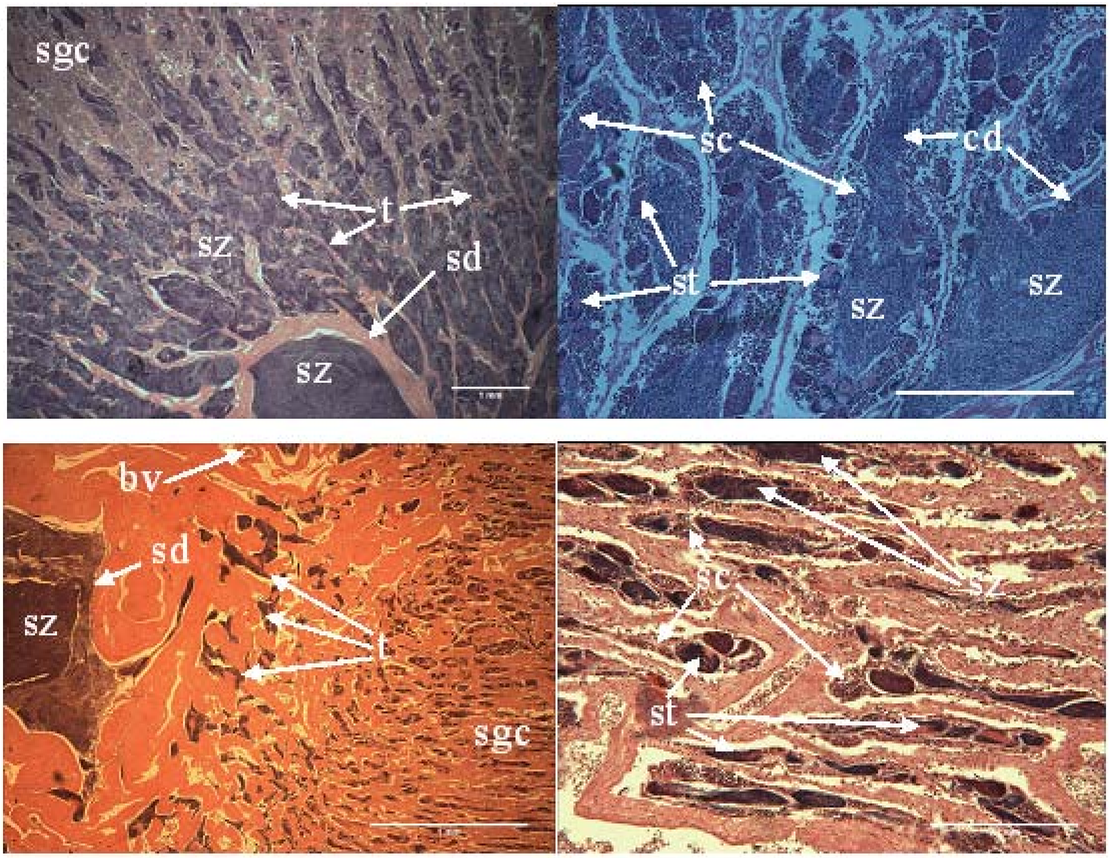


Figure 4.12. Histological sections of the development eastern Australian salmon testicular tissue according to the criteria outlined in Table 3.2: **A)** Stage 1 testis at x20 (left) and x40 (right) magnification showing spermatogenic germ cells, **B)** Stage 2 testis at x10 (left) and x20 (right) magnification showing spermatogenic cysts, **C)** Stage 2/3 testis at x10 (left) and x20 (right) magnification showing spatial organization of testis with spermatozoa in collecting ducts and spermatogenic cysts around the periphery, **D)** Stage 3 testis at x2 (left) and x10 (right) magnification, **E)** Stage 4 testis at x2 (left) and x10 (right) and **F)** Stage 5 testis at x4 (left) and x20 (right) magnification showing residual spermatozoa in collecting ducts, seminiferous tubules and sperm duct. Abbreviations: **bv**, blood vessel; **cd**, collecting duct; **sc**, spermatocytes; **sd**, sperm duct; **sg**, spermatogonia; **sgc**, spermatogenic cyst; **st**, spermatids; **sz**, spermatozoa; **t**, seminiferous tubule.

4.4. Discussion

Timing of reproduction

Eastern Australian salmon in S.E. Australia have a prolonged spawning season. Significant reproductive activity was evident through a 6 month period from the austral late spring to early autumn (October to March) with some minor activity also occurring in September and April. Fish with elevated GSIs and Stage 4 ('running ripe') gonads were recorded from the NSW coast from as far north as Coffs Harbour (~ 30º15'S) and south to Eden (~ 37ºS). The previous reported northern extent of spawning was some 740 km further south of Coffs Harbour, at Bermagui (~36º30'S: Stanley & Malcolm 1977). The observation of fish in spawning condition considerably further north than previously reported could be a result of a population range expansion. Alternatively, this could be simply because fish had not been sampled in northern NSW before (probably because the main distribution of the species was restricted to more southern waters when most previous work was done during the 1960s and 1970s). It is interesting to note that the spawning period is currently the same as that reported more than 40 years previously. This previous research on the reproductive cycles of eastern Australian salmon in NSW and eastern Victoria also reported spawning to occur between September and April (Malcolm 1966a, Stanley & Malcolm 1977). Spawning of eastern Australian salmon has also been reported to occur at approximately the same time of year in NZ (November–April/May: Hartill & Walsh 2005).

The latitudinal variation in ovarian and testicular development between fish collected from southern and northern NSW is consistent with previous work on this species in S.E. Australian waters. Stanley and Malcolm (1977) reported that increases in gonad weights began in December for fish from eastern Victoria, but one month earlier in November for fish from southern NSW. Such temporal variation in reproductive biology with latitude has been previously reported for several other fish species in S.E. Australian waters, including eastern sea and river garfish *Hyporhamphus australis* and *H. regularis ardelio* (Hughes & Stewart 2006), estuary perch *Macquaria colonorum* (Walsh *et al.* submitted), black bream *Acanthopagrus butcheri* (Sarre & Potter 1999) as well as for the congeneric western Australian salmon and Australian herring in south-western (SW) Australia (Malcolm 1960, Fairclough *et al* 2000). Spawning cycles in marine teleosts are closely linked with environmental variables, the most important of which are water temperature and photoperiod (Lam 1983, Bye 1990). The slight lag in gonad development with increasing latitude is thus likely to be a result of the slightly cooler water temperatures in southern NSW during the mid-late spring compared with those in northern NSW, which potentially provides the cue for gonad development. Nonetheless, the commencement of gonad maturation appears to correspond with the increased strength of the southward flowing EAC which brings warm (> 18ºC) water from the Coral Sea down the east coast of NSW reaching the north coast of NSW by September and southern NSW by October (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Warm water does not reach the Lakes Entrance area of eastern Victoria until December–January, which is also when the largest gonad weights were reported to occur in that region (Stanley & Malcolm 1977).

The spawning season in NSW waters was relatively consistent through the three spawning seasons sampled which suggests that gonad maturation and spawning are tightly regulated by an environmental cue (or cues). There was some evidence of multiple spawning peaks (via two GSI peaks) during the 2006/07 and 2007/08 spawning seasons, however these can be attributed to peak spawning in northern NSW occurring during October/November and in southern NSW during February/March. The fact that the ovarian development expected of eastern Australian salmon approaching spawning condition has not been observed in Tasmanian waters, even though substantial numbers of fish greater than size/age-at-maturity are present during the spawning season (Stanley & Malcolm 1977; Chapter 2), suggests that any such environmental cue(s) are not sufficiently strong to induce the full sexual maturation and spawning gonad development seen in mainland waters in Tasmania. It is relevant that during this period, average water temperatures around Tasmania (< 16ºC) are lower than those of mainland waters of Victoria and NSW (18 to 24ºC) where spawning does occur (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). It has been previously suggested for the closely related Australian herring in SW Australia that maturation of the gonads may depend on water temperatures remaining above a certain critical level (Fairclough *et al.* 2000). Our results, in addition to those of Stanley & Malcolm (1977), suggest that this critical water temperature may be ~ 18ºC for eastern Australian salmon.

The spawning period centred on the months of summer, which corresponds with the highest average water velocities recorded for the EAC (Ridgway & Dunn 2003). In summer, warm water from the Coral Sea flowing south down the coast of NSW into the Tasman Sea may reach surface water velocities of up to 5 knots and it has been suggested to aid the transport and dispersal of larval eastern Australian salmon southwards to the main nursery areas in Tasmania and along the S.E. coast of Victoria (Malcolm 1966a, Nicholls 1973, Stanley & Malcolm 1977). The evidence presented here for spawning activity occurring between October and March each year is supported by records of larval eastern Australian salmon up to 40 km offshore from Sydney between November and May (Gray 1995, Smith & Suthers 1999) as well as from eastern Tasmanian waters between March and May (Neira *et al.* 1997).

The back-calculated estimates of hatching dates of small juveniles sampled in Tasmanian waters are in accordance with the spawning period determined from the examination of gonadal development. Most back-calculated hatching dates for 0+ fish were between November and March, with a few fish estimated to have been born as late as the start of July. These dates suggest that, at least for the juveniles sampled, most were not derived from spawning which occurred off northern NSW during October. However, assuming passive transport of larvae and a conservative southward transport rate of 1.5 knots due to the EAC and related anticyclonic eddies, larval eastern Australian salmon would be capable of travelling ~ 1,500 km south in 27 days. It is therefore feasible that larvae spawned off Coffs Harbour (the northernmost location spawning has so far been recorded) could potentially reach the southern tip of Tasmania, ~ 1,580 km to the south, by the time it is ready to settle to its juvenile habitat. These calculations clearly do not take into account the influences of temporal and spatial variability in local oceanography or the behaviour of the larvae itself, but do demonstrate that recruits to S.E. Australian waters could have originated from spawning events considerable distances to the north.

A similar dispersal strategy has been suggested for the congenerics, western Australian salmon and Australian herring. After spawning in the SW corner of Western Australia (WA) between February and June each year, early life-history stages are dispersed eastwards into the Great Australian Bight to nearshore nursery areas in South Australia (SA) by the prevailing eastward flowing Leeuwin Current which flows most intensely between May and July, juveniles arriving in SA from July to September (Malcolm 1960, Cappo 1987, Fairclough *et al.* 2000). Indeed, it has been suggested that the differences in the timing of peak spawning within the genus *Arripis* are related primarily to ensuring the optimal dispersal of their larval and juvenile stages to their respective nursery areas (Fairclough *et al.* 2000).

Fecundity

Eastern Australian salmon are a highly fecund species, with BF ranging between 71,300 – 1,730,000 hydrated eggs per female in S.E. Australian waters; substantially higher than levels reported for this species from NZ waters (60,000 – 750,000: Hartill & Walsh 2005). BF in the related Australian herring is much lower, ranging from 32,000 to 207,000 eggs per female due to its smaller average size. However mean relative BF in Australian herring (473 eggs/g: Fairclough *et al.* 2000) was more than double that for eastern Australian salmon (205 eggs/g). Tailor *Pomatomus saltatrix*, a similar-sized pelagic species which fulfils a comparable ecological niche in S.E. Australian waters to that of eastern Australian salmon, possesses similar BF estimates (range

115,000 – 1,260,000 eggs: Robillard *et al.* 2008). Maximum BF for eastern Australian salmon is similar to or larger than values recorded for several other marine teleost species which grow to much larger sizes (e.g., skipjack tuna *Katsuwonus pelamis* ~1.4 million- Ashida *et al.* 2008, yellowfin tuna *Thunnus albacares* ~1.6 million- Schaefer 1996, cobia *Rachycentron canadum* ~2 million- Brown-Petersen *et al.* 2001, red snapper *Lutjanus campechanus* ~1.7 million- Collins *et al.* 1996, amberjack *Seriola dumerili* ~1.8 million- Harris *et al.* 2007, white marlin *Tetrapterus albidus* ~0.6 million- Arocha & Barrios 2009). The mean relative BF for eastern Australian salmon is also comparable with many other medium-sized pelagic species worldwide (e.g., blue mackerel *Scomber australasicus* 134 eggs/g- Rogers *et al.* 2009, Atlantic horse mackerel *Trachurus trachurus* 150 eggs/g- Abaunza *et al.* 2008, silver pomfret *Pampus argenteus* 176 eggs/g- Alamatar *et al.* 2004, *K. pelamis* 148 eggs/g- Ashida *et al.* 2008).

Although there were multiple identifiable batches of oocytes at various stages of development present in eastern Australian salmon ovary sections (see below), it was not possible to estimate how many spawning events an individual female was involved in during the spawning season. In order to estimate the spawning frequency of eastern Australian salmon, targeted short-term (daily) temporal sampling during the spawning season of females to identify the presence of post-ovulatory follicles (POFs) in ovaries using histological analyses would be required. The degenerative state of any identified POFs could then be used to estimate how recently spawning had occurred (Hunter & Macewicz 1983).

Overall, the relationship between BF and both size (FL) and age was exponential, which has been previously reported for Australian herring (Fairclough *et al.* 2000) and other temperate fish species (e.g., Oriental trumpeter whiting *Sillago aeolus* – Rahman & Tachihara 2005, amberjack – Harris *et al.* 2007, tailor – Robillard *et al.* 2008). This relationship highlights the potential enhancement to reproductive output of populations by the presence of large, old fish (e.g., Brooks *et al.* 1997, Parker 2006). In addition, older larger females also produce greater numbers of large eggs (Chambers *et al.* 1989, Zastrow *et al.* 1989, Chambers & Waiwood 1996, Kjesbu *et al.* 1996) which have also been suggested to result in greater post-hatching larval survival (Brooks *et al.* 1997, Berkeley *et al.* 2004, Parker 2006). The increased survival probability associated with the production of larger larvae from larger eggs has been shown to increase survival during periods of low food availability, produce larvae which are more competitive for food, and by virtue of their faster swimming speeds, may have a reduced risk of predation in the pelagic environment (Hutchings 2002).

Maturity

The population structure, distribution and life-history of eastern Australian salmon in S.E. Australia present substantial difficulties when sampling for estimation of life-history parameters. The overall movement northwards of fish with increasing age together with the lack of any reproductive development in fish from Tasmanian waters complicates any sampling designed to estimate the onset of maturity. Sampling larger fish from only southern waters will be biased towards immature individuals that have not yet commenced their northward migration. Such samples are akin to sampling outside of the spawning season in areas where spawning does occur and will therefore artificially increase the proportion of fish assessed as immature in the larger size and older age classes. Alternatively, sampling only from northern waters where there are relatively few small, young fish may bias the estimates of size and age at maturity in the opposite direction.

Data from the present study demonstrate that eastern Australian salmon in NSW waters typically reach maturity (L_{50}) at ~ 31 cm FL and (A_{50}) ~ 2.2 years with no differences between sexes or fish collected from northern and southern NSW. These sizes and ages are considerably smaller than those previously estimated for this species in the waters of both S.E. Australia (39 cm FL and 3.5 to 4 years: Stanley & Malcolm 1977) and NZ (39 to 40 cm FL and ~ 4 years: Hartill & Walsh 2005).

It is also substantially smaller than the estimate made from pooling the data from each state during the present study (L_{50} ~ 42 cm).

Stanley and Malcolm (1977) estimated their size-at-maturity of 39 cm FL based on observations that there was little variation in ovarian weight throughout the year in fish < 38 cm FL collected from Tasmanian waters only, despite the fact that spawning was not considered to occur in Tasmanian waters (Malcolm 1966a). Stanley and Malcolm (1977) did not sample fish smaller than 39 cm FL from waters anywhere in mainland Australia, despite the fact that the main spawning area was considered to be southern NSW and eastern Victoria (Malcolm 1966a). Had these investigators collected fish < 39 cm FL from mainland waters they may have observed the onset of maturity at a smaller size.

Acknowledging the difficulty in sampling such a species representatively, we are confident that the estimates of size (31 cm FL) and age (2 to 3 years) at 50% maturity are sensible only for NSW waters, where most spawning occurs. More detailed information on the relative abundance of any given age class in the spawning population is needed before a population estimate of the age at 50% maturity can be made. In addition, more work examining the cue(s) for the northwards migration of fish from Tasmanian waters and associated sexual maturation is needed to better describe this species life-history.

<u>Gonad histology</u>

The macroscopic staging criteria used throughout the year were confirmed by the description of microscopic features in histological analysis of sectioned gonads and allowed an accurate picture of the seasonal maturation of ovarian and testicular tissues for eastern Australian salmon to be developed.

Ovaries

Immature ovaries contained very small numbers of oogonia, but the principle constituents of the ovary were previtellogenic chromatin nucleolar and perinucleolar oocytes. These primary growth oocytes are the typical primary components of immature fish ovaries (Blazer 2002). Both oocyte types formed dense lamellae typical of teleosts and represented a reservoir of primordial previtellogenic primary growth oocytes (Tyler & Sumpter 1996) and were present in histological sections of all ovarian stages. Cortical alveoli were the first distinct cytoplasmic structures visible within the oocyte and first appeared in cortical alveolar oocytes in resting/developing ovaries and along with lipid droplets almost entirely filling the cytoplasm. Lipid droplets often begin to accumulate at the same time as the cortical alveoli in the oocytes of many marine fish species (DeVlaming 1983, West 1990). These droplets are involved in the formation of the large (0.24 – 0.28 mm dia.) oil globule seen in the freshly spawned ova of eastern Australian salmon (Neira *et al.* 1997).

Cortical alveolar oocytes were replaced as the dominant oocyte type by yolk granule oocytes in histological sections of maturing ovaries which mainly occurred prior to the spawning season. In the early stages of yolk-granule oocyte development, the cortical alveoli were still evident, but more prominent yolk granules or globules become apparent along with lipid droplets. Yolk-granule oocytes in the middle stage of development where most of the cytoplasm was filled with yolk globules with the cortical alveoli pushed to the periphery of the oocyte were apparent in some ripe ovaries. During final yolk-granule oocyte maturation, the yolk globules fused and appear as a hyaline homogeneous mass in running ripe ovary sections. The histological feature of the running ripe ovaries was the presence of hydrated oocytes. Hydration has been shown to be particularly pronounced in marine teleosts that broadcast-spawn pelagic eggs and the process ensures that the eggs are buoyant in seawater (Wallace & Selman 1981, West 1990). The simultaneous presence in running ripe ovaries of hydrated oocytes, yolk-granule oocytes, cortical alveolar oocytes as well as primary growth oocytes provides strong evidence that eastern Australian salmon in NSW possess asynchronous oocyte development and are multiple batch spawners (sensu DeVlaming 1983).

Post-ovulatory follicles, resulting from recent ovulation, were not observed in histological sections of spent ovarian tissue in this study, even though the ovaries exhibited macroscopic features which indicated them to be spent (Table 4.1: bloodshot, rubbery and flaccid). POFs have been shown to rapidly degenerate after ovulation and it has been estimated that POFs cannot be distinguished from atretic oocytes only 2 days after spawning in the northern anchovy *Engraulis mordax* (Hunter & Macewicz 1983), degeneration occurring even faster at higher water temperatures (Takita *et al.* 1983). Histological sections of spent eastern Australian salmon ovaries did, however, contain remnant yolk granule oocytes undergoing atresia confirming that such ovaries were indeed correctly identified as post-spawning. These atretic oocytes were obvious based on their irregular shape, the changed appearance of the yolk and the breakdown of the outer oocyte membranes; features which have been described for many other fish species (West 1990, Blazer 2002). Histological analysis of ovarian tissue at the commencement of post-spawning degeneration and resorption in western Australian salmon also failed to find POFs but did contain large numbers of atretic oocytes similar to the spent eastern Australian salmon ovaries presented here (Malcolm 1960). The lack of POFs indicative of recent spawning in the ovaries of fish collected as part of this study may simply be the result of our small sample size (n = 5) for histological analysis. Alternatively, spawning may occur off ocean beaches (e.g., around rocky headlands or in deep water), or at night. The vast majority of fish collected as part of this project were sampled from commercial catches taken in daylight, either directly from ocean beaches (beach hauling) or over sandy substrate close to shore (purse seining) where the fish are easy to see and catch (pers. obs.). Immediate post-spawning female fish with ovaries containing identifiable POFs may not therefore have been sampled in this work because they were not present close to shore during the day. In NZ spawning is thought to occur in open water close to the seabed as schools of eastern Australian salmon with running ripe ovaries have been reported from bottom trawls taken from water 60 – 100 m deep (Jones *et al.* 1992).

Testes

Each lobe of eastern Australian salmon testes could be divided into two distinct regions after histological preparation and microscopic viewing. The inner region of each testicular lobe section was dominated by numerous seminiferous tubules and the sperm duct which contained free spermatozoa (in mature males) whereas the periphery of each testicular lobe was made up of testicular tissue surrounding the developing germ cells in spermatogenic cysts. This marked gradient in spermatogenic development, with undifferentiated spermatogonia in the periphery of the lobe and the most advanced germ cells (spermatocytes, spermatids and spermatozoa) in the vicinity of the collecting duct, suggests a tight spatiotemporal organization of spermatogenesis similar to other teleosts with similar reproductive strategies (e.g., Atlantic cod *Gadus morhua*: Almeida *et al.* 2008).

The presence of spermatogonia as the predominant germ cell type in immature testes is typical of juvenile male teleosts (e.g., Grier & Taylor 1998, Blazer 2002, Almeida *et al.* 2008). During the rapid growth phase through developing/resting and maturing, the gradient in spermatogenic development becomes obvious with the periphery of the testicular lobe containing many spermatogonial generations including early spermatids (round) and spermatocytes, whereas late (elongated) spermatids and spermatozoa are more abundant nearer the collecting ducts. In eastern Australian salmon testes, all spermatids present in one cyst developed synchronously and presented the same shape. The origin of this spermatogenic gradient appears to be the peripheral rim of the testis lobe where new cysts with proliferating spermatogonia were forming. The continued addition of new spermatogonial cysts resulted in appositional growth of the testis lobe and displacement of the peripheral zone away from the collecting duct. The presence of spermatozoa in maturing testes is not surprising given that they occur mainly in the months leading up to spawning, however spermatozoa were present in developing/resting ovaries which occur mainly during the non-spawning part of the year.

In ripe and running ripe testes, the separation of the peripheral zone and the region of the collecting duct becomes most accentuated with large amounts of mature spermatozoa present in seminiferous tubules and the sperm duct indicative of imminent spawning activity. The size of the peripheral zone of spermatocytes and spermatids also became progressively smaller in the development of ripe to running ripe testes until all spermatogenic cysts containing spermatids had reached the spermiation stage where spermatozoa are released into the tubular lumen and the entire testis lobe filled with spermatozoa in a maturational wave proceeding from the central collecting duct region towards the periphery. With the spawning associated release of sperm, spent testes showed histological characteristics typical of regressed testes containing only small numbers of spermatogenic cysts along with residual sperm being progressively removed by Sertoli cells in the lobular lumen (Blazer 2002, Almeida *et al.* 2002). Histological analysis of western Australian salmon testicular tissue undergoing degeneration of spermatogenic products was very similar to that of eastern Australian salmon testes estimated to be spent in the present study, consisting of few spermatocytes and spermatids along with residual spermatozoa in tubules (Malcolm 1960).

<u>Oocyte size frequency</u>

The distributions of oocyte diameters in the present study confirm that eastern Australian salmon possess asynchronous oocyte development and a multiple spawning strategy during the spawning season. It was possible to follow the development of a single batch of ova from maturation through to ovulation. In actively spawning ovaries (running ripe), the size frequency distribution was virtually continuous from the primordial population of primary oocytes through several smaller modes representing oocytes in various stages of vitellogenesis to a population undergoing hydration in preparation for ovoposition (Wallace & Selman 1981, Tyler & Sumpter 1996). The size frequency of oocyte diameters of spawning eastern Australia salmon was similar to that of the other Australian members of the family Arripididae, western Australian salmon and Australian herring; both of which possess multiple modal peaks during the spawning season and have been shown to be multiple batch spawners with asynchronous oocyte development (Malcolm 1960, Fairclough *et al.* 2000).

By far the most numerous oocytes (< 0.1 mm dia.), present in ovaries of all reproductive stages, was the reservoir of primary growth oocytes, most likely perinucleolar and chromatin nucleolar oocytes. The increased numbers of oocytes with diameters > 0.1 mm seen in developing/resting fish were likely to be cortical alveolar oocytes resulting from the commencement of vitellogenesis in these ovaries. In maturing ovaries, the mode of primary oocytes > 0.1 mm dia. became less numerous as more oocytes within the ovary began to commence vitellogenesis resulting in the increased numbers of oocytes evident between 0.2 and 0.6 mm dia.. This group of oocytes were likely primarily cortical alveolar oocytes as well as developing yolk granule oocytes which had formed from the cortical alveolar oocytes first evident in developing/resting ovaries. In ripe ovaries, the continued development of cortical alveolar oocytes into partial and completely yolked oocytes resulted in the broad mode of oocytes between 0.3 and 0.7 mm dia. in November–April. Oocyte diameters of 0.5 – 0.7 mm were also recorded during this time period by Stanley & Malcolm (1977) for in the region north of Bermagui. The largest diameter oocytes (0.7 – 0.9 mm) seen in the ovaries of ripe fish represented actively hydrating, or already hydrated oocytes, ready to be spawned. Freshly extruded eastern Australian salmon ova have previously reported to be 0.8 – 0.9 mm dia. (Stanley & Malcolm 1977), similar to the sizes of the largest preserved oocytes presented here.

5. MORTALITY AND PER RECRUIT ANALYSES

OBJECTIVES ADDRESSED

This chapter addresses objective 3 of the original Project No. 2006/018 to "Develop yield per recruit and spawner-biomass per recruit models at present levels of fishing mortality".

5.1. Introduction

Information on the harvestable yield per fish in a population (yield per recruit or YPR) is useful in managing the efficient exploitation of fish stocks. Likewise, the spawning stock biomass per recruit (SSB/R) is a proxy for the expected reproductive potential of an average recruit (Goodyear 1993). Related to this, the spawning potential ratio (SPR) is an index of the reproductive health of an exploited population and can be calculated by dividing the fished SSB/R by the unfished SSB/R (Goodyear 1993). Threshold levels of SPR to ensure population persistence have been examined by Mace & Sissenwine (1993) with the conclusion that larger demersal fish like gadoids can persist at relatively low levels of SPR, while smaller demersal species and pelagic species require relatively high levels of SPR to ensure population replacement. The recommended conservative threshold level of SPR for species for which the stock-recruitment relationship is unknown is 0.30 (Mace & Sissenwine 1993).

Such per recruit analyses can be useful for fisheries managers when attempting to maximise yield from a stock and when assessing the effect on this yield of varying the size/age at first harvest and fishing effort. The SSB/R and SPR analyses can provide information on the sustainability of stocks under different management scenarios. Therefore, the aim of this chapter was to calculate estimates of YPR, SSB/R and SPR for eastern Australian salmon across its distribution and under current fishing levels to help in assessing management arrangements for this stock.

5.2. Materials and methods

5.2.1. *Estimation of mortality rates*

Estimates of total mortality (Z) were made from the slope of the descending limb of the catch curve (i.e., by fitting a regression to the natural logarithm of age frequency against age for all fully recruited age classes), unless otherwise stated. The method assumes constant recruitment and survival for all cohorts.

Estimates of natural mortality (M) were made using three independent methods. The first was based on the maximum reported age using the method of Hewitt & Hoenig (2005) which assumes that 1.5% of a stock will survive to the maximum age. The maximum age was taken to be 12 years (Chapter 3). A second estimate of M was made using the approximation of Jensen (1996) that estimates M as 1.5 times the von Bertalanffy growth function parameter k. A third estimate of M was made using the method of Pauly (1980) based on the relationship between M, growth and water temperature. The growth parameters were as defined in Chapter 3 (L_∞ = 63.2 cm FL, k = 0.25 yr^{-1}) and water temperature was estimated to be between 15 and 20°C based on mean annual water temperatures between Tasmanian and central NSW (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html), and also the temperatures used for consumption rate analyses (Chapter 7).

Estimates of fishing mortality (*F*) were made by subtracting the estimates of *M* from *Z*.

5.2.2. Per recruit analyses

YPR and SSB/R analyses were done using the information on growth and mortality rates for eastern Australian salmon derived during the present study. The method used was based on that of Beverton & Holt (1957) and assumes that: *M* is constant for all ages after recruitment; (ii) *F* is constant after the age at first capture; (iii) recruitment is constant, and; (iv) the fish are a closed population. The analyses were done assuming knife-edge recruitment at the most likely ages of full recruitment (assumed to be ages 2 or 3 based on the age composition data from each state – Chapter 2). We used a range of values for *M* and *F* (based on the mortality rates estimated above). Growth of fish was estimated using the growth parameters in chapter 3 (L_∞ = 63.2 cm FL, k = 0.25 yr^{-1}, t_o = -0.14 yr) and the length/weight relationship was given by:

Weight = 0.0192 x FL $^{2.9666}$

where weight is kg and FL is cm.

Sexual maturity was related to FL according to the logistic relationships described in Chapter 4, with L_{50} being either 31.0 cm FL (NSW) or 42.0 cm FL (all states combined).

SPR was calculated by dividing the SSB/R for any value of *F* by the estimated SSB/R value for the unfished stock (Goodyear 1993).

5.3. Results

5.3.1. Mortality rates

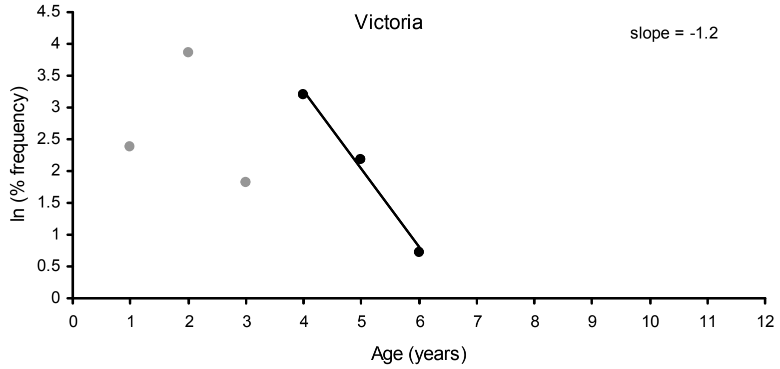
Estimates of the instantaneous rate of total mortality (*Z*) from catch curves ranged between 1.0 and 1.5 (Fig. 5.1). The catch curves were fitted to ages 3 to 6 years for Tasmania, 4 to 6 years for Victoria, 5 to 10 years for southern NSW and 7 to 12 years for northern NSW. Age 4 was chosen as the first age class for the catch curve in Victoria, despite age 2 being the most abundant, because it was considered more precautionary given the very small sample sizes in that state that may have been biased towards young fish.

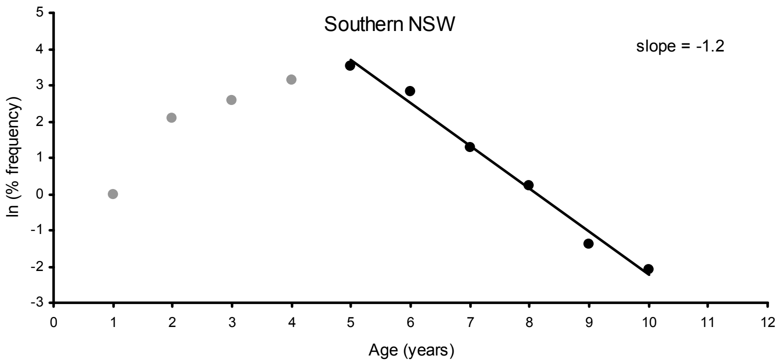
Estimates of natural mortality (*M*) ranged between 0.35 (based on 1.5% of fish attaining a maximum age of 12 years – Hewitt & Hoenig 2005) and 0.50 (based on the relationship between M, growth and water temperature – Pauly 1980) (Table 5.1).

Table 5.1. Estimates of natural mortality (*M*) for eastern Australian salmon.

Method	Parameter	*M*
Hewitt & Hoenig 2005	t_{max} = 12 yr	0.35
Jensen 1996	k = 0.25 yr^{-1}	0.38
Pauly 1980	Temp. = 15°C	0.44
Pauly 1980	Temp. = 20°C	0.50

Estimates of *F* (= *Z* – *M*) therefore ranged between 0.5 and 1.15.





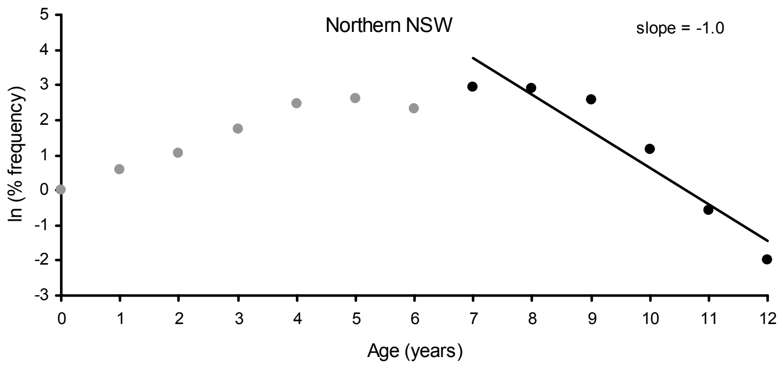


Figure 5.1. Catch curves for eastern Australian salmon from Tasmania, Victoria, southern NSW and northern NSW. Gray symbols represent age classes prior to the most abundant, black symbols represent those age classes that were used for catch curves.

5.3.2. *Per recruit analyses*

YPR analysis showed that, calculated using knife-edged selectivity to the fishery at age 2 years, as F increases the YPR also increases, except for when $M = 0.35$ (Fig. 5.2). When age at recruitment is 3 years the YPR increases with F for all estimates of M.

Regardless of the age at recruitment to the fishery, the SSB/R and SPR decline rapidly as F increases (Fig. 5.2) under all scenarios. Under the current range of probable F values (0.5 to 1.15), the SPR ranged between 0.12 and 0.32 for recruitment at age 2, and between 0.26 and 0.48 for recruitment at age 3 if the L_{50} is 31 cm FL. The SPR ranged between 0.05 and 0.21 for recruitment at age 2, and between 0.13 and 0.34 for recruitment at age 3 if the L_{50} is 42 cm FL.

5.4. Discussion

The estimates of mortality rates for eastern Australian salmon are uncertain and should be treated with caution. The standard approach of using cross-sectional catch curves to estimate Z assumes a closed population (i.e., there is no immigration or emigration), constant mortality for all age classes, constant vulnerability (i.e., the availability and catchability for all age classes on the descending limb of the catch curve is constant), and that recruitment is constant. It is probable that all of these assumptions are violated for eastern Australian salmon. The major bias may result from the life-history of this species whereby fish progressively move northwards with increasing age, resulting in emigration of older individuals from discrete sampling areas and immigration into others. Catch curves based on samples with this bias typically have convex descending limbs and this is evident in the catch curve from Tasmania. In addition, catch curves based on older age classes that have partially emigrated from a sampling area will over-estimate Z. The values of Z for eastern Australian salmon in the present study (1.0 to 1.5) may therefore be over-estimates. However, the catch curve for fish from northern NSW (Z = 1.0) should provide a reasonable estimate of Z on the terminal age classes in the population. It should be noted, however, that mortality on these older (7 to 12 years) age classes will be much less than on the younger age classes because commercial fishers in northern NSW are substantially restricted in their targeting of this species. The way to overcome violation of the assumptions of catch curve analysis would be to obtain an age composition that is representative of the population as a whole, rather than in discrete portions of its distribution. Obtaining such a representative sample, given the life-history and population structure of eastern Australian salmon, is difficult. Nevertheless, given these caveats, the range of Z between 1 and 1.5 is certainly plausible. In fact, the only previous estimate of Z for this stock (Z = 1.4) is from Stanley (1978) who analysed tag/recapture rates during the1960s.

The estimates of M (0.35 to 0.5) in the present study were slightly inconsistent with previous estimates for this species. Stanley (1978) estimated M to be higher (between 0.5 and 1) based on tag/recapture rates. Estimates of M for this species in New Zealand are generally lower than those during the present study and have been summarized by Hartill & Walsh (2005). They concluded that M was likely to fall between 0.18 and 0.25 based on a range of studies and methods of estimation. The uncertainty in estimating M is incorporated in the per recruit analyses by using a range of values between 0.35 and 0.45.

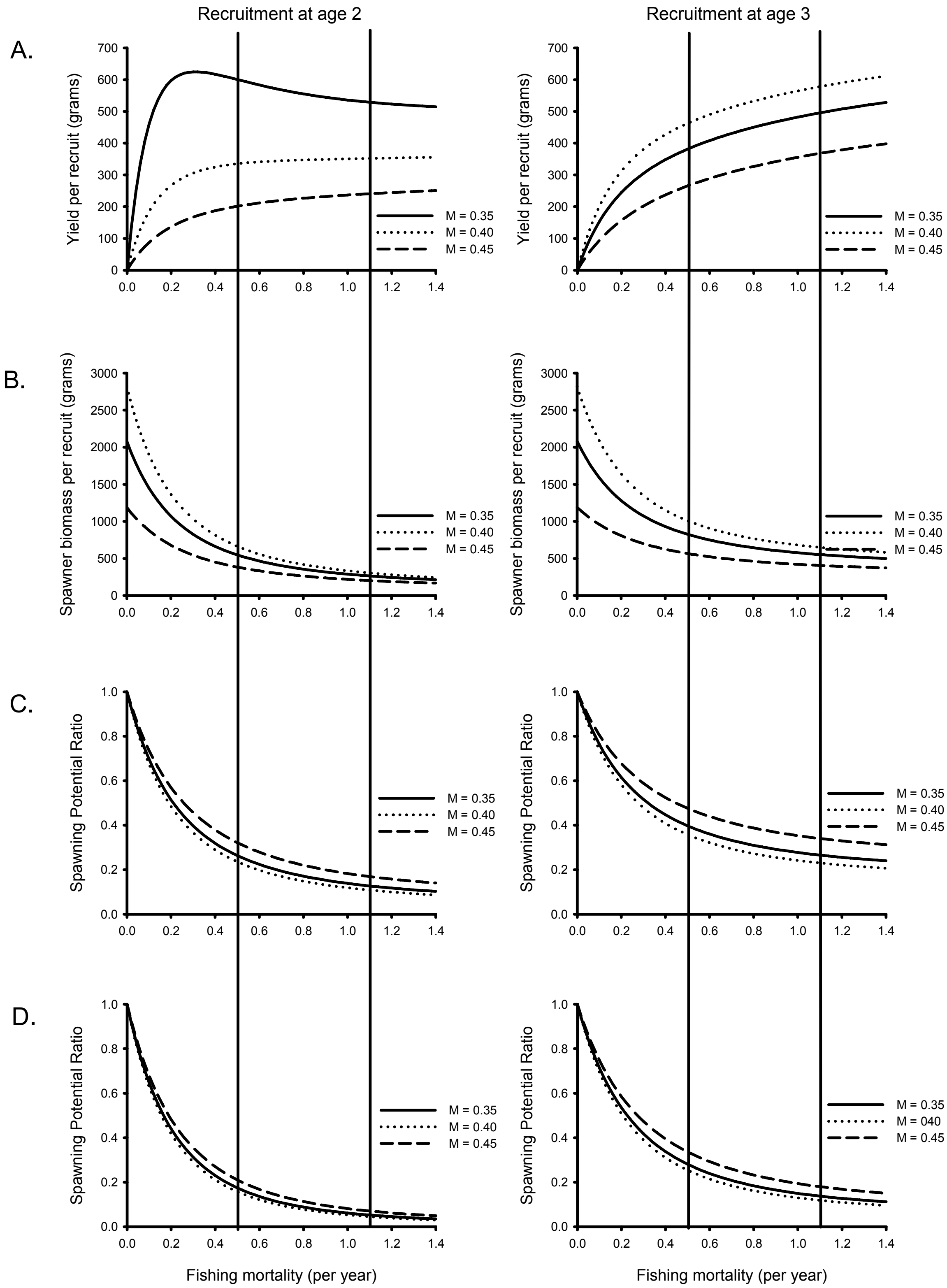


Figure 5.2. Yield per recruit (A.), spawner biomass per recruit (B.) and spawning potential ratio (C. & D.) versus fishing mortality for eastern Australian salmon under a range of natural mortality estimates, knife-edge recruitment at ages 2 and 3 years and a size at 50% maturity of 31 cm (B. & C.) and 42 cm (D.) fork length. The vertical lines represent the current estimates of fishing mortality.

The YPR analyses showed that yield would increase with increasing fishing mortality under most scenarios. However, the most precautionary scenario examined (age at full recruitment of 2 years and $M = 0.35$), showed slight declines in yield with increasing fishing. Stanley (1978) also used simple YPR calculations and concluded that greater yields could be achieved by increasing F from the estimated range of 0.3 to 0.7 during the 1960s. Given the large uncertainty in our mortality estimates, and the fact that our estimates of F range up to 1.15 (much greater than during the 1960s – Stanley 1978) the more precautionary assessment for eastern Australian salmon in S.E. Australia at present is that any increases in F are unlikely to produce increases in yield.

YPR analysis does not consider stock sustainability, as reproduction is ignored. The SPR estimates in the present study based on an L_{50} of 31 cm FL ranged between 0.12 and 0.48, bracketing the conservative threshold level of SPR for species for which the stock-recruitment relationship is unknown (0.30: Mace & Sissenwine 1993). The stock-recruitment relationship for this species is unknown and a precautionary threshold SPR of 0.30 may therefore be appropriate. However, the SPR estimates based on an L_{50} of 42 cm FL were well below 0.30 under all scenarios except when $M = 0.45$ and an age at recruitment of 3 years (SPR = 0.34). The L_{50} for salmon remains unresolved because of the latitudinal variation in reproductive activity (Chapter 4), however it will be between the estimates of 31 cm and 42 cm FL used here. The higher estimate (42 cm FL) is almost certainly unrealistically large. The uncertainty concerning the size (and age) at which salmon mature, in association with the large uncertainty surrounding the mortality estimates, means that these SPR calculations should be interpreted cautiously. Given the excessive fishing mortality under some scenarios, it would be prudent to regularly monitor the status of the spawning biomass and recruitment levels. It should be noted that there have been no signs of declines in the spawning stock of salmon in S.E. Australia, nor in recruitment levels of juveniles. In fact most indications are that the spawning stock has increased substantially in recent years (Chapter 2).

6. STOCK STRUCTURE

OBJECTIVES ADDRESSED

This chapter addresses objective 1 of the original Project No. 2006/018 to "Determine whether eastern Australian salmon comprise a single stock along S.E. Australia".

Also see publication as Appendix 4 – Hughes, J.M., Stewart, J., Gillanders, B.M., and Suthers, I.M. In press. An examination of the population structure of the eastern Australian salmon (*Arripis trutta*) stock in south-eastern Australia. Proceedings of the International Symposium on Advances in Fish Tagging and Marking Technology. February 2008, Auckland, New Zealand. Transactions of the American Fisheries Society.

6.1. Introduction

Previous research done in the 1960s suggested that eastern Australian salmon comprised a single stock distributed throughout the coastal waters of Tasmania, New South Wales (NSW) and eastern Victoria; however the degree of mixing within this stock was unknown (Stanley 1978). This single stock conclusion was based on observations of the movement of tagged fish along with a latitudinal gradient of increasing fish size, age and reproductive activity from south (Tasmania) to north (NSW) (Nicholls 1973, Stanley & Malcolm 1977, Stanley 1978, Chapter 2). This distribution is hypothesized to be partly driven by a size/age specific migration pattern where a one-way migration of juveniles from Tasmania across Bass Strait occurs with the onset of sexual maturity at 39 cm FL/~ 4 years old (Stanley & Malcolm 1977, Stanley 1980). No evidence of spawning was observed in Tasmanian waters and it was concluded that the juvenile salmon observed in these waters originated elsewhere, probably between approximately Lakes Entrance and north of Bermagui (Stanley & Malcolm 1977) advected there by the southward flowing East Australian Current (EAC) (Nicholls 1973, Stanley & Malcolm 1977, Kailola *et al.* 1993, Chapter 3).

The issue of how best to manage eastern Australian salmon has been discussed for several decades. Work done in the 1960s (Stanley 1978) concluded that the stock was under-utilized. Expansion of markets, including the salmon cannery in Eden, resulted in increased landings during the 1970s until the late 1990s (Chapter 1), when the cannery closed and the market declined. There remains the potential for increased markets overseas (Wilson & McCallum 2001); however these have yet to be developed. A national workshop to determine research priorities for the genus *Arripis* was held in Adelaide in 1995, and highlighted the almost total lack of information available on which to manage this species. In particular, managers highlighted the need for information on stock structure so as to develop a model to manage salmon across the three state jurisdictions over which they occur. More recently, the increased abundance and northern distribution (into Queensland waters: Green 2005) of salmon has raised concerns regarding their management. These concerns have been exacerbated because of the decision to make salmon a recreational only species in NSW north of Barrenjoey Headland in 2001, with commercial fishers being limited to a 100 kg/day bycatch limit.

Arripidids are a highly mobile family of fishes all of which undertake extensive migrations of up to thousands of kilometres in length motivated by life-history, reproductive or seasonal cues (Malcolm 1959, Stanley 1978, Cappo *et al.* 2000, Ayvazian *et al.* 2004). The physical and chemical characteristics of the different water bodies encountered by fish migrating over large distances are likely to vary. Specific trace elements present in the environment of fish are incorporated into the growing surface of their otoliths and these can reflect the ambient environmental conditions of the water in which fish reside (Fowler *et al.* 1995a, b). Since fish that spend at least part of their lives in different water masses often produce otoliths of different elemental composition, the otolith elemental composition (or 'elemental fingerprint') can serve as an environmentally induced tag for different groups of fish (Campana *et al.* 2000). This technique has become increasingly popular and extensively used over the past 20 years for examining movement patterns and distinguishing among populations and stocks of many fish species throughout the world (e.g., Edmonds *et al.* 1989, Campana & Gagné 1995, Campana *et al.* 2000, Daverat *et al.* 2005, McCulloch *et al.* 2005, Tzeng *et al.* 2005).

The aim of this chapter was to use a multi-faceted approach utilising a combination of methods to assess the stock structure of eastern Australian salmon and determine whether eastern Australian salmon should be managed as a single stock. These included analysis of otolith microchemistry and physical morphometrics (otolith shape and fish size-at-age) between various locations. In addition, an analysis of historical (1960s) and current (NSW Gamefish) tagging data was done to examine patterns of movement.

6.2. Materials and methods

6.2.1. Otolith microchemistry

6.2.1.1. Sample collection and experimental design

Eastern Australian salmon were collected during a seven week period in 2007 (March 30 to May 16) by commercial and recreational fishers from NSW, Victoria and Tasmania using beach haul nets, purse seine nets or trolling. A subsample (n = 12 to 89) of fish was taken from each catch and frozen. The age of each fish collected was estimated by counting opaque increments in otolith sections (see Chapter 3). Five fish estimated to be four years old (Table 6.1) and ten fish estimated to be five years old (Table 6.2) were randomly chosen from each of two randomly chosen sites (separated by km to tens of km) from each of four locations: northern NSW (NNSW), southern NSW (SNSW), Victoria and Tasmania (Fig. 6.1; Tables 6.1 & 6.2). It was possible to get four year old fish from only one site in northern NSW (Table 6.1). Selecting fish from the same age class (i.e., four or five year olds) for comparisons was done to ensure that the fish had been alive for the same period and minimised the possibility of a confounding temporal influence on spatial comparisons (Fowler *et al.* 2005).

Figure 6.1. Locations of samples taken for analysis of otolith microchemistry.

Table 6.1. Details of capture sites and times, fishing gears used and lengths (mean ± S.E.) for four year old Australian salmon. *n* is sample size, FL is fork length.

Location	**Site**	**Latitude, Longitude**	**Month 2007**	***n***	**Gear**	**FL (cm)**
Northern NSW	Stockton Beach	32º 49’ S, 151º 54’ E	May	5	Beach haul	43.58 ± 0.39
Southern NSW	Bermagui	36º 25’ S, 150º 05’ E	April	5	Purse seine	45.55 ± 0.61
	Eden	37º 04’ S, 149º 54’ E	March	5	Trolling	45.96 ± 1.13
Victoria	Lakes Entrance	37º 52’ S, 147º 59’ E	May	5	Purse seine	43.32 ± 0.73
	Pettmans Beach	37º 49’ S, 148º 11’ E	April	5	Purse seine	44.84 ± 1.46
Tasmania	Babel Island	39º 56’ S, 148º 19’ E	April	5	Purse seine	41.34 ± 1.28
	Flinders Island	39º 56’ S, 148º 12’ E	April	5	Purse seine	40.40 ± 1.45

Table 6.2. Details of capture sites and times, fishing gears used and lengths (mean ± S.E.) for five year old Australian salmon. *n* is sample size, FL is fork length.

Location	Site	Latitude, Longitude.	Month 2007	*n*	Gear	FL (cm)
Northern NSW	Stockton Beach 1	32º 49' S, 151º 54' E	May	10	Beach haul	44.84 ± 0.62
	Stockton Beach 2	32º 49' S, 151º 54' E	May	10	Beach haul	46.90 ± 0.32
Southern NSW	Bermagui	36º 25' S, 150º 05' E	April	10	Purse seine	46.65 ± 0.75
	Eden	37º 04' S, 149º 54' E	April	10	Purse seine	49.09 ± 0.71
Victoria	Lakes Entrance	37º 52' S, 147º 59' E	May	10	Purse seine	45.24 ± 0.58
	Pettmans Beach	37º 49' S, 148º 11' E	April	10	Purse seine	45.69 ± 0.66
Tasmania	Babel Island	39º 56' S, 148º 19' E	May	10	Purse seine	45.06 ± 0.42
	Flinders Island	39º 56' S, 148º 12' E	April	10	Purse seine	40.65 ± 0.97

6.2.1.2. Sample preparation and analysis

All fish collected were frozen for at least 24 hours before being defrosted and dissected. The sagittal otoliths were removed using Teflon-coated forceps and cleaned in Milli-Q deionized water. Otoliths were air dried overnight and stored in plastic 1.5 mL microcentrifuge tubes. One otolith from each fish was embedded in indium spiked (~30 ppm) two-part epoxy resin (Struers Epofix) and a ~ 300 µm thick section was taken through the core perpendicular to the long axis of the otolith using a slow speed saw (Buehler Isomet) and two spaced diamond blades. The blades were lubricated in Milli-Q water and each otolith section was then polished using 9 µm lapping film and Milli-Q water. Sections were then fixed to a glass microscope slide in random order (up to 14 sections per slide) using indium spiked (~200 ppm) thermoplastic glue (Crystalbond 509) and sonicated for five minutes in an ultrasonic cleaner (Unisonics Australia FXP4). Slides were allowed to dry overnight in a laminar flow cabinet before being transferred into individual clean sealable plastic bags prior to analysis.

Salmon otoliths were analysed using a New Wave Nd Yag 213 nm UV laser operated in Q-switch mode connected to an Agilent 7500cs inductively coupled plasma-mass spectrometer (ICP-MS). The laser was operated at a frequency of 5 Hz and 65% power. To determine detection limits, the chamber gases were analysed without any sample present for 30 s prior to the commencement of ablation. Otolith sections were ablated in a sealed chamber and ablated otolith material was transported in an argon and helium carrier gas stream to the ICP-MS. A reference standard (NIST 612, National Institute of Standards and Technology) was analysed at the beginning and end of each session and periodically throughout the session to correct for mass bias and instrument drift. Concentrations of each element analysed (Lithium-7 (Li), Sodium-23 (Na), Magnesium-25 (Mg), Manganese-55 (Mn), Strontium-88 (Sr) and Barium-138 (Ba)) were standardised to Calcium-43 (Ca), by expressing concentrations of elements as ratios to Ca.

Two approaches were used for analysis of otolith chemistry. Firstly, for all otolith sections, both the core region and outer edge were ablated by the laser using a 30 µm diameter spot. The core region represented juvenile otolith growth and the outer edge represented otolith growth immediately prior to collection. Secondly, otolith chemistry information was also collected from otolith sections from the five year old fish using transect analysis. The laser was programmed to follow a transect path across the otolith section from the core region to the outer edge of the otolith at a scan speed of 3 µm/s. Each transect ablated a 30 µm wide track along the ventral edge of the sulcus. Prior to ablation, a 100 µm width pre-ablation transect was used to clean the transect path of any surface contamination. This axis was chosen because the incremental microstructure of the otolith was well defined along this axis and was also roughly perpendicular to the axis of sampling making it easy to relate chemical composition to age (Fowler *et al.* 2005). The sequential data for each otolith transect were smoothed with a 9-point running median, followed by a 9-point running mean as described in Sinclair *et al.* (1998).

The elemental concentration profiles for each element were matched to fish age using otolith annuli as temporal references. After each otolith was analysed, a digital image of the ablated transect was captured and the distances between, and widths of, each annulus, were measured along the transect. The temporal reference points along each transect and 6 corresponding life history stages for each five year old fish analysed were as follows: increment 0- from the start of the transect to the inner edge of the first annulus, increment 1- from the inner edge of the first annulus to the inner edge of the second annulus, increment 2- from the inner edge of the second annulus to the inner edge of the third annulus, increment 3- from the inner edge of the third annulus to the inner edge of the fourth annulus, increment 4- from the inner edge of the fourth annulus to the inner edge of the fifth annulus, and increment 5- from the inner edge of the fifth annulus to the edge of the otolith. The elemental transect data were then simplified by calculating a mean from the elemental data for each stage of the fishes life. Therefore, for each otolith analysed, there was a series of six means for each element relating to each stage in the life history of the fish.

6.2.1.3. Statistical analyses

Spot analysis

Univariate analyses of variance (ANOVA) were used to determine whether elemental compositions (Li, Na, Mg, Mn, Sr, Ba) varied between the core and edge of the otolith as well as between sites and/or locations. For five year old fish, three-factor ANOVAs treated 'Core/Edge' as fixed, and 'Site' as a random factor nested within 'Location'. As the experimental design for four year old fish was unbalanced (only one site in northern NSW), two-factor ANOVAs treated 'Core/Edge' as fixed, and 'Site' as a random factor. If data were heterogeneous (Cochran's C-test, $p < 0.05$) data were Ln(x+1) transformed. Where significant differences were detected ($p < 0.05$), means were compared using Student-Newman-Keuls (SNK) tests to determine where the differences occurred.

Discriminant analysis was used to determine whether significant differences in elemental 'fingerprints' or 'signatures' for all elements combined were found among locations, and if significant differences were found then the variables contributing to the differences were ascertained. Discriminant function analysis (DFA) was used to determine the ability of elemental signatures to correctly assign fish to their collection locations. Backward stepwise functions were determined in SYSTAT (Point Richmond, CA) and then used to classify fish to groups using a jackknifed method with prior probabilities of group membership being equal. The accuracy of classifications to these groups was determined as the percentage calculated to be correct. This analysis was done separately for both the core region and outer edge of the otoliths of both four and five year old fish.

Transect analysis

Multivariate analysis of the elemental 'signature' for all elements combined for each year of the fishes life (increment) was done using a 'factor-analytic' (FA) approach where significant variation between sites was identified by reducing the differences between sites to the smallest number of factors possible (i.e., the factor(s) describing the main differences between the sites). The FA approach used here was a way of parameterising the variation between sites using the smallest number of parameters. The underlying factor was represented as a factor score; factor loadings were then used to create a variate which was plotted and graphically used to examine differences between the elemental signatures of fish between sites for each increment in turn. In order to obtain a measure of uncertainty (95% confidence intervals – C.I.s) for each of these factor scores and averaged factor scores, a bootstrapping technique was used where the original data was re-sampled 200 times and the analysis repeated on each of these datasets by sampling fish with replacement from each site in turn. Non-overlapping 95% C.I.s indicated significant differences in the elemental fingerprints of fish collected from between sites for a given increment.

Since there were six variates (elements) in the multivariate analysis, estimating all specific variances and covariances in a FA model required 7 × 6/2 = 21 parameters. The following FA models were therefore fitted both with (a) and without (b) the specific variances:

- A null model (Null) with no site effects,
- A first order FA parameterization model (1) which assumed there was only one underlying factor explaining the variation between sites for each year of the fishes life, involving either an additional six or 11 extra parameters, depending on whether specific variances were fitted (1a) or not (1b),
- A second order FA parameterization model (2) which assumed there were two underlying factors explaining the variation between sites for each year of the fishes life, involving either an additional 12 or 17 parameters, depending on whether specific variances were fitted (2a) or not (2b), and
- An unstructured (US) model where all specific variances and covariances were fitted, involving an additional 21 parameters.

In order to determine which model adequately explained the variation using the minimum number of parameters, likelihood ratio tests (LRTs) were used to compare nested models. The likelihoods for the different models were presented compared to the null model by calculating twice the difference in the likelihoods and comparing this to a χ^2 distribution with c degrees of freedom, where c is the extra number of parameters.

The use of a 'factor-analytic' breakdown was implemented as described in Thompson *et al.* (2003). All models were fitted using the mixed model software package ASReml (Gilmour *et al.* 2008). All other calculations and data manipulations were performed using the R statistical package (R Development Core Team 2008).

Note that the initial approach was to attempt to characterise the variation in otolith chemistry of fish collected from eight sites from throughout S.E. Australia, rather than between a fixed factor "location"; related to the region of S.E. Australia where the fish were collected. We chose this approach so as to avoid the imposition of an artificial structure on the data by nesting sites within locations which could obscure the detection of important differences between sites. Nonetheless, when multi-variate FA analyses failed to find significant differences between sites within a location, further analyses were done on pooled data for both sites from each location. The null hypothesis was that the elemental fingerprint did not differ over the life of the fish between the sites/locations where they were collected.

In order to satisfy the assumptions of normality and homogeneity of data for each element, a stabilising transformation was used. Where required, a displaced logarithmic transformation of the form "log (x + *c*)" where c is a constant was applied to the data. The constant *c* was chosen, where appropriate, to render the residuals displayed in a normal QQ plot to lie as close to a straight line as possible, and, if not, to at least obtain a symmetric distribution of residuals. The ultimate objective of the transformation was to stabilise the variation and make the residuals as normal as possible in order to reduce any excessive influence of individual data points on the results.

6.2.2. Otolith shape

Otoliths from the samples collected for analysis of otolith microchemistry were also used to compare various indices of shape between locations. The analyses were done only on those fish aged five years old.

All otolith measurements were done using the image analysis software Image J (version 1.381). Only the left sagittal otoliths were used. Otoliths were viewed under x6 magnification, sulcus side down and were all oriented in the same way (with the longest axis horizontal) (Fig. 6.2). The image analysis software was used to measure otolith area, perimeter, length and width (see Fig. 6.2). The aspect ratio and circularity, dimensionless descriptors of shape, were calculated as:

Aspect ratio = length/width.

Circularity = perimeter^2/area

Otolith outline shape was described using the Fourier analysis plugin in Image J. The Fourier analysis describes the otolith shape using a series of harmonics, each having four coefficients (see Glasbey & Horgan 1995). The starting point for tracing each otolith edge was the tip of the posterior margin (see Fig. 6.2).

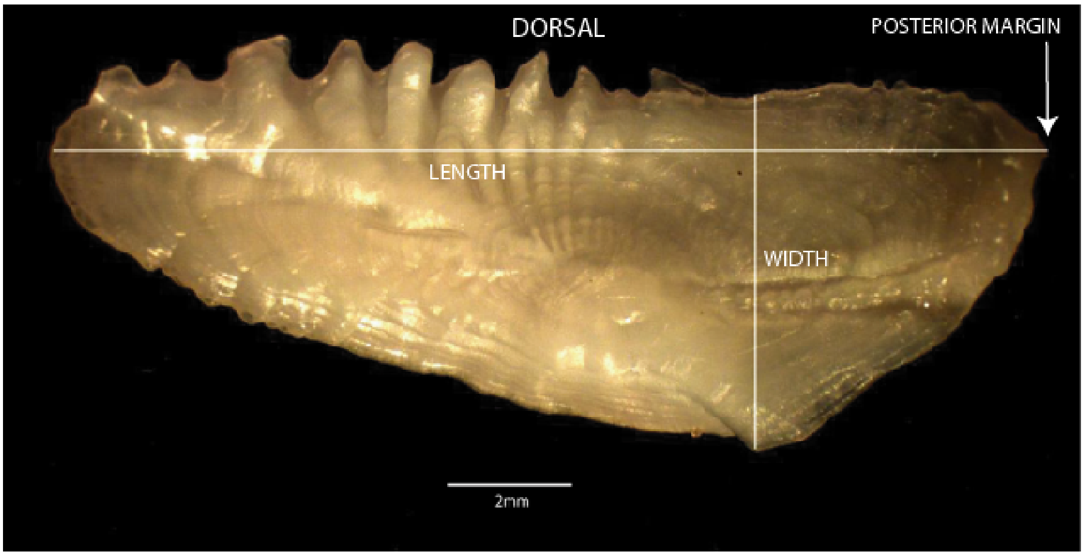


Figure 6.2. Whole left sagittal otolith of an eastern Australian salmon showing relevant landmarks and measurements of length and width.

The first harmonic describes the centre point of the otolith (i.e., where on the page the otolith is situated), while the second harmonic describes the orientation and dimensions of the otolith as an ellipse. Otolith position, orientation and size were standardized by removing these two harmonics from the analysis. A pilot analysis indicated that, after removing the first two harmonics, 99% of the otolith shape was described by the next 19 harmonics (76 coefficients).

The otolith morphometric data were compared between locations by ANOVA using the statistical package GMAV5. Variances were tested for homogeneity using a Cochran's *C*-test. GMAV5 can only analyse balanced data sets, so data were drawn at random so that each location had equal sample sizes. Post-hoc SNK tests were performed to identify differences between locations.

A comparison of otolith shape between locations was done using the statistical package PRIMER (Clarke & Gorley 2001). The data compared were the 76 Fourier coefficients from each otolith. Data were not transformed and were compared using a Bray-Curtis similarity matrix. Non-metric multidimensional scaling (MDS) was used to ordinate the matrix and analysis of similarity (ANOSIM) was used to test for statistical differences between locations.

6.2.3. Fish size

The fork lengths of fish that were estimated to be aged five years old were compared between locations using ANOVA as described above.

6.2.4. Movements of tagged fish

More than 8,000 Australian salmon are listed as being tagged and released since 1984 in the NSW Gamefish Tagging Database. However, a substantial proportion of these fish are listed as being tagged and released in South Australian and West Australian waters, and it is likely that these fish were the western species. Five hundred and seventy seven Australian salmon are listed as being recaptured, of which 404 were considered to be the eastern species (based on the location of tagging) with usable information on release and recapture.

In addition, a large tagging study was done on eastern Australian salmon during the 1960s and the information summarized in Stanley (1978). These results are used to assist in understanding salmon movements across state jurisdictions.

6.3. Results

6.3.1. Otolith microchemistry

6.3.1.1. Univariate spot analyses

Core-edge comparisons

Significant differences in elemental concentrations existed between the core region and outer edge of the otolith for all elements analysed (Li, Na, Mg, Sr, Ba) except Mn for both four and five year old fish (Figs 6.3 & 6.4, Tables 6.3 & 6.4). The otolith core region consistently contained significantly more Li, Na, Mg and Ba than the otolith edge in both four and five year old fish although the magnitude of this variation differed by location (Figs 6.3 & 6.4, Tables 6.3 & 6.4). In addition, the magnitude of the difference in some elemental concentrations between the core region and the edge of the otolith also varied depending on whether the fish was from the four or five year age class. For example, the difference in Li concentrations between otolith cores compared with edges of four year old fish was always greater than that for five year old fish collected from the same sites at the same time. In contrast, the otolith edge consistently contained significantly more Sr than the core region in both four and five year old fish, but once again the magnitude of the variation differed by location and age class.

Spatial comparisons

A significant difference in Na concentrations was found between some sites for four year old fish (Fig. 6.3, Table 6.3). Otoliths of fish collected from both Tasmanian sites (Babel Island and Flinders Island) had higher Na concentrations than fish collected from Stockton Beach, and otoliths of fish from Flinders Island were higher in Na than those from Eden (Fig. 6.3). No spatial differences existed for the other elements analysed (Li, Mg, Mn, Sr, Ba) (Fig. 6.3, Table 6.3).

In five year old fish, no significant spatial differences existed for the elements Li, Na, Mn, Sr and Ba (Fig. 6.4, Table 6.4). The only significant difference found was for Mg between sites within locations (Fig. 6.4, Table 6.4). Otoliths of fish collected from Bermagui had higher Mg concentrations than fish from Eden in southern NSW. Similarly, the otoliths of fish collected from Pettmans Beach in Victoria had higher Mg in than fish from Lakes Entrance.

6.3.1.2. Multivariate spot analyses

A significant difference in multi-element signatures was detected between locations for elements in both the otolith core region (Wilks' $\lambda = 0.682$, $F_{9,180} = 3.416$, $p = 0.0007$) and outer edge (Wilks' $\lambda = 0.565$, $F_{12,193} = 3.878$, $p < 0.0001$) of five year old fish (Fig. 6.5). The difference in core regions appeared to be driven by the influence of fish from southern NSW being different to those fish from the other 3 locations sampled and Victorian fish being different to those from Tasmania (Fig. 6.5a). For the outer edge of the otolith, Tasmania separated from the other 3 locations (Fig. 6.5b). There was however, considerable overlap between southern NSW and Victoria and southern NSW and northern NSW (Fig. 6.5b). The 95% confidence ellipses around the mean values for each location suggests that there is less separation between the four locations for the otolith core region – ellipses overlapped for all locations (Fig. 6.5a) – than for the outer edge where the ellipse around the mean value for Tasmania was entirely separate to those of the other 3 locations (Fig. 6.5b).

A low percentage of five year old fish were correctly classified on the basis of multi-element signatures in the core region (44%) and outer edge (38%) of the otolith (Table 6.5). Correct classification of fish to their sampling locations based on elements in the core region ranged from 20% for fish from northern NSW up to 65% for fish from Victoria (Table 6.5a). For the outer edge of the otolith, correct classification of fish to their sampling locations ranged from 20% for fish from southern NSW up to 65% for Tasmania (Table 6.5b).

A significant multi-element signature difference was also detected between locations for elements in both the otolith core region (Wilks' $\lambda = 0.553$, $F_{6,60} = 3.445$, $p = 0.0054$) and outer edge (Wilks' $\lambda = 0.231$, $F_{12,74} = 4.582$, $p < 0.0001$) of four year old fish (Fig. 6.6). The difference appeared to be due to the influence of fish from Victoria being different to fish from Tasmania for the otolith core region (Fig. 6.6a). There was however, considerable overlap between southern NSW and Victoria and northern NSW overlapped the other 3 locations (Fig. 6.6a). Once again, the multi-element signatures for the outer edge of the otolith separated out locations better than those for the core region, with the ellipse for Tasmania again completely separate to those of the other 3 locations (Fig. 6.6b). There was considerable overlap between northern NSW and southern NSW as well as some overlap between southern NSW and Victoria (Fig. 6.6b).

A low percentage of four year old fish were correctly classified on the basis of multi-element signatures in the core region (43%), but higher for the outer edge (57%) of the otolith (Table 6.6). Correct classification of fish to their sampling locations based on elements in the core region ranged from 0% for fish from northern NSW up to 60% for fish from Victoria (Table 6.6a). For the outer edge of the otolith, correct classification of fish to their sampling locations ranged from 20% for fish from southern NSW up to 80% for Tasmania (Table 6.6b).

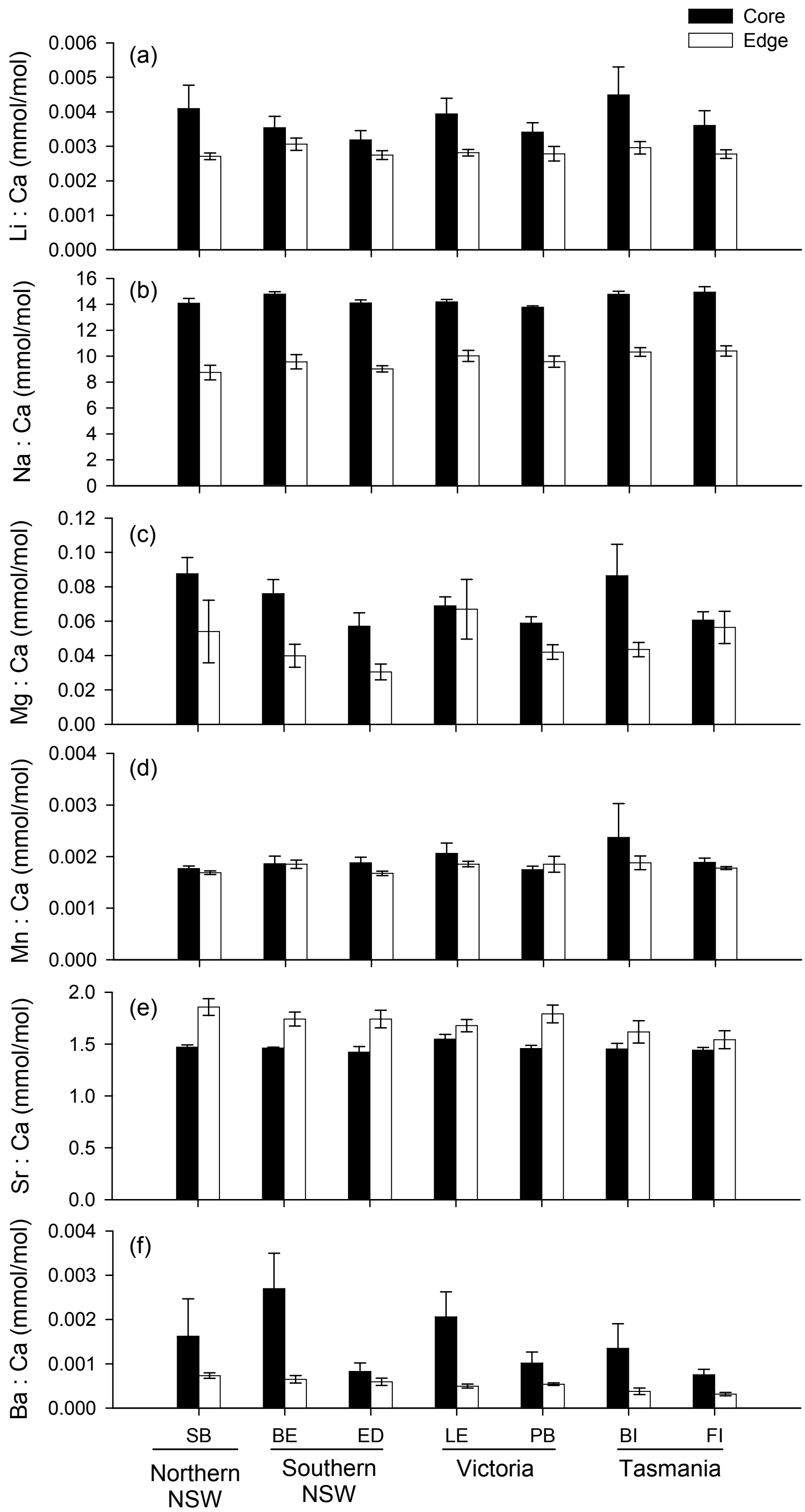


Figure 6.3. Mean (± standard error) concentration ratios of a) Li:Ca, b) Na:Ca, c) Mg:Ca, d) Mn:Ca, e) Sr:Ca and f) Ba:Ca from the core region (■) and outer edge (□) of four year old Australian salmon otoliths collected from northern NSW (SB = Stockton Beach), southern NSW (BE = Bermagui, ED = Eden), Victoria (LE = Lakes Entrance, PB = Pettmans Beach) and Tasmania (FI = Flinders Island, BI = Babel Island). *n* = 5 for each site.

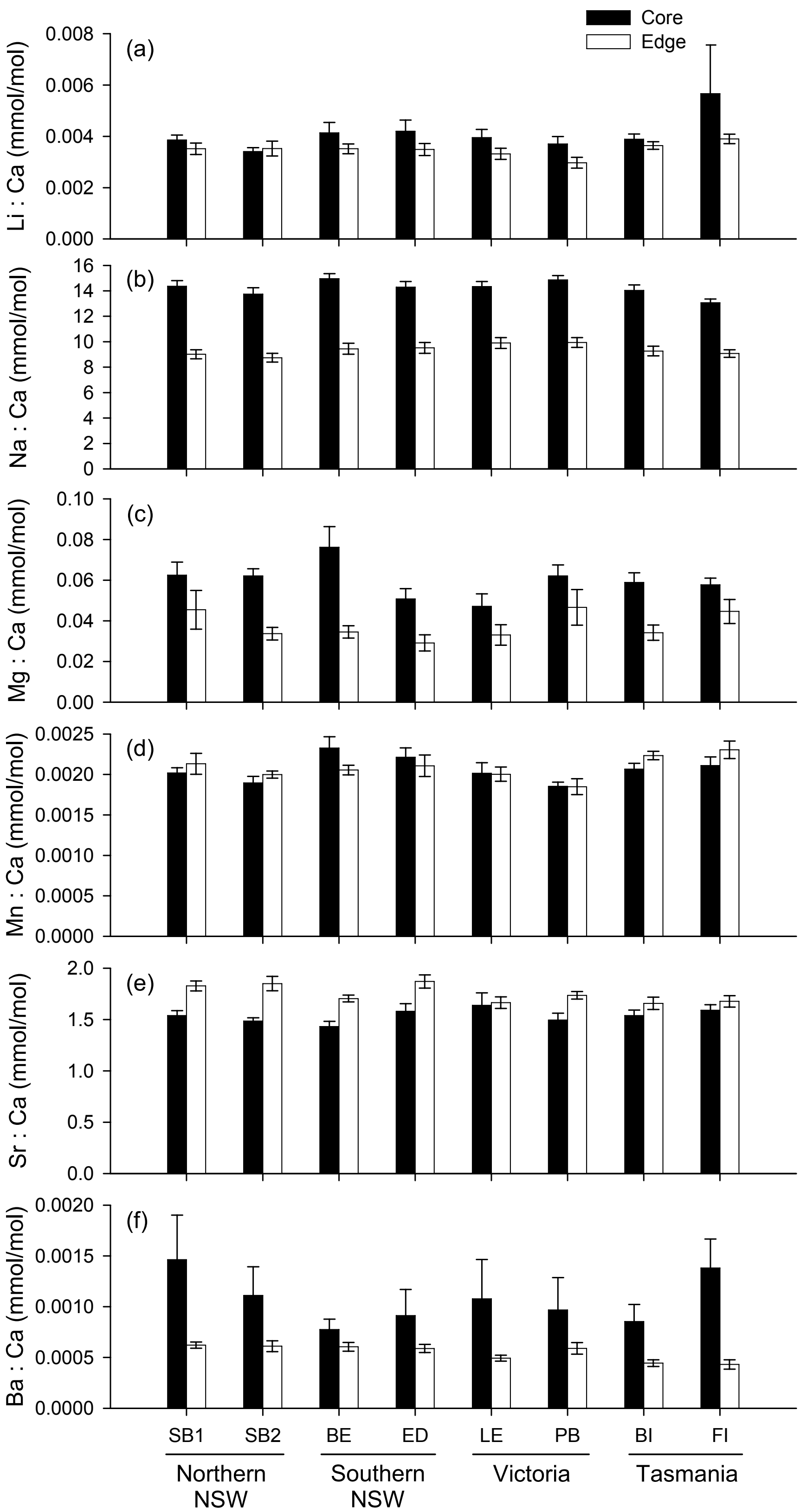


Figure 6.4. Mean (± standard error) concentration ratios of a) Li:Ca, b) Na:Ca, c) Mg:Ca, d) Mn:Ca, e) Sr:Ca and f) Ba:Ca from the core region (■) and outer edge (□) of five year old Australian salmon otoliths collected from northern NSW (SB1 = Stockton Beach 1, SB2 = Stockton Beach 2), southern NSW (BE = Bermagui, ED = Eden), Victoria (LE = Lakes Entrance, PB = Pettmans Beach) and Tasmania (FI = Flinders Island, BI = Babel Island). *n* = 10 for each site.

Table 6.3. ANOVA results comparing elemental concentrations (Li, Na, Mg, Mn, Sr, Ba) of core regions and outer edges of otoliths from four year old fish collected from Stockton Beach (northern NSW), Bermagui and Eden (southern NSW), Lakes Entrance and Pettmans Beach (Victoria), and Babel and Flinders Islands (Tasmania). **P* < 0.05, ***P* < 0.01, ****P* < 0.001 *df* is degrees of freedom.

Source	***df***	***F***
Li		
Core-Edge	1	30.45**
Site	6	0.89
Core-Edge x Site	6	0.71
Residual	56	
Na		
Core-Edge	1	627.53***
Site	6	3.64**
Core-Edge x Site	6	0.96
Residual	56	
Mg		
Core-Edge	1	14.76**
Site	6	1.81
Core-Edge x Site	6	1.24
Residual	56	
Mn		
Core-Edge	1	4.01
Site	6	0.88
Core-Edge x Site	6	0.43
Residual	56	
Sr		
Core-Edge	1	33.61**
Site	6	1.60
Core-Edge x Site	6	1.51
Residual	56	
Ba		
Core-Edge	1	14.45**
Site	6	2.04
Core-Edge x Site	6	1.42
Residual	56	

Table 6.4. ANOVA results comparing elemental concentrations (Li, Na, Mg, Mn, Sr, Ba) of core regions and outer edges of otoliths from five year old fish collected from Stockton Beach 1 and 2 (northern NSW), Bermagui and Eden (southern NSW), Lakes Entrance and Pettmans Beach (Victoria), and Babel and Flinders Islands (Tasmania). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, *df* is degrees of freedom.

Source	***df***	***F***
Li		
Core-Edge	1	9.65*
Location	3	1.70
Site (Location)	4	1.02
Core-Edge x Location	3	0.87
Core-Edge x Site(Location)	4	0.55
Residual	144	
Na		
Core-Edge	1	1003.59***
Location	3	4.38
Site(Location)	4	1.13
Core-Edge x Location	3	1.58
Core-Edge x Site(Location)	4	0.60
Residual	144	
Mg		
Core-Edge	1	46.55**
Location	3	0.09
Site(Location)	4	3.58**
Core-Edge x Location	3	1.24
Core-Edge x Site(Location)	4	1.19
Residual	144	
Mn		
Core-Edge	1	1.18
Location	3	5.34
Site(Location)	4	1.20
Core-Edge x Location	3	14.44
Core-Edge x Site(Location)	4	0.19
Residual	144	
Sr		
Core-Edge	1	53.61**
Location	3	0.36
Site(Location)	4	1.85
Core-Edge x Location	3	3.62
Core-Edge x Site(Location)	4	0.88
Residual	144	
Ba		
Core-Edge	1	36.47**
Location	3	1.55
Site(Location)	4	0.57
Core-Edge x Location	3	1.40
Core-Edge x Site(Location)	4	0.65
Residual	144	

Table 6.5. Results of discriminant function analysis (DFA) where five year old fish from each location were classified to each group based on otolith elemental signatures (Li, Na, Mg, Mn, Sr, Ba). The percentage of fish classified to each group is shown for a) the core region, and b) the outer edge of the otolith. Overall, 44% (core) and 38% (edge) were correctly classified. Values in bold indicate fish which were correctly classified. n = 20 for each location.

		Northern NSW	Southern NSW	Victoria	Tasmania
a)	Northern NSW	**20**	15	25	40
	Southern NSW	10	**40**	30	20
	Victoria	15	20	**65**	0
	Tasmania	20	10	20	**50**
b)	Northern NSW	**35**	15	25	25
	Southern NSW	30	**20**	35	15
	Victoria	25	20	**30**	25
	Tasmania	15	10	10	**65**

Table 6.6. Results of discriminant function analysis (DFA) where four year old fish from each location were classified to each group based on otolith elemental signatures (Li, Na, Mg, Mn, Sr, Ba). The percentage of fish classified to each group is shown for a) the core region, and b) the outer edge of the otolith. Overall, 43% (core) and 57% (edge) were correctly classified. Values in bold indicate fish which were correctly classified. n = 5 for northern NSW, n = 10 for southern NSW, Victoria and Tasmania.

		Northern NSW	Southern NSW	Victoria	Tasmania
a)	Northern NSW	**0**	40	40	20
	Southern NSW	20	**40**	10	30
	Victoria	10	20	**60**	10
	Tasmania	10	40	0	**50**
b)	Northern NSW	**60**	40	0	0
	Southern NSW	40	**20**	30	10
	Victoria	0	10	**70**	20
	Tasmania	0	0	20	**80**

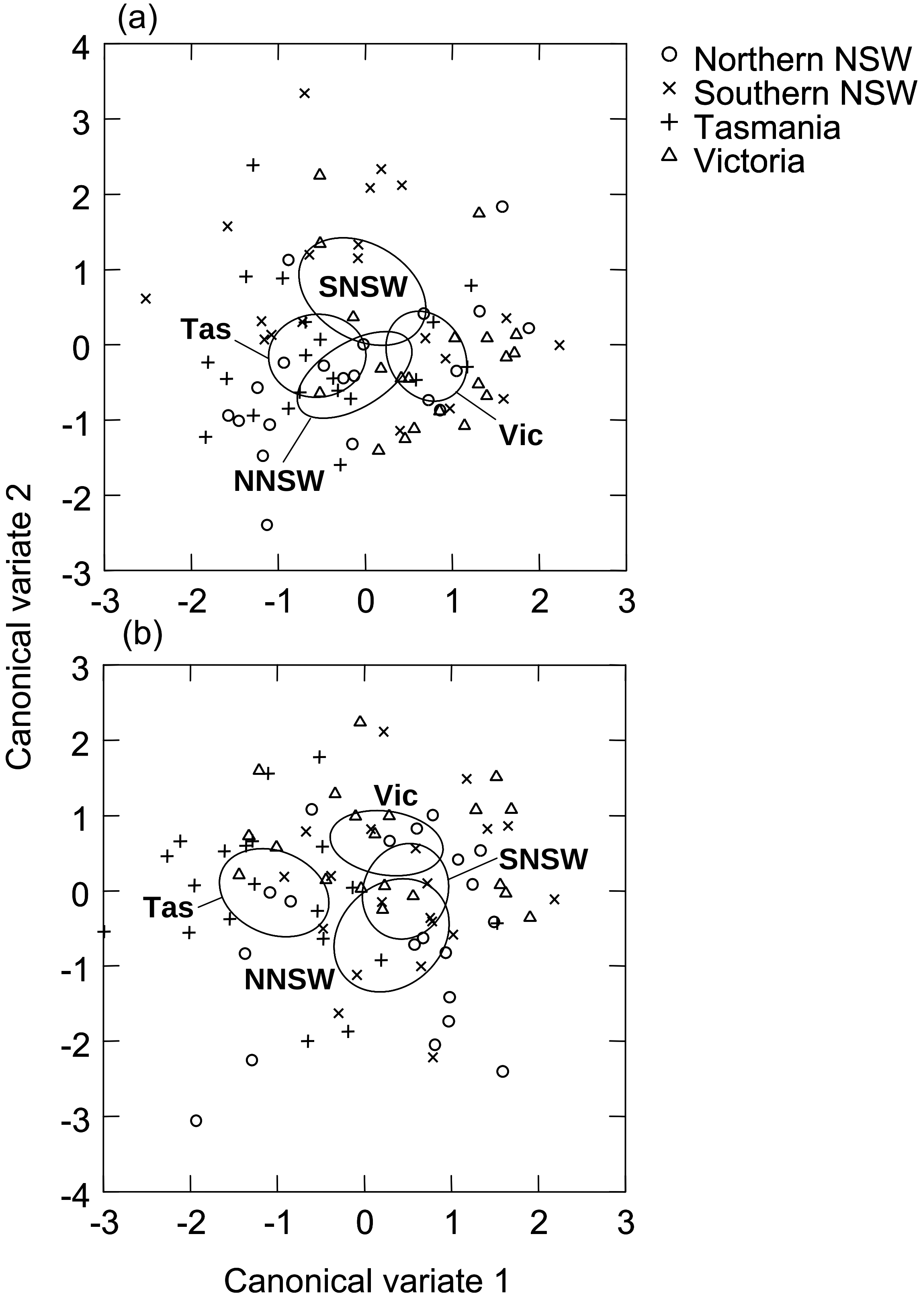


Figure 6.5. Canonical variate plot summarising variation in otolith elemental signatures for five year old Australian salmon from northern NSW (NNSW- ○), southern NSW (SNSW- ×), Victoria (Vic- Δ) and Tasmania (Tas- +) for a) the core region, and b) the outer edge. Ellipses represent 95% confidence intervals around the means for each location. *n* = 20 for each location.

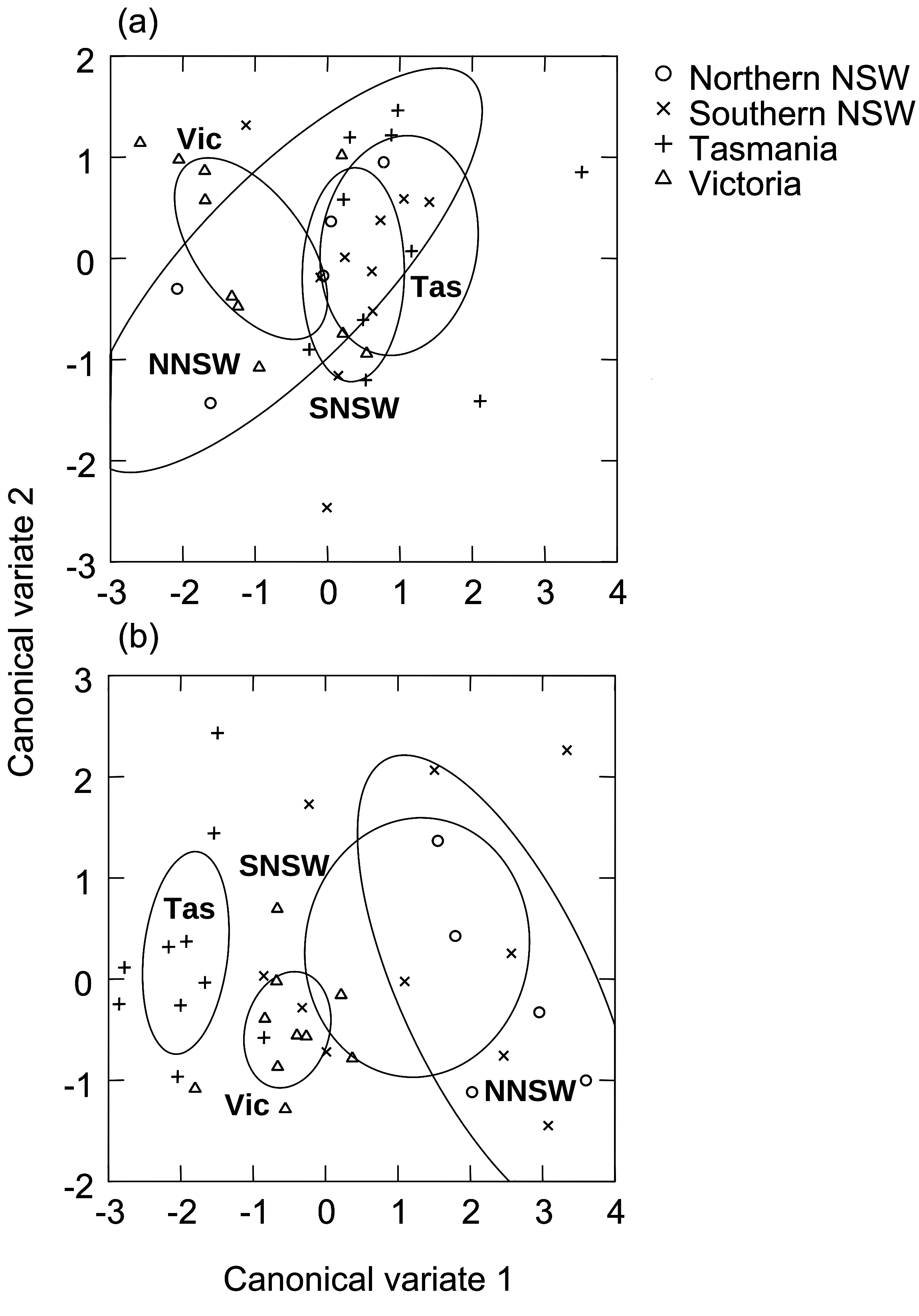


Figure 6.6. Canonical variate plot summarising variation in otolith elemental signatures for four year old Australian salmon from northern NSW (NNSW- ○), southern NSW (SNSW- ×), Victoria (Vic- Δ) and Tasmania (Tas- +) for a) the core region, and b) the outer edge. Ellipses represent 95% confidence intervals around the means for each location. *n* = 5 for northern NSW, *n* = 10 for other locations.

6.3.1.3. Transect analyses

A log (x + *c*) transformation was applied in most cases to satisfy the assumptions of normality and homogeneity of data for each element and each increment (Table 6.7).

Table 6.7. The values of *c* used in the displaced logarithmic [log(x + *c*)] transformation for each element and each increment. A dash "–" indicates that no transformation was required. Explanations of increment numbers are provided in the text.

	Increment number (core-edge)					
Element	0	1	2	3	4	5
Li	-0.0021	-0.0008	-0.001	0.001	0.001	0
Na	–	0	0	–	-6	–
Mg	-0.02	0.025	-0.01	-0.0125	-0.016	-0.02
Mn	0	0.000085	0.0002	0.000075	0.00025	0.00025
Sr	-1	-0.15	–	-1.25	–	–
Ba	0	0.00025	0	-0.00035	-0.00025	0

Elemental profiles for all elements were successfully related to age for 71 five year old fish from the eight sites in S.E. Australia. As it was not possible to present all profiles here, an example of a typical profile for each element is presented in Figure 6.7. The profiles for each element showed several different levels of variation which occurred together with some regular patterns which were consistent for all profiles for a given element. The profiles for Li (Fig. 6.7A) and Mn (Fig. 6.7D) showed considerable variation across all increments but elemental concentrations were generally higher through the 0 increment than through subsequent increments (i.e., 1 to 5). The profile for Na showed a gradual consistent decline thought life of the fish from increment 0 through to increment 5, with some levelling off of Na concentrations occurring from increments 2 to 5 (Fig. 6.7B). The profiles for Mg, Sr and Ba differed from the profiles of the other elements in showing some evidence of systematic, sinusoidal variation with annual periodicity, indicating considerable within-year variation in elemental concentrations (Figs 6.7C, E & F). There was also considerable variation in the amplitude of peaks and troughs across increments, reflecting significant between-year variation (e.g., Fig. 6.7D). There was some variation with respect to alignment of the peaks/troughs with opaque and translucent zones. For example, peaks in elemental concentration aligned with opaque zones for some profiles (Fig. 6.7C & F), but aligned with translucent zones for others (Fig. 6.7E). Finally, the systematic, sinusoidal variation in Mg, Sr and Ba was part of larger scale temporal trends in elemental concentration through the life of the fish. For Mg and Ba, there was a trend for initially high concentrations through the 0 increment, relatively low concentrations through increments 1 to 4 and a slight increase over increment 5 (Figs. 6.7C & E). For Sr, the trend was reversed with lower concentrations occurring over the 0 increment, higher concentrations through increments 1 to 4 and again a slight increase over increment 5 (Fig. 6.7D).

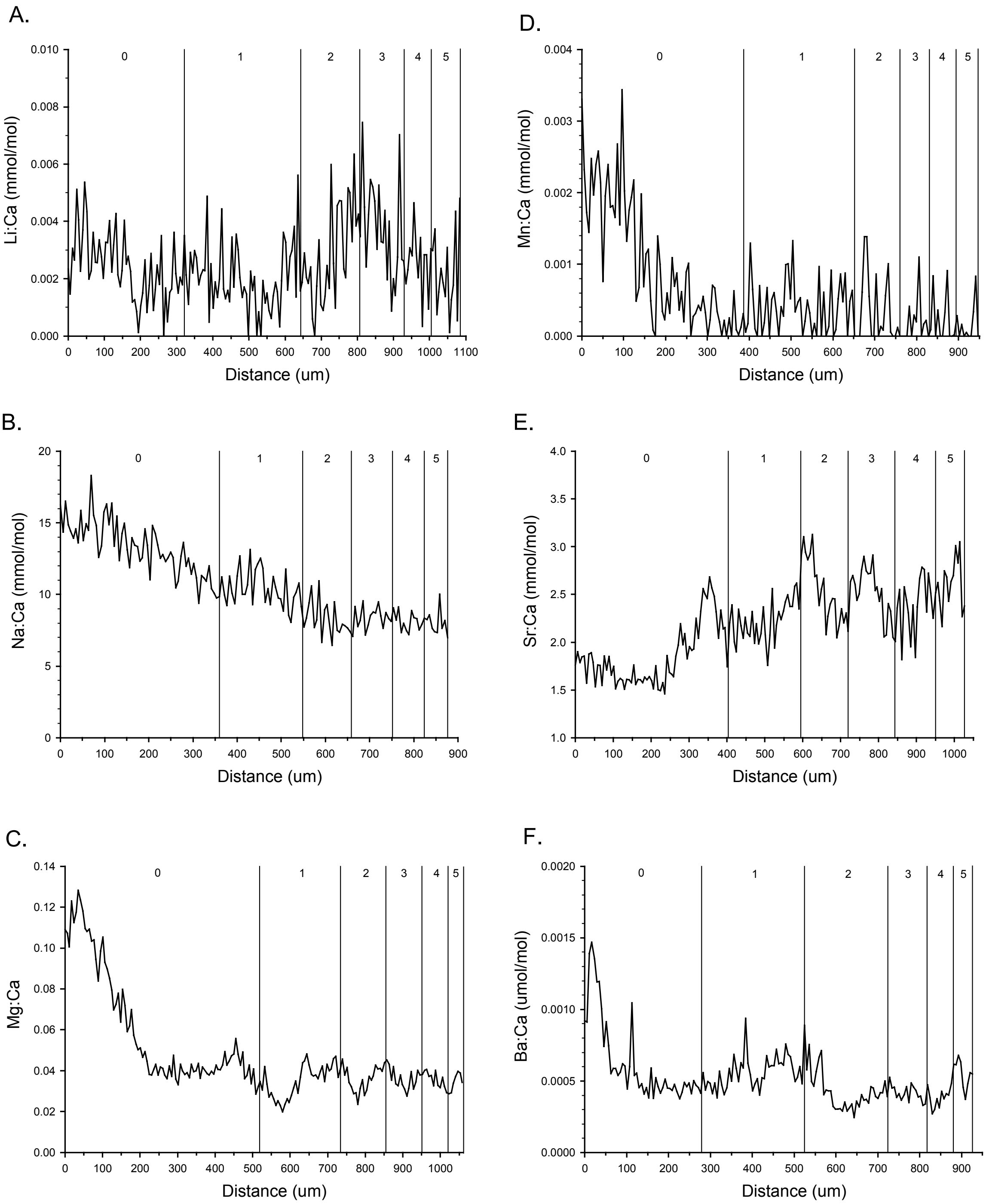


Figure 6.7. Examples of typical age-related profiles in elemental concentrations for transect analysis of eastern Australian salmon otoliths for one fish from each location demonstrating the types of variation in elemental concentration with fish age that were observed: A) Li:Ca (Eden), B) Na:Ca (Lakes Entrance), C) Mg:Ca (Bermagui), D) Mn:Ca (Stockton Beach), E) Sr:Ca (Babel Island), and F) Ba:Ca (Flinders Island). The vertical lines on each graph indicate the approximate position of opaque zones along the transect. The numbers at the top of each graph indicate the increments which corresponded to each stage of the fish's life.

Transect Multivariate Analyses

The log-likelihood differences for performing LRTs are given in Table 6.8. These log-likelihoods showed that a first order FA parameterization model with specific variances fitted (1a) provided a significantly better fit to the elemental fingerprint data to explain the variation between sites than the null model for increments 0, 4 and 5, but not for increments 1, 2 or 3. However, for all increments, fitting the unstructured model (US) provided little further increase in log-likelihood for the extra 15 parameters. This indicated that a LRT comparing any model involving six or more additional parameters to FA model 1a would be non-significant. It was therefore determined, that overall, FA model 1a sufficiently explained the variation in elemental fingerprints between sites for all increments and therefore, there was no attempt to fit an FA model 2.

Table 6.8. Results of multivariate analysis of elemental fingerprints for various models fitted to the transect data which explained the variation between sites for each increment. The log-likelihood values shown are compared to the Null model (i.e., no site effects). The comparison between model 1a and the Null model is shown for each increment with accompanying statistical significance calculated using LRTs (NS – non significant; * – $p < 0.05$, *** – $p < 0.001$). *df* is degrees of freedom, US is the unstructured model. Explanations of increment numbers are provided in the text.

Model	***df*(model) – *df*(Null)**	**Log-likelihood differences by increment number (core-edge)**					
		0	**1**	**2**	**3**	**4**	**5**
Null		0	0	0	0	0	0
1a	6	7.1*	5.0 ^{NS}	5.6 ^{NS}	6.2 ^{NS}	12.4***	7.7*
1b	12	7.1	5.0	6.0	9.0	15.1	8.0
US	21	7.2	5.3	7.6	10.5	15.5	11.3

The factor loadings used to create the variate representing the elemental signature for each increment of fish collected from each site using FA model 1a are shown in Table 6.9. For five of the six increments (i.e., increments 0, 1, 3, 4 & 5) Na had the highest factor loading, with Sr possessing the highest factor loading for increment 2 (Table 6.9). The factor scores representing the elemental signature of each increment from each site are plotted in Figure 6.8; factor scores for each site with non-overlapping 95% C.I.s indicated significantly different elemental fingerprints for that increment. For increment 0, the elemental fingerprints of Australian salmon from the two northern NSW sites were significantly different to those of fish collected from Lakes Entrance and Babel Island (Fig. 6.8A). For increment 3, the elemental fingerprint of Australian salmon from just one of the northern NSW sites (Stockton Beach 2) was significantly different to those of Lakes Entrance and Babel Island (Fig. 6.8D). For increments 4 and 5, fish from the two northern NSW sites had a significantly different elemental fingerprint to fish collected from Eden, Lakes Entrance and Babel Island (Figs 6.8E & F). There were no significant differences between sites detected for increments 1 or 2 (Figs 6.8B & C). These results show the sites with the most consistent separation occurs between the two northern NSW sites (Stockton Beach 1 & 2) and Babel Island (Tasmania) and Lakes Entrance (Victoria). The factor scores from the two northern NSW sites, Stockton Beach 1 & 2, were consistently the lowest through all six increments (Fig. 6.8). In addition, the Flinders Island factor scores were lower than for those of the other sites (except the northern NSW sites) for five of the six increments.

When the factor scores for each site were combined and averaged for each location (Fig. 6.9), the consistently lower factor scores for northern NSW compared with the other locations for each increment was more obvious. For all stages of the fishes life (except increment 3; Fig. 6.9D), northern NSW was significantly different to at least one of the other locations in S.E. Australia. For increment 0, there was significant separation between northern NSW and all three other locations (Fig. 6.9A). For increments 1 and 4, the average factor score for northern NSW was significantly lower than for Victoria (Figs 6.9B & E). For increment 2, the factor score for northern NSW was significantly lower than that of Tasmania (Fig. 6.9C) and for increment 5, it was significantly lower than that of both southern NSW and Victoria (Fig. 6.9F).

Table 6.9. Factor loadings used to create a variate representing the elemental signature for each increment of fish collected from each site using FA model 1a. The element with the highest factor loading for each increment is presented in bold italics. Explanations of increment numbers are provided in the text.

Element	**Increment number (core-edge)**					
	0	**1**	**2**	**3**	**4**	**5**
Li	-0.056	0.042	-0.041	0.047	0.0078	-0.12
Na	***0.53***	***-0.44***	0.24	***0.47***	***-0.54***	***-0.53***
Mg	0.17	0.00011	-0.30	-0.23	0.46	0.26
Mn	0.17	0.081	0.025	-0.017	0.10	0.21
Sr	-0.12	0.11	*0.40*	0.17	-0.07	0.15
Ba	-0.025	0.091	0.22	0.20	-0.078	0.098

6.3.2. Otolith shape

6.3.2.1. Otolith morphometrics

Analyses of variance showed no significant differences between locations for otolith perimeter, circularity and width. There were, however, differences between locations for otolith area, aspect ratio and length.

<u>Otolith area</u>

Otoliths from Tasmanian fish had a significantly smaller area than those from NNSW and SNSW, but were not significantly different with those from Victoria (Tables 6.10 & 6.11). Fish from Victoria had significantly smaller otolith areas than those from SNSW.

Table 6.10. Results from the ANOVA for otolith area. n = 15 per location.

Source	**SS**	**DF**	**MS**	**F**	**P**
Location	282.30	3	94.10	5.82	<0.01
Residual	905.5075	56	16.17	905.51	
Total	1187.80	59			

Table 6.11. Results from the SNK test for otolith area.

Location	**Tasmania**	=	**Victoria**	=	**NNSW**	=	**SNSW**
Mean	43.77		45.60		47.31		49.65
S.E.	1.39		0.76		0.85		1.04

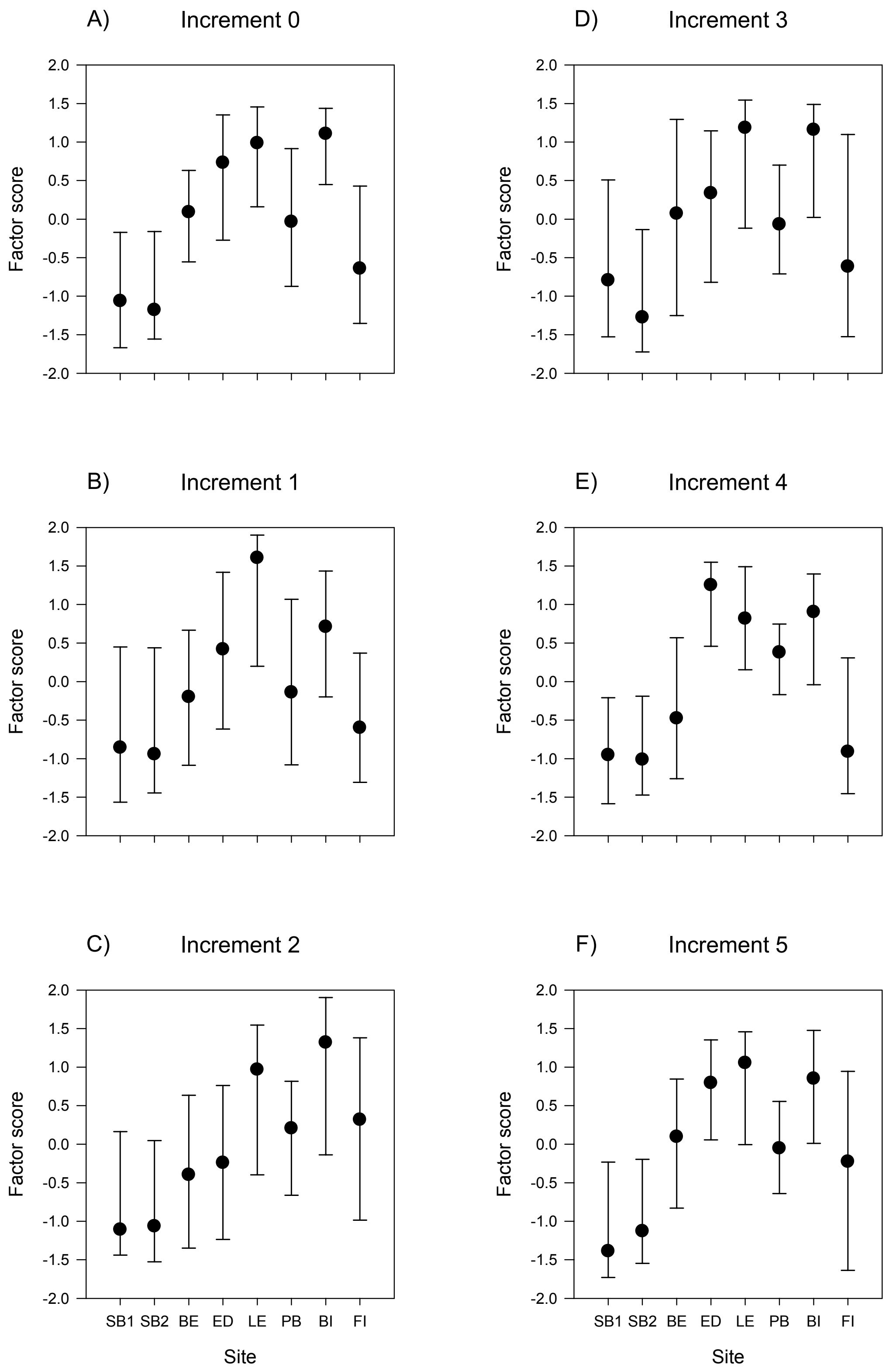


Figure 6.8. Factor scores representing the elemental fingerprint of otoliths for each stage in the fish's life collected from each site in S.E. Australia: A) increment 0, B) increment 1, C) increment 2, D) increment 3, E) increment 4 and F) increment 5. Error bars are -95% confidence intervals. Definitions for each increment are given in the text. Abbreviations are: Stockton Beach 1- SB1, Stockton Beach 2- SB2, Bermagui- BE, Eden- ED, Pettmans Beach- PB, Lakes Entrance- LE, Babel Island- BI and Flinders Island- FI.

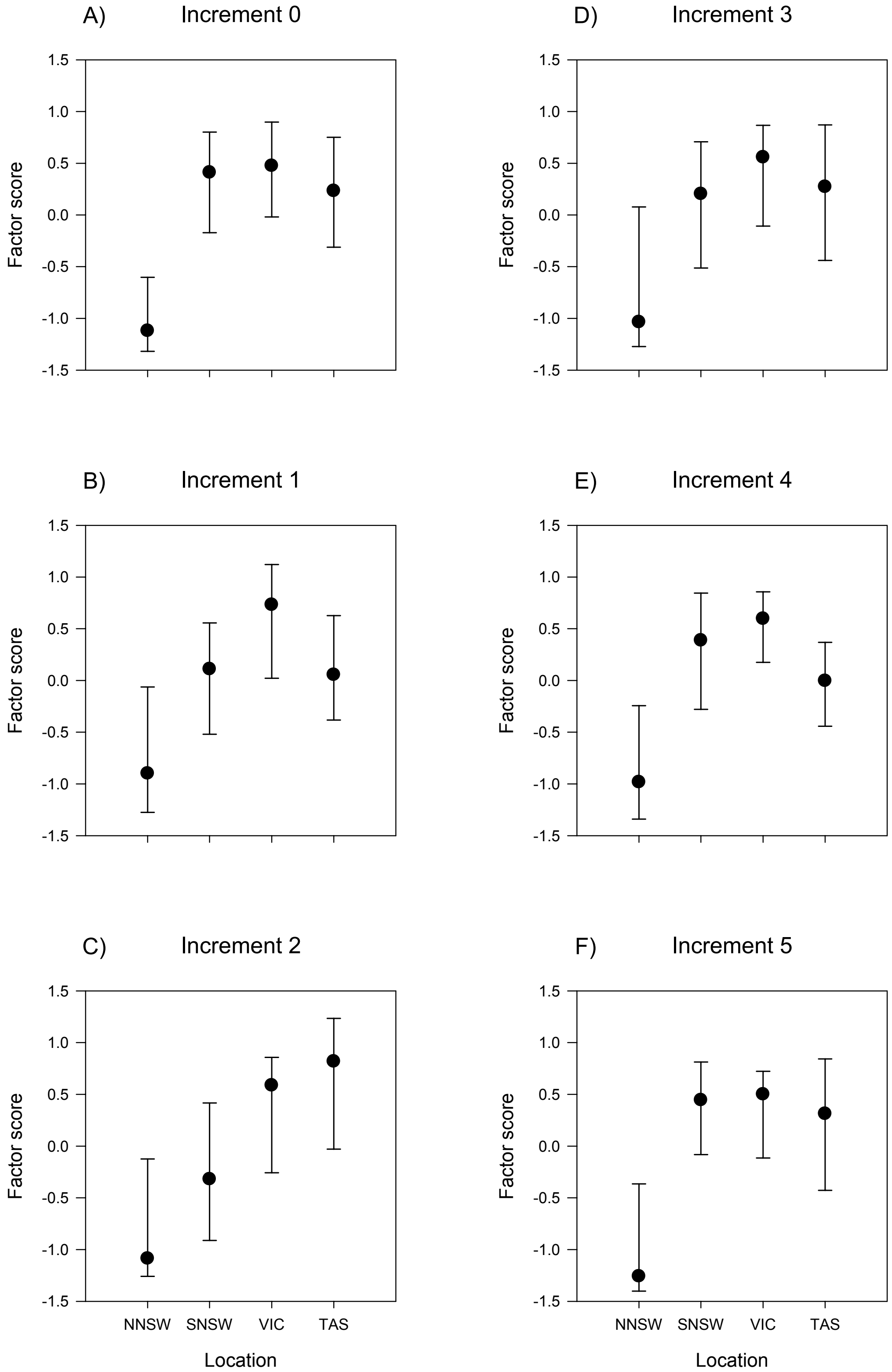


Figure 6.9. Average factor scores representing the elemental fingerprint of otoliths by location (combined sites) for each stage in the fish's life collected from S.E. Australia: A) increment 0, B) increment 1, C) increment 2, D) increment 3, E) increment 4 and F) increment 5. Error bars are 95% confidence intervals. Definitions for each increment are given in the text. Abbreviations are: Northern NSW- Stockton Beach 1 & 2, Southern NSW- Bermagui & Eden, Victoria- Pettmans Beach & Lakes Entrance, Tasmania- Babel Island & Flinders Island.

Otolith aspect ratio

Otoliths from Tasmanian fish had a significantly smaller aspect ratio than those from the more northern locations (Tables 6.12 & 6.13).

Table 6.12. Results from the ANOVA for aspect ratio. n = 15 per location.

Source	SS	DF	MS	F	P
Location	1.5246	3	0.5082	17.66	<0.01
Residual	1.6117	56	0.0288		
Total	3.1364	59			

Table 6.13. Results from the SNK test for aspect ratio.

t	Tasmania	<	Victoria	=	NNSW	=	SNSW
Mean	2.45		2.73		2.78		2.89
S.E.	0.04		0.05		0.05		0.04

Otolith length

There was a significant difference in otolith length between locations (Table 6.14). The SNK test showed that fish from Tasmania and Victoria had significantly shorter otoliths than those from SNSW (Table 6.15).

Table 6.14. Results from the ANOVA for otolith length. n = 15 per location.

Source	SS	DF	MS	*F*	*P*
Location	6.8894	3	2.2965	5.16	0.0032
Residual	24.9093	56	0.4448		
Total	31.7987	59			

Table 6.15. Results from the SNK test for otolith length.

Location	Tasmania	=	Victoria	=	NNSW	=	SNSW
Mean	12.95		12.98		13.31		13.80
S.E.	0.14		0.11		0.20		0.21

6.3.2.2. Fourier analysis

The MDS ordination and ANOSIM indicated that, overall, there were no significant differences in otolith shape between locations (Fig. 6.10). However, there was a significant difference between SNSW and Tasmania (Table 6.16).

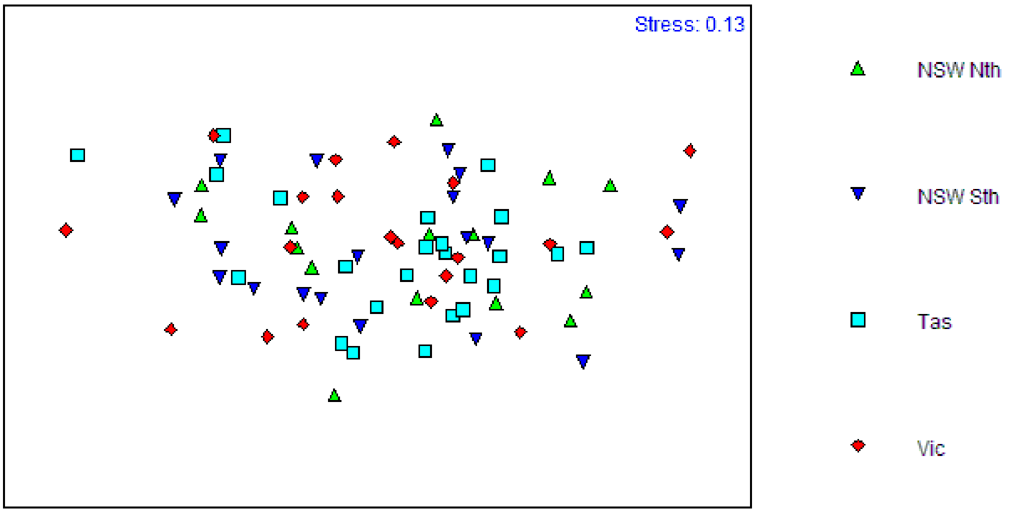


Figure 6.10. Two dimensional MDS ordination of the Bray-Curtis similarity values between otolith shape (Fourier descriptors) for salmon aged five years old from each location.

Table 6.16. Results from the ANOSIM comparing otolith shape (Fourier descriptors) for salmon aged five years old from each location.

Sample statistic (Global R): 0.014
Significance level of sample statistic: 24.7%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 246
Pairwise Tests

Groups		R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
NNSW,	SNSW	-0.051	92.6	Too Many	999	925
NNSW,	Tas	0.066	10.2	Too Many	999	101
NNSW,	Vic	-0.033	76.3	Too Many	999	762
SNSW,	Tas	0.084	3.2	Too Many	999	31
SNSW,	Vic	-0.057	99.9	Too Many	999	998
Tas, Vic		0.03	15	Too Many	999	149

6.3.3. Fish size

ANOVA indicated a significant difference in length of fish aged five years old between locations (Table 6.17).

Table 6.17. Results from the ANOVA for fish length. n = 20 per location.

Source	SS	DF	MS	*F*	*P*
Location	199.00	3	66.33	10.55	<0.01
Residual	478.36	76	6.29		
Total	677.36	79			

The SNK test showed that fish aged five years old from Tasmania were significantly smaller than those sampled from the three more northern locations (Table 6.18). There were no significant differences between the sizes of fish aged five years old from the more northern locations.

Table 6.18. Results from the SNK test for fish length.

Location	Tasmania	<	Victoria	=	NNSW	=	SNSW
Mean	42.54		45.46		45.49		46.87
S.E.	0.82		0.43		0.39		0.49

Further examination showed that fish from one of the Tasmanian sites (Flinders Island) were significantly smaller than those from all other sites (Table 6.19). There were no differences between the other Tasmanian site (Babel Island) and the more northern locations (Table 6.20).

Table 6.19. Results from the ANOVA for fish length including separate Tasmanian sites. *n f* 16 per location.

Source	SS	DF	MS	*F*	*P*
Location	250.33	4	62.58	9.53	<0.01
Residual	492.30	75	6.56		
Total	742.63	79			

Table 6.20. Results from the SNK test for fish length including separate Tasmanian samples.

Location	Flinders Island	<	Babel Island	=	NNSW	=	Victoria	=	SNSW
Mean	41.4		45.31		45.35		45.59		46.51
S.E.	1.06		0.45		0.45		0.48		0.54

6.3.4. Movements of tagged fish

Analysis of tag/recapture data for eastern Australian salmon shows that individual fish can travel long distances (Fig. 6.11). The longest distance travelled by a tagged salmon was by a fish tagged near Newcastle in NSW which was recaptured near Mallacoota in Victoria (~ 550km). This fish was at liberty for 197 days and was tagged during winter and recaptured the following autumn. Of the 404 fish with useable data, 137 had moved northwards, 211 had moved southwards and 56 were recaptured at the same latitude where they were tagged.

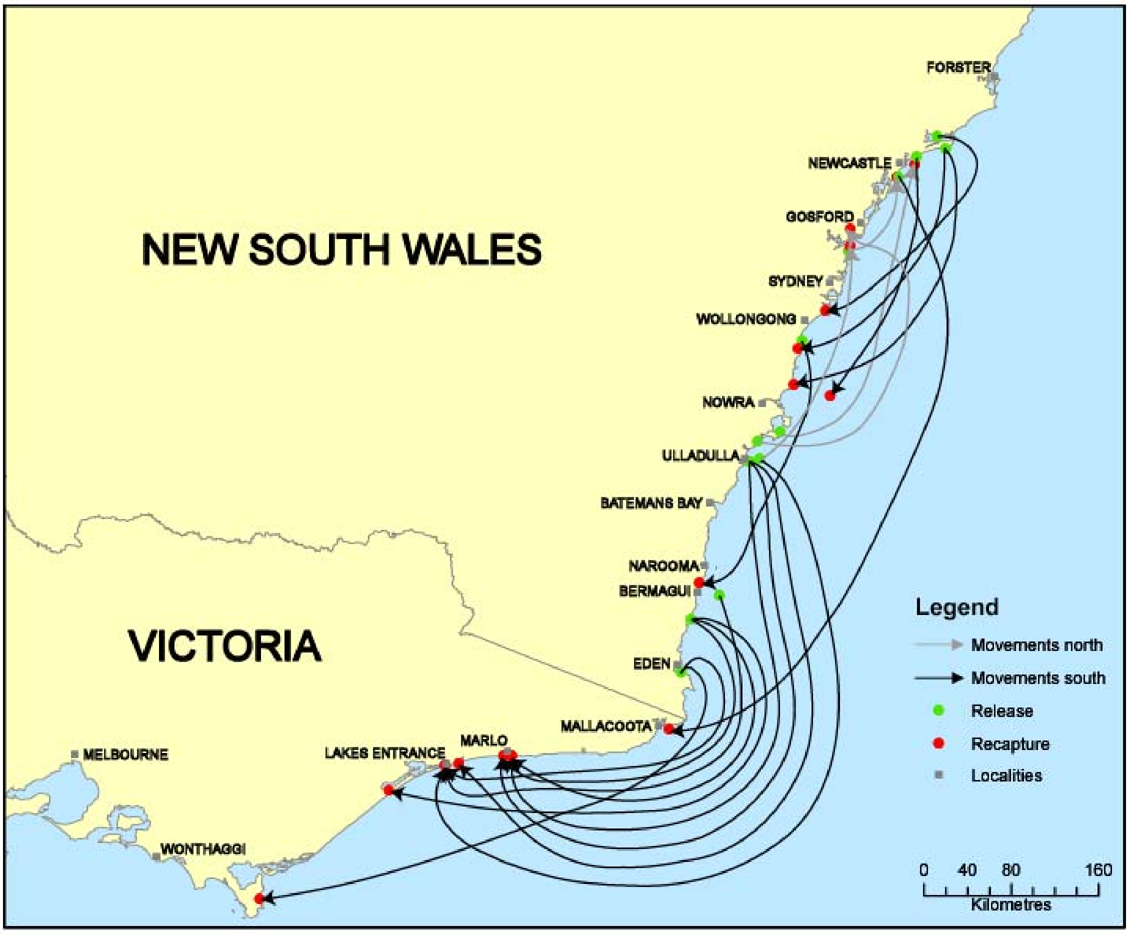


Figure 6.11. Map showing the 20 tagged eastern Australian salmon that were recaptured farthest from their release locations.

The data from the tagging study done in the 1960s showed an overall movement of fish from Tasmania to Victoria and NSW (Fig. 6.12). There was also evidence of some movement southwards from NSW to eastern Victoria.

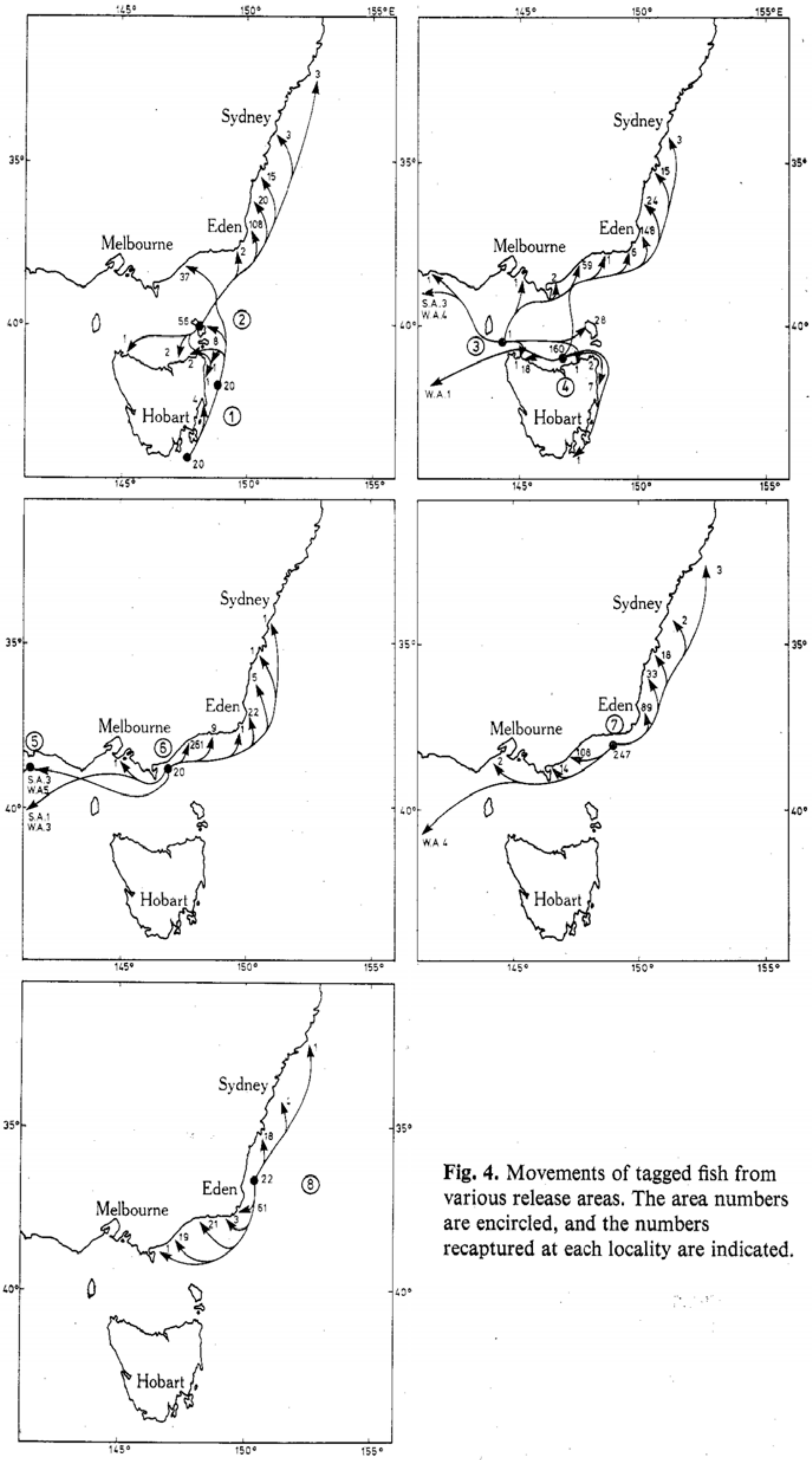


Figure 6.12. Movements of eastern Australian salmon tagged and released during the 1960s. The figure is from Stanley (1978).

6.4. Discussion

The multi-faceted approach we used has allowed a better understanding of the stock structure of eastern Australian salmon in south-eastern Australia. Importantly, such an approach has highlighted the potential for misinterpreting some sources of data when studying stock structure. As discussed below, using only otolith chemistry data from core/edge spot analysis may have resulted in very different conclusions to those based on otolith transect data when interpreted in association with life-history and population structure information.

Tag/Recapture data

The movements of tagged eastern Australian salmon suggest that the stock is well mixed. Data from fish tagged in Tasmania during the 1960s showed a general movement from Tasmania to Victoria, probably along the Flinders Island chain, and then into NSW (Stanley 1978). It was hypothesized that the salmon that moved towards western Victoria during that study were the western species. Stanley (1978) concluded that the northerly movement of fish from Tasmania was a one way movement as none of the 2,767 salmon tagged in mainland waters were recaptured in Tasmania. It was also suggested that this movement across Bass Strait occurs with the onset of sexual maturity (Stanley & Malcolm 1977, Stanley 1978). Salmon tagged in NSW also displayed movements southwards; however there was an overall northerly dispersal pattern which occurs with increasing size/age (Stanley 1978). Salmon tagged in NSW in more recent years also suggest a well mixed stock. Recaptured tagged fish show significant movements between NSW and Victoria. The data from the NSW Gamefish Tagging Database shows that many of the salmon that travelled the greatest distances moved southwards and were recaptured in Victorian waters. This may present a biased view because salmon were not tagged in Victorian waters and so fish moving from Victoria to NSW were therefore unable to be detected. There have been no recaptures of tagged salmon in northern NSW and as such we have little information with which to assess fish movements in this area. However, both tagging datasets indicate that Australian salmon in S.E. Australia comprise a well mixed stock.

Otolith shape and fish size-at-age

Analysis of fish morphometrics (fish size-at-age and otolith shape) suggest that some eastern Australian salmon from Tasmanian waters differ from their more northern counterparts. This difference was driven by one sample of fish that was caught off Flinders Island that were significantly shorter fish at age five years old. These fish also had shorter otoliths, with a smaller area and aspect ratio than those from the more northern locations. This suggests that the growth rate of fish from this sample was significantly slower than fish from all other samples.

Otolith microchemistry

The spot analyses supported the use of otolith chemistry to evaluate differences in water bodies in which the fish had lived. Differences in elemental concentrations were detected between the core region and outer edge of otoliths for all elements except Mg. Spot analyses of the core region represents sampling of the juvenile part of the otolith, whilst edge ablations reflect the elements present during the life of the fish immediately prior to capture. The outer edge of Australian salmon otoliths contained significantly more Sr:Ca than the core region in both four and five year old fish, and conversely, the core region contained significantly more Ba:Ca that the outer edge in both four and five year old fish. Correlations between ambient and otolith Sr:Ca and Ba:Ca concentrations have been investigated in several studies and a strong positive relationship exists for both elements (Bath Martin *et al.* 2004, Elsdon & Gillanders 2003, 2005). The concentrations of both Sr:Ca (Kalish 1990, Secor 1992, Bath Martin *et al.* 2004) and Ba:Ca (Elsdon & Gillanders 2005) in otoliths have also previously been shown to be related to environmental salinity. The low Sr:Ca and high Ba:Ca concentrations found in core regions of otoliths suggest that as juveniles Australian salmon are found in low (or lower) salinity environments than the environment they experience as adults. Indeed, it has been reported that Australian salmon are found in estuaries as juveniles (Stanley & Malcolm 1977, Pease *et al.* 1981, Robertson 1982, Kailola *et al.* 1993). Juveniles and subadults of this species have also been recorded from estuaries and tidal rivers in New Zealand (Graham 1956).

There was some spatial variation in the concentration of individual elements in the otoliths of eastern Australian salmon collected from different sites. Four year old fish showed significant differences between some sites for Na:Ca concentration with the two southernmost sites (BI & FI) having significantly higher Na:Ca concentrations than the northernmost site (SB). However, it has become generally accepted that Na is an inappropriate element for drawing conclusions from otolith microchemistry analyses as it is an element which is under strong physiological regulation (Campana 1999). Some spatial variation in Mg:Ca concentration also occurred in five year old fish with significant differences between sites within the southern NSW (BE > ED) and Victoria (PE > LE) locations. The fact that variation for one element between sites within two of the locations was greater than the differences between the locations themselves does not provide an informative pattern, but does highlight the lack of useful information provided by the univariate analyses of spot ablation-generated single element data in the context of this study.

The core-edge multi-element signatures for both four and five year old fish showed considerably better separation between locations for analyses of the outer edge of the otolith compared to that for analyses of the otolith core. Similarly for the differences between the cores and edges for the single-element analyses discussed above, the multi-elemental pattern may reflect similarities in the environment of juveniles or may be a result of ontogenetic factors, or a combination of both. It is not possible to entirely discount the influence of ontogeny on the otolith elemental signatures seen in this study without controlled experiments in the laboratory (Elsdon & Gillanders 2005). The poorer separation seen in the core analyses compared with the edge may be because juveniles occur in more similar environments. Alternatively there may be a significant amount of population mixing when the fish are young. The better separation of locations for edge elemental fingerprints may therefore reflect the dispersal of Australian salmon from estuarine nursery areas to offshore areas of the S.E. Australian coast with age.

Results from the DFA using multi-element signatures to classify fish to a location showed that attempting to classify fish using the core signature (overall 43 & 44% for four and five year olds respectively) resulted in a low degree of accuracy. Using the signatures from the outer edge region of the otolith also resulted in a poor rate of correct classifications (overall 57 & 38% for four and five year olds respectively), but it is worth noting that the highest percentages of correctly classified fish using the otolith edge signatures came consistently from Tasmania for both four and five year old fish (80 & 65% respectively). This result showed that there was a clear multi-element signature from the otolith edges of Tasmanian fish which helped to separate them from fish from the other three locations.

The transect-based, multivariate statistical analyses involving age-related mean elemental fingerprints, provided a far more useful insight into the movement and stock structure of eastern Australian salmon in S.E. Australia. The data for the first stage in the fishes life (i.e., increment 0) displayed significant regional variation with the elemental fingerprint of fish from northern NSW significantly different to those caught in southern NSW, Victoria or Tasmania (between which there were no differences). This result suggests that the five year old fish sampled from northern NSW recruited to different areas than the more southern fish. The different elemental fingerprints for fish collected from the two northern NSW sites at Stockton Beach consistently had the lowest factor scores for all stages of the fish's life. The fact that this spatial pattern in otolith chemistry was temporally consistent over all six increments analysed suggest it to be a real pattern, presumably related to the environmental characteristics of each region, which repeatedly separated northern fish from those from the rest of their distribution in S.E. Australia. This result suggests that the five year old eastern Australian salmon sampled from northern NSW may have spent their entire lives in different waters to those of the more southern fish.

These spatial patterns in otolith elemental signatures through the life of five year old Australian salmon in S.E. Australia are consistent with a model which suggests that increased population mixing occurs with both increasing age and decreasing latitude in S.E. Australia. Both past research (Stanley 1978), and the results in Chapter 2 show quite clearly that the distribution of fish within S.E. Australian waters is highly stratified by age, with marked differences in the age structures of fish collected from different latitudes. In terms of interpreting the spatial patterns in elemental fingerprints evident here, this means that a five year old fish sampled from Victoria could have had its origin in Victoria itself or migrated there from Tasmania with the approach of sexual maturity (Malcolm 1966c, Stanley 1978, Chapter 4). Similarly, a five year old fish sampled from southern NSW could have originated in southern NSW itself, could have migrated from Victoria, or from Tasmania via Victoria. Thus the potential population mixing which occurs between the ages of three and six in Victorian and southern NSW waters likely results in the similar age-related otolith elemental signatures seen in transect analyses of five year old fish collected from these three regions. In contrast however, a five year old fish sampled from the waters of northern NSW is most likely to have recruited to, and lived in, more northerly waters than fish from the other areas sampled. This hypothesis suggests that if older (> five years) fish had been used in these analyses, then greater mixing of fish recruited to different areas would be expected and that the otolith chemical fingerprints of later otolith increments (i.e., > five) would be more similar between all locations.

The other significant temporally stable spatial pattern in otolith elemental fingerprints was for five year old fish from the Flinders Island site in the NE of Tasmania. The elemental fingerprint of fish from this site had consistently the lowest factor score (excluding the two sites in northern NSW) of any site in S.E. Australia. This result supports the results of the core/edge spot analyses whereby fish from Tasmanian waters exhibited distinct otolith elemental signatures. We suggest that these five year old fish from Tasmanian waters are part of the S.E. Australian salmon stock that have not yet migrated northwards across Bass Strait with the approach of maturity. They are late developers that have remained in Tasmanian waters since recruitment and so exhibit slower growth rates and differing otolith chemistry than fish which had migrated from the area and their more northerly counterparts. We suggest that these late developers do move northwards and therefore mature sometime after five years of age. The fact that no fish older than ~ 6 years old have been sampled in Tasmanian waters supports this assertion (Stanley 1978, Chapter 3).

Conclusions

The age-specific information on the chemistry of eastern Australian salmon otoliths presented here has provided an informative tool to aid our understanding of the life-history and demography of this species in S.E. Australia. The data support the suggestion that eastern Australian salmon are a single, large, well mixed stock in S.E. Australia and that co-operative assessments and management between state jurisdictions may therefore be prudent.

7. DIET AND CONSUMPTION RATES

OBJECTIVES ADDRESSED

This chapter addresses objective 7 of the original Project No. 2006/018 to "Describe diet and potential localised impacts on prey items".

7.1. Introduction

In addition to their economic importance to commercial and recreational fisheries in south-eastern (S.E.) Australia, eastern Australian salmon play a key ecological role as both high trophic level predators as well as prey in nearshore pelagic food webs. Eastern Australian salmon have been described previously as "a voracious carnivore" (Graham 1956) which feeds mainly on teleost fishes, squid and pelagic crustaceans like euphausiids (Malcolm 1966a, Baker 1971, Stanley 1980, Penlington 1988). This places them at a high trophic level similar to that of other pelagic piscivorous teleosts like the small tunas – longtail tuna *Thunnus tonggol* (Griffiths *et al.* 2007) and mackerel tuna *Euthynnus affinis* (Griffiths *et al.* 2009). Adult eastern Australian salmon in turn are preyed upon by a suite of apex marine predators like bottlenose *Tursiops truncatus* (Gales *et al.* 1992) and Maui's dolphins *Cephalorhynchus hectori maui*, killer whales *Orcinus orca*, Australian sea lions *Neophoca cinerea* (Barnes *et al.* 2004), seals (Malcolm 1966a), and tiger *Galeocerdo cuvier*, great white *Carcharodon carcharias*, grey nurse *Carcharias taurus* and whaler *Carcharhinus* spp. sharks (pers. obs.). Large schools of eastern Australian salmon (up to a reported 800 t (Malcolm 1966a)) feed by co-operatively herding prey towards the surface to form a "baitball" which many winter-nesting seabirds such as terns (*Sterna* spp.), petrels (*Pterodroma* spp.), prions (*Pachyptila* spp.) and shearwaters (*Puffinus* spp.) are reliant on to make pelagic prey available to them (Barnes *et al.* 2004).

Eastern Australian salmon are a highly mobile species which undergo seasonal movements of potentially thousands of km in length (Malcolm 1966a, Stanley 1978, Chapter 6). They also posses relatively fast growth rates (Nicholls 1973, Hartill & Walsh 2005, Chapter 3). In combination with observations of the voracious feeding behaviour of eastern Australian salmon, it is therefore likely that this species requires substantial quantities of prey in order to accommodate their high energy requirements for growth and metabolism. Consequently, eastern Australian salmon may exert a substantial 'top-down' effect on the nearshore pelagic ecosystem of S.E. Australian waters, as has been demonstrated for pelagic species from similar trophic levels in other ecosystems (e.g., Griffiths *et al.* 2007, 2009). There has recently been emphasis on understanding ecological interactions in marine ecosystems as well as a need to develop tools to better predict these interactions, which to be effective, require estimates of the predation rates (or 'predatory impact') of fish populations (Essington 2003). The need for dietary information for use in population models has also been highlighted by the recently increasing global interest in ecosystem-based fisheries management (Scandol *et al.* 2005). Dietary studies are crucial for providing data for these models in terms of the direction and magnitude of trophic flows between ecological functional groups, which can only be achieved by quantifying diet composition and 'predatory impact' based on daily ration estimates (Griffiths *et al.* 2007, Marasco *et al.* 2007). Although information on diet composition is readily available for many fish species, estimating 'predatory impact' remains problematic because all existing methodologies have important limitations (Essington *et al.* 2001). The approach presented here was therefore to employ three diverse techniques to provide a range of 'predatory impact' estimates for eastern Australian salmon; experimental gastric evacuation experiments coupled with stomach content analyses, bioenergetics modelling and empirical regression modelling.

The genesis of the NSW component of this study was the concerns of commercial and recreational fishers about the impact that apparently increasing numbers of eastern Australian salmon may be having on stocks of their prey. In particular, fishers raised concerns about the potentially excessive consumption of economically and recreationally important species like Australian sardines (*Sardinops sagax*), eastern sea garfish (*Hyporhamphus australis*) and sand whiting (*Sillago ciliata*). The specific aims of this chapter were therefore to: examine the spatial, temporal and size-related variability in diet composition, and to estimate consumption rates and daily ration for eastern Australian salmon in S.E. Australian waters.

7.2. Materials and methods

7.2.1. Sample collection and processing

The samples for dietary composition analyses were taken from the eastern Australian salmon sampled for biological analysis in each state (see Chapters 3 and 4). In Tasmania, additional sampling of juveniles was done during a 24-hour period in February 2009 with fish collected at 3 hourly intervals in order to examine diurnal feeding behaviour.

Researchers in NSW and Tasmania developed a standard sampling process for the dietary study. Once in the laboratory, all fish collected were measured (fork length – FL) to the nearest mm, and weighed to the nearest g. The stomach was then dissected and any contents removed and prey items present identified to the lowest possible taxon, counted, measured where possible (standard length – SL to the nearest mm) and a wet weight (WW – to the nearest 0.01g in NSW and 0.001 g in Tasmania) obtained. Loose otoliths and vertebrae were not used in subsequent analyses because of their ability to accumulate in the stomach and cause overestimation of dietary importance (Olson & Galvan-Magana 2002, Chipps & Garvey 2007). Intact otoliths which could be removed from teleost prey remains were used to identify fishes based on examination of otolith shape. This was especially useful in identifying heavily digested prey items which would have otherwise been unrecognizable based on external morphometric characteristics alone.

Each prey type was allocated into a broad prey category based on those of Griffiths *et al.* (2009) to assist in the description of the overall diet and calculation of consumption rates. These groups were defined as: pelagic fish (PF) – fish which live in the pelagic zone; demersal fish (DF) – fish which live on or near the seabed; pelagic crustaceans (PC) – crustaceans (or life stages) which live in the pelagic zone; benthic crustaceans (BC) – crustaceans which live on or near the seabed; molluscs (M) – hard-shelled animals such as gastropods and bivalves; cephalopods (C) – refers specifically to squids; plants (P) – algae, seagrass and terrestrial plants; and miscellaneous (Misc) – organisms or items which occurred in very small numbers. Economically important species were defined as those for which existed a commercial or recreational fishery.

A quantitative stomach fullness index (SFI) was calculated for each fish to examine possible temporal variations in feeding intensity. The SFI was calculated by taking the stomach contents weight as a percentage of the whole fish weight minus the stomach contents.

7.2.2. *Dietary analyses*

7.2.2.1. Combined diet analyses

Diet was determined as the contribution of each prey type to the overall diet in terms of percentage wet weight (%WW) and percentage frequency of occurrence (%FO) and was calculated only from fish stomachs which contained prey. The diet composition data for fish from each state was combined to investigate variation with region, season and fish size. Regions were defined as northern NSW, southern NSW, Victoria and Tasmania. Seasons were summer, autumn, winter and spring. Variation in diet with fish length was investigated by dividing fish into three size classes: small (*S*, < 20 cm FL), medium (*M*, 20 to 40 cm FL) and large (*L*, > 40 cm FL).

Non-metric multidimensional scaling (nMDS) was used to examine differences in diet composition in terms of biomass among regions, seasons and fish of different sizes. The biomass of each prey taxon was represented as a percentage of the total prey biomass for each catch in order to standardise the relative contributions of prey across all catches. Data were left untransformed and a similarity matrix was constructed using the Bray-Curtis similarity coefficient (Clarke 1993). Analysis of similarities (ANOSIM) was used to test whether diet composition differed significantly between regions, seasons or fish size classes. Similarity percentages (SIMPER) were used to determine the prey items which made the greatest contribution to the similarity in samples within a priori groups (i.e., region, season, size) and dissimilarity between a priori groups. All multivariate analyses were carried out using PRIMER (Plymouth Routines In Multivariate Research) software version 6.1.9.

7.2.2.2. Small juvenile diet analyses

Variation in the diet of small juvenile eastern Australian salmon from Tasmania was investigated in addition to the analyses of the data combined across each state. To quantify the contribution of each dietary group to the overall diet of each fish, the frequency of occurrence (%F) and percent contribution by number (%N) and wet weight (%WW) was calculated. These data were then used to calculate the Index of Relative Importance (IRI) of each dietary group to the diet of each fish using the equation (Pinkas *et al.* 1971):

$$IRI = (\%N + \%WW) \times \%F$$

The IRI for each dietary group was then divided by the total IRI for all dietary groups to give the relative importance of each to the overall diet as a percentage (%IRI).

The gut contents index (GCI) was also determined to investigate variations in feeding intensity between seasons, regions and over a diurnal cycle. The GCI was equivalent to the SFI calculated above. Salmon with empty stomachs were also used in the calculation of GCI values. A Kruskal-Wallis test was then applied to determine if feeding intensity differed significantly (P = 0.05) between seasons, regions or over a diurnal period, and post hoc Tukey Kramer tests used to identify pairwise differences. ANOVA was used to assess the relationship between tidal height and feeding intensity over the 24-hour cycle.

Non-metric multidimensional scaling (nMDS) was used to examine differences in diet composition between juvenile size classes, seasons, regions, and time of day as described above.

7.2.3. Regurgitation of stomach contents

The stress associated with some of the capture methods used to collect wild fish causes the regurgitation of stomach contents in many species, particularly piscivorous predators (e.g., Begg & Hopper 1997, Sutton *et al.* 2004). This has the potential to result in a loss of information or biased estimates of diet composition, feeding periodicity, and rates of food consumption and gastric evacuation. To quantify regurgitation we sampled the stomach contents that were retained in a purse seine net following the capture of 50 t of eastern Australian salmon near Bermagui (NSW) on 14 November 2007. It was assumed that the fine mesh (1/2 inch) in the bag of the purse-seine net retained all regurgitated stomach contents. A representative 30 fish subsample was also taken from this catch and the stomach contents examined as described below.

Regurgitation of stomach contents can also lead to potential bias when comparing the diets of fish collected with different fishing gears. The two main gear types used for the collection of eastern Australian salmon in the present study were beach haul and purse seine net. A single factor analysis of variance (ANOVA) was used to compare the mean stomach fullness of eastern Australian salmon caught using the two different sampling gears.

7.2.4. Daily ration and prey consumption rates

We estimated daily consumption rates of eastern Australian salmon using one direct experimental and two indirect empirical techniques in order to provide a range of values for daily consumption. The three methods used were: 1) experimentally measuring gastric evacuation rates in the laboratory using wild-caught captive fish and then applying this rate to the observed diet of wild fish collected for stomach content analysis; 2) using a bioenergetics model (Fish Bioenergetics 3.0 – The University of Wisconsin) designed to quantify the physiological and ecological constraints to growth and the strength of predator-prey relationships (Hanson *et al* 1997, Hartman & Kitchell 2008); and 3) using an empirical formula derived for multiple regression models for a suite of fresh and saltwater fishes dependent on shape, size, habitat, temperature and food type (Palomares & Pauly 1989, 1998). From each technique, it was therefore possible to estimate the amount of food ingested (*Q*) by a fish population expressed as a fraction of its biomass (*B*) per year (*Q/B*). *Q/B* was calculated using each technique at two environmentally relevant temperatures for S.E. Australian coastal waters, 15 & 20ºC.

7.2.4.1. Gastric evacuation experiments

This work was done in NSW. Experimental eastern Australian salmon were caught by rod and line from coastal waters (< 2 nm from shore) between Big Marley Beach (34º07'S, 151º09'E) and Little Garie Beach (34º11'S, 151º04'E) NSW. The fish were transported to the Cronulla Fisheries Research Centre Aquarium Facility on Port Hacking (34º04'S, 151º09'E) within 0.5 to 2 hours of capture. The fish were maintained in captivity in a cylindrical (Ø = 496 cm, depth = 159 cm) 35,000 L flow-through seawater tank with a 12 h:12 h light:dark photoperiod. Their diet was kept similar to prey found in the stomachs of wild-caught fish (pilchards, yellowtail scad, sandy sprats, eastern school whiting, squid and school prawns). Two groups of fish were collected; the first during the period 13 to 16 May 2008 and the second on 17 October and 6 November 2008.

Two gastric evacuation experiments were done on these captive fish; the first during the period 21 to 23 July 2008 at an average water temperature of ~ 15ºC and the second during the period 30 April to 2 May 2009 at an average water temperature of ~ 20ºC. Initial trials indicated that it took 2 to 3 days for eastern Australian salmon to completely clear their guts following a meal, therefore on both occasions fish were starved for 4 days prior to experiments to ensure they had completely cleared their stomachs. Prior to commencing the experiments, it was established from analyses of the stomach contents of wild fish that Australian sardines (*Sardinops sagax*) were the most important food item by weight, and scads (yellowtail scad *Trachurus novaezelandiae* and jack mackerel *Trachurus declivis*, hereafter together *Trachurus spp.*) the most important in terms of numbers. Both Australian sardines and yellowtail scad were offered to the fish prior to the experiments; Australian sardines were readily accepted, however yellowtail scad were rarely eaten, therefore the experiments were done using Australian sardines only. Each Australian sardine to be fed to the experimental fish was pre-weighed (to the nearest 0.01 g) and a small soft plastic green bead with a unique number printed on it coated with epoxy resin (Polyplex Clear Cast, Fiberglass International) carefully inserted into its body cavity using forceps (Fig. 7.1). This enabled the exact quantity of food ingested by any given fish to be determined from analysis of the labelled beads present in the fish's stomach. In each gastric evacuation experiment the fish were fed to satiation. The elapsed time from feeding to the time the fish was euthanased using an overdose with Aqui-S anaesthetic (Aqui-S New Zealand Ltd) was recorded (to the nearest minute). Freshly sampled fish were measured (fork length – FL) to the nearest mm, and weighed to the nearest g. The entire viscera was then removed from the fish (within 5 minutes of death), the stomach split open and the Australian sardine remains contained within weighed to the nearest 0.01 g and the numbers of all beads present recorded.

Figure 7.1. Example of the numbered plastic green beads used to identify individual Australian sardines fed to captive eastern Australian salmon in experiments to estimate stomach evacuation time.

Following completion of the experiments, gastric evacuation data were represented by plotting the proportion of the meal remaining in the fish's stomachs against time post-feeding (hours – h) and linear functions fitted to the data. The integral of these linear functions was then used to calculate the evacuation time (A_i) for Australian sardines at 15.1 and 19.4ºC in units of proportion/h. A_i represents the average amount of time required to evacuate the average proportion of all Australian sardine meals in the stomach at any instant in time.

Daily consumption rates of prey for wild eastern Australian salmon were then estimated using the methods of Olson & Mullen (1986) where the feeding rate (in g/h) is predicted by dividing the mean wet weight (g) of the stomach contents per eastern Australian salmon (from the diet analysis above) by the average time required to evacuate the average proportion of prey type i (A_i – as calculated above). This represents the prey consumption per hour, so that the feeding rate is multiplied by the number of hours per day in which the predator feeds to estimate the daily meal (*M*). Because eastern Australian salmon are known to also feed at night (they are recreationally caught at night – pers. obs.), it was assumed that they feed over the entire diel cycle and the feeding rate was therefore multiplied by 24. Daily ration was then calculated by expressing *M* as a percentage of the average wet weight of fish examined. Daily ration could then be scaled up to give an estimate of *Q/B* at each experimental temperature. Size related variation in consumption was also investigated among three sizes classes of fish: small (*S*, <20 cm FL), medium (*M*, 20 – 40 cm FL) and large (*L*, >40 cm FL). All empty stomachs were included in the estimation of daily ration because they represent the true proportion of the population that may not have fed prior to capture. Because captive eastern Australian salmon would not eat food other than Australian sardines, A_i could only be estimated for this prey item. This was not considered likely to bias results as the most important dietary component for wild eastern Australian salmon was teleost fishes (97.8% by WW), and more specifically pelagic fish species which were assumed to be of similar digestibility to Australian sardines based on their similar size and 'softness'. This approach has been previously used by many other researchers in the absence of specific Ai estimates for all prey items in the diet (e.g., Menard *et al.* 2000, Olson & Galvan-Magana 2002, Griffiths *et al.* 2007, 2009). The A_i estimate for Australian sardines was therefore applied to all prey items in the diet, as any potential errors in the calculation of daily ration would be small in comparison to the large influence of teleost fishes to the overall diet and therefore unlikely to bias results.

7.2.4.2. Bioenergetics modelling

The bioenergetics model (Fish Bioenergetics 3.0; Hanson *et al.* 1997) used here is based on the "Wisconsin model" and has been used extensively over the past 20 years in more than 250 publications and is designed to quantify the physiological and ecological constraints to growth and the strength of predator-prey relationships (Hartman & Kitchell 2008). The model is designed to construct energy budgets within boundary conditions for the growth of individual fish. The boundaries range from maximum feeding/metabolic rates (modified by temperature, fish size and food type) to the minimum rates required by fasting fish.

This model is based on the following energy balance equation which calculates the amount of energy consumed by the fish on a daily basis as specific consumption rates in joules per gram (J/g) of fish:

Consumption = Growth + Respiration + Wastes

where growth (g/day) was calculated based on the overall standard von Bertalanffy growth function (VBGF) for eastern Australian salmon in S.E. Australia and associated weight presented in Chapter 3. The size ranges of eastern Australian salmon were determined using the VBGF estimates of size-at-age 0 of 2.33 cm FL and size at maximum longevity (oldest eastern Australian salmon recorded 12+ years) of 60.16 cm FL (Chapter 3). The physiological parameters used to estimate eastern Australian salmon metabolism (respiration and wastes) and energy density (6,279 J/g) were taken from Hartman & Brandt (1995) as estimated for bluefish (tailor) *Pomatomus saltatrix*. Tailor was considered to be an excellent proxy for eastern Australian salmon as both species are schooling pelagic perciform teleosts, have similar distributions in Australia (Hutchins & Swainston 1986), ecology (Silvano & Begossi 2005), diet (Buckel & Conover 1997, Scharf *et al.* 2004), feeding behaviour (Hartman & Brandt 1995a), spawning migrations (Ward *et al.* 2003) and thus likely also trophic positions in nearshore Australian waters. As the most important dietary component for wild eastern Australian salmon was teleost fishes (97.8% by WW), and more specifically pelagic fishes (particularly sardines), which we assumed were of similar digestibility to Australian sardines based on their similar size and 'softness', we used the energy content of Australian sardines (8,709 J/g-Parrish *et al.* 2000) as a proxy for the energy content of all teleosts in the diet. Australian sardines were also used in the gastric evacuation experiments. Simulations were done at 15 and 20ºC for the estimation of consumption rates (g prey/g predator/day) which were in turn converted to *Q/B* estimates for small, medium and large eastern Australian salmon. Energy losses due to reproduction were not included in the model.

7.2.4.3. Empirical multiple regression modelling

The 3rd method employed to estimate food consumption was the empirical formula of Palomares & Pauly (1989, 1998). This formula derives multiple regression models from 108 fresh and saltwater fish populations (38 species) for the prediction of *Q/B* using the easily obtainable population parameters of asymptotic weight, habitat temperature, a morphological variable and food type as independent variables (Palomares & Pauly 1998):

$$\log Q/B = 7.964 - 0.204 \log W_\infty - 1.965\, T' + 0.083\, AR + 0.532\, h + 0.398\, d,$$

where W_∞ is the asymptotic weight (g), T' is water temperature (ºK), AR is the aspect ratio of the caudal fin, and h and d are dummy variables indicating herbivores (h = 1, d = 0), detritivores (h = 0, d = 1) and carnivores (h = 0, d = 0). As eastern Australian salmon are primarily carnivores (Malcolm 1966a, Baker 1971, Stanley 1980, Penlington 1988), h and d were both set to 0. The aspect ratio of the caudal fin (AR) is a dimensionless, species-specific constant defined by the equation:

$$AR = f^2 / s,$$

where f is the height of the caudal fin (cm) and s is its surface area (cm^2) extending to the narrowest part of the caudal peduncle. This variable is used to quantify the activity level of fishes and was derived from the observation that active fishes with high metabolism (and hence high food consumption) have caudal fins with a high AR, whereas sluggish fish with low metabolic rates (and low food consumption) have caudal fins with a low AR (Palomares & Pauly 1989). AR was measured for a broad size range of fish. An estimate of *Q/B* was then calculated at 15 and 20ºC.

7.3. Results

7.3.1. Overall composition of the diet

A total of 5,109 stomachs were examined, 1,955 of which were empty (38.3%). The overall diet consisted of 135 prey taxa with a total biomass of 41,928.3 g (Tables 7.1 & 7.2). Teleost fishes were shown to be the primary prey for eastern Australian salmon in S.E. Australia (97.7% by WW) (Table 7.3). Of these, pelagic fishes (93.9%) were by far the largest contributor to the diet. This group consisted primarily of the schooling baitfish; Australian sardine (overall 34.7%), *Trachurus* spp. (30.2%), slimy mackerel *Scomber australasicus* (5.4%), sandy sprat *H. vittatus* (4.2%) and Australian anchovy *Engraulis australis* (3.3%), however the importance of these prey varied with location (Tables 7.1 & 7.2). Demersal fishes (mainly eastern school whiting S*illago flindersi*) were the second most important group in the diet in terms of WW (3.8%) (Tables 7.1, 7.2 and 7.3). All other prey groups contributed < 0.9% to the overall diet by WW. Economically important species contributed 92.5% by WW of the overall diet. ANOSIM indicated that there was no significant inter-annual variation in the composition of the diet over the 4 years of sampling (2006 – 2009) in northern NSW (Global R = 0.052, P = 0.093) and southern NSW (Global R = -0.009, P = 0.541), two years of sampling (2007 to 2008) in Victoria (Global R = 0.407, P = 0.100) or 3 years of sampling (2008 to 2010) in Tasmania (Global R = 0.139, P = 0.073). The dietary composition data were therefore pooled for all years from each location.

Table 7.1. Prey taxa consumed (% wet weight) by eastern Australian salmon in four seasons in northern and southern NSW between October 2006 and March 2009. Fish with empty stomachs were not included in the analysis. Prey categories are PF – pelagic fishes, DF – demersal fishes, M – molluscs, C – cephalopods, PC – pelagic crustaceans, BC – benthic crustaceans, P – plants, Misc – miscellaneous. [E] denotes species of economic importance.

Family (or higher taxon)	Prey	Category	Northern NSW					Southern NSW				
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall
Teleosts												
Ambassidae	*Ambassis jacksoniensis*	PF										
Atherinidae	*Atherinason hepsetoides*	PF										
	Atherinosoma presbyteroides	PF										
	Kestratherina brevirostris	PF										
Arripididae	*Arripis trutta* [E]	PF										
	Unidentified atherinid	PF										
Carangidae	*Trachurus declivis* [E]	PF				1.482	0.405					
	Trachurus novaezelandiae [E]	PF				4.783	1.306					
	Trachurus sp. [E]	PF	37.095		12.83	33.23	17.868	36.890	54.947	26.42	61.80	38.459
Clupeidae	*Hyperlophus vittatus* [E]	PF	7.477	2.509	51.01		7.624		0.111	5.861		2.960
	Sardinops sagax [E]	PF	25.039	89.533	20.92	3.877	46.280		11.553	27.87		17.951
	Spratelloides robustus	PF							0.006	0.417		0.210
	Sprattus novaehollandiae	PF										
	Unidentified sprat	PF										
	Unidentified clupeid	PF			0.188	0.787	0.233		0.013	0.430		0.219
Dinolestidae	*Dinolestes lewini*	PF				0.681	0.186					
Engraulidae	*Engraulis australis* [E]	PF				19.70	5.380			0.035		0.017
Emmelichthyidae	*Emmelichthys nitidus* [E]	PF										
Galaxiidae	*Galaxias cleaveri* [E]	PF										
	Galaxias maculatus [E]	PF										
	Unidentified galaxiid	PF										
Gempylidae	*Thyrsites atun* [E]	PF										
Gerreidae	*Parequula melbournensis* [E]	DF										
Gobiidae	Unidentified gobiid	DF										

Family (or higher taxon)	**Prey**	**Category**	**Northern NSW**					**Southern NSW**				
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**
Hemiramphidae	*Hyporhamphus australis* [E]	PF				5.272	1.440					
Leptoscopidae	*Lesueurina platycephala*	DF										
Mugilidae	*Myxus elongatus* [E]	PF								0.235		0.117
Pomatomidae	*Pomatomus saltatrix* [E]	PF		0.197			0.084					
Scombridae	*Scomber australasicus* [E]	PF	18.433		0.641	16.06	8.190	50.200	1.344	3.096		8.674
Scorpididae	*Atypichthys strigatus*	PF				0.234	0.064					
Sillaginidae	*Sillago ciliata* [E]	DF				1.908	0.521					
	Sillago flindersi [E]	DF		0.526	0.271	5.701	1.807	1.720	0.833	25.24		13.103
	Sillago sp.[E]	DF		0.307	1.264		0.256		0.556			0.195
Teleostei	Unidentified teleost remains		9.383	6.512	11.08	2.979	6.582	8.470	26.881	7.104	20.00	14.463
Molluscs												
Calyptraeidae	*Sigapatella calyptraeformis*	M				0.011	0.003		0.005			0.002
Mactridae	*Spisula trigonella*	M						0.020				0.003
Marginellidae	*Austroginella muscaria*	M										
Naticidae	Unidentified naticid	M				0.004	0.001					
Trochidae	*Bankivia fasciata*	M	0.004	0.009		0.001	0.005		0.024	0.043		0.030
	Phasianotrochus sp.	M										
Turritellidae	*Gazameda gunnii*	M							0.169			0.059
Volutidae	Unidentified volutid	M							0.001			0.000
Gastropoda	Unidentified gastropod remains	M	0.003	0.001		0.004	0.002					
Donacidae	*Donax deltoides*[E]	M	0.004				0.001					
Glycymerididae	*Glycymeris striatularis*	M				0.011	0.003					
	Glycymeris sp.	M	0.001				0.000					
	Unidentified glycymeridid	M								0.011		0.006
Mytilidae	*Mytilus edulis*[E]	M							0.043	0.022		0.026
	Unidentified mytilid	M				0.004	0.001		0.019			0.007
Nuculidae	*Nucula obliqua*	M		0.002			0.001					
Bivalvia	Unidentified bivalve remains	M				0.037	0.010	0.020		0.023		0.015
Mollusca	Unidentified mollusc remains	M	0.001				0.001	0.030	0.024		0.271	0.016

Family (or higher taxon)	Prey	Category	Northern NSW					Southern NSW				
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**
Loliginidae	*Photololigo* sp.[E]	C				1.467	0.401					
Sepiolidae	*Euprymna tasmanica*	C							0.134			0.047
Teuthida	Unidentified Teuthida	C						0.450		0.075		0.097
Cephalopoda	Unidentified cephalopod remains	C	0.009				0.002	0.110	0.051			0.032
Crustaceans												
Amphipoda	*Gammaridea* sp.	BC										
	Unidentified corophioid	BC										
	Unidentified eusirid	BC										
	Unidentified exoedicerotid	BC										
	Unidentified hyalellid	BC										
	Unidentified paracalliopid	BC										
	Unidentified amphipod	BC										
Balanidae	*Austromegabalanus nigrescens*	BC	0.008				0.002					
	Balanus trigonus	BC						0.003				0.000
Tetraclitidae	*Tesseropora rosea*	BC								0.011		0.006
Brachyura	Unidentified brachyuran	BC	0.036				0.007					
	Unidentified brachyuran megalopa	PC			0.265	0.030	0.034	0.017	0.310	0.162	5.742	0.292
	Unidentified brachyuran zoea	PC										
Grapsidae	Unidentified grapsid	BC										
Leucosiidae	*Ebalia intermedia*	BC										
Majidae	Unidentified majid	BC							0.003			0.001
Portunidae	*Ovalipes australiensis*[E]	BC		0.010			0.004		1.262	0.358		0.622
	Ovalipes sp.[E]	BC	0.010				0.002					
Caridea	*Macrobrachium* sp.	BC										
Cladocera	Unidentified cladoceran	PC										
Copepoda	Unidentified calanoid	PC										
	Unidentified copepod	PC										
Diogenidae	*Diogenes senex*	BC				0.030	0.008					
Euphausiacea	*Nyctiphanes australis*	PC										

Family (or higher taxon)	Prey	Category	Northern NSW					Southern NSW				
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall
	Unidentified euphausiid	PC							0.128			0.045
Isopoda	*Ligia australiensis*	BC										
	Paritodea ungulata	BC										
	Zuzara venosa	BC										
	Unidentified valvifera	BC										
	Unidentified isopod	BC		0.005	0.046	0.051	0.021	0.063	0.235	0.167	0.011	0.174
Luciferidae	*Lucifer hanseni*	PC										
Mysidae	*Paramesopodopsis rufa*	PC										
	Unidentified mysid	PC							0.124	0.016		0.052
Palaemonidae	*Palaemon intermedius*	BC										
Penaeidae	*Penaeus* sp.[E]	BC								0.016		0.008
Sergestidae	Unidentified sergestid	PC										
Stomatopoda	Unidentified squillid	BC										
	Unidentified stomatopod larvae	PC			0.032		0.003					
Thalassinidae	*Biffarius ceramicus*	BC										
	Unidentified thalassinid	BC										
Upogebiidae	Unidentified upogebiid	BC							0.001			0.000
Crustacea	Unidentified crustacean remains	BC							0.030			0.010
Plantae												
Alariaceae	*Ecklonia radiata*	P						0.063	0.018			0.015
Algae	Unidentified algae	P				0.007	0.002				0.368	0.006
Bonnemaisoniaceae	*Asparagopsis* sp.	P						0.000				0.000
Chlorophyta	Unidentified chlorophyte	P								0.019		0.009
Casuarinaceae	Unidentified casuarinaceae	P								0.000		0.000
Caulerpaceae	*Caulerpa filiformis*	P	0.161				0.033					
Dictyotaceae	*Dictyopteris muelleri*	P							0.005			0.002
	Dictyota dichotoma	P							0.104			0.036
	Padina fraseri	P	0.002				0.000					
Magnoliophyta	Unidentified magnoliophyte	P										

Family (or higher taxon)	Prey	Category	Northern NSW					Southern NSW				
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**
Phaeophyta	Unidentified phaeophyte	P	0.005		0.003		0.001		0.004	0.004		0.003
Rhodophyta	Unidentified rhodophyte	P										
Sargassaceae	*Cytsophora moniliformis*	P							0.001			0.000
	Sargassum sp.	P	0.016				0.003		0.002		0.412	0.008
Tracheophyta	Unidentified tracheophyte	P										
Zosteraceae	*Zostera capricorni*	P		0.001			0.001	0.021	0.021	0.187		0.103
Plantae	Unidentified plant remains	P	0.002	0.000	0.000	0.000	0.000					
Miscellaneous												
Aphroditidae	*Aphrodite australis*	Misc										
Onuphidae	*Australonuphis teres*	Misc								0.051		0.026
Bryozoa	Unidentified bryozoan	Misc				0.001	0.000			0.000		0.000
Chondrillidae	*Chondrilla australiensis*	Misc		0.023			0.010					
Insecta	Unidentified insect	Misc										
Nematoda	Unidentified nematode	Misc						0.105	0.038		0.249	0.032
Polychaeta	Unidentified polychaete	Misc										
Serpulidae	*Galeolaria caespitosa*	Misc	0.003				0.001		0.001			0.000
Sipuncula	Unidentified sipunculid	Misc							0.017			0.006
Teleostei	Fish eggs	Misc										
	Fish scales	Misc										
Zooplankton	Unidentified gelatinous zooplankton	Misc	0.704				0.143					
Charcoal		Misc							0.011			0.004
Fishing hook		Misc		0.008	0.001		0.003					
Rock		Misc	0.015		0.006	0.082	0.026	0.037	0.103	0.009	0.119	0.048
Sediment		Misc										
Wood		Misc	0.004				0.001					
Unidentified	Unidentified material	Misc	1.586	0.356	1.425	1.556	1.039	1.782	0.872	2.094	11.01	1.779
Total wet weight (g)			4226.5	8858.9	2058.	5688.	20832.4	698.3	1850.2	2623.	92.3	5264.1

Family (or higher taxon)	**Prey**	**Category**	**Northern NSW**					**Southern NSW**				
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**
Number of prey taxa consumed			24	16	15	29	54	18	42	31	10	56
Number of stomachs examined			253	160	114	265	792	166	463	325	82	1036
Number of empty stomachs			174	73	44	150	441	137	323	161	66	687
Average wet weight (g) of prey consumed per fish			53.500	101.82	29.40	49.46	59.351	24.078	13.216	15.99	5.769	15.083

Table 7.2. Prey taxa consumed (% wet weight) by eastern Australian salmon in four seasons in Victoria and Tasmania between February 2007 and January 2010 and for all states combined (bold). Fish with empty stomachs were not included in the analysis. Prey categories are PF – pelagic fishes, DF – demersal fishes, M – molluscs, C – cephalopods, PC – pelagic crustaceans, BC – benthic crustaceans, P – plants, Misc – miscellaneous. [E] denotes species of economic importance.

Family (or higher taxon)	**Prey**	**Category**	**Victoria**					**Tasmania**					**Total**
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**	
Teleosts													
Ambassidae	*Ambassis jacksoniensis*	PF		10.530			0.125						**0.003**
Atherinidae	*Atherinason hepsetoides*	PF									0.501	0.002	**0.001**
	Atherinosoma presbyteroides	PF								0.079		0.010	**0.004**
	Kestratherina brevirostris	PF									1.670	0.007	**0.003**
	Unidentified atherinind	PF		3.883			0.046		0.100	0.353	10.245	0.094	**0.034**
Arripididae	*Arripis trutta*	PF									3.764	0.017	**0.006**
Carangidae	*Trachurus declivis*	PF						1.991				1.679	**0.790**
	Trachurus novaezelandiae	PF											**0.649**
	Trachurus sp.	PF			54.77		53.890	45.869				38.681	**28.721**
Clupeidae	*Hyperlophus vittatus*	PF		24.795			0.295						**4.168**
	Sardinops sagax	PF						31.797				26.815	**34.653**
	Spratelloides robustus	PF											**0.026**
	Sprattus novaehollandiae	PF						0.157				0.133	**0.047**
	Unidentified sprat	PF						4.464		21.369		6.580	**2.308**
	Unidentified clupeid	PF								61.283		8.074	**2.975**
Dinolestidae	*Dinolestes lewini*	PF											**0.092**
Engraulidae	*Engraulis australis*	PF						1.935				1.632	**3.248**
Emmelichthyidae	*Emmelichthys nitidus*	PF						1.962				1.654	**0.580**
Galaxiidae	*Galaxias cleaveri*	PF									0.971	0.004	**0.002**
	Galaxias maculatus	PF						0.022			6.936	0.049	**0.017**
	Unidentified galaxiid	PF						0.006				0.005	**0.002**
Gempylidae	*Thyrsites atun*	PF						1.028				0.867	**0.304**
Gerreidae	*Parequula melbournensis*	DF						1.740		7.092		2.402	**0.842**
Gobiidae	Unidentified gobiid	DF		14.937			0.178						**0.005**

Family (or higher taxon)	Prey	Category	Victoria					Tasmania					Total
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall	
Hemiramphidae	*Hyporhamphus australis*	PF											**0.715**
Leptoscopidae	*Lesueurina platycephala*	DF						0.012				0.010	**0.004**
Mugilidae	*Myxus elongatus*	PF											**0.015**
Pomatomidae	*Pomatomus saltatrix*	PF			1.839		1.809						**0.090**
Scombridae	*Scomber australasicus*	PF			10.26		10.095						**5.429**
Scorpididae	*Atypichthys strigatus*	PF											**0.032**
Sillaginidae	*Sillago ciliata*	DF											**0.259**
	Sillago flindersi	DF			0.217		0.214						**2.549**
	Sillago sp.	DF											**0.152**
Teleostei	Unidentified teleost remains		79.036	3.062	30.37		30.252	8.846	9.043	7.851	4.174	8.698	**8.949**
Molluscs													
Calyptraeidae	*Sigapatella calyptraeformis*	M											**0.002**
Mactridae	*Spisula trigonella*	M											**0.000**
Marginellidae	*Austroginella muscaria*	M			0.005		0.004						**0.000**
Naticidae	Unidentified naticid	M											**0.001**
Trochidae	*Bankivia fasciata*	M											**0.006**
	Phasianotrochus sp.	M									0.106	0.000	**0.000**
Turritellidae	*Gazameda gunnii*	M											**0.007**
Volutidae	Unidentified volutid	M											**0.000**
Gastropoda	Unidentified gastropod remains	M			0.001		0.001	0.002		0.000		0.001	**0.002**
Donacidae	*Donax deltoides*	M											**0.000**
Glycymerididae	*Glycymeris striatularis*	M											**0.000**
	Glycymeris sp.	M											**0.002**
	Unidentified glycymeridid	M											**0.001**
Mytilidae	*Mytilus edulis*	M											**0.003**
	Unidentified mytilid	M											**0.001**
Nuculidae	*Nucula obliqua*	M											**0.000**
Bivalvia	Unidentified bivalve remains	M			0.068		0.067	0.012		0.001		0.010	**0.012**
Mollusca	Unidentified mollusc remains	M			0.143		0.141						**0.006**

Family (or higher taxon)	Prey	Category	Victoria					Tasmania					Total
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall	
Loliginidae	*Photololigo* sp.	C											**0.199**
Sepiolidae	*Euprymna tasmanica*	C											**0.006**
Teuthida	Unidentified Teuthida	C											**0.012**
Cephalopoda	Unidentified cephalopod remains	C							0.013		2.064	0.010	**0.008**
Crustaceans													
Amphipoda	*Gammaridea* sp.	BC									1.260	0.006	**0.002**
	Unidentified corophioid	BC						0.003	0.008	0.043		0.009	**0.003**
	Unidentified eusirid	BC						0.001	0.060		3.688	0.019	**0.007**
	Unidentified exoedicerotid	BC						0.017	2.016	0.285	8.454	0.131	**0.046**
	Unidentified hyalellid	BC						0.004				0.004	**0.001**
	Unidentified paracalliopid	BC						0.003				0.003	**0.001**
	Unidentified amphipod	BC		0.597			0.007	0.017	0.237	0.030	2.545	0.034	**0.012**
Balanidae	*Austromegabalanus nigrescens*	BC											**0.001**
	Balanus trigonus	BC											**0.000**
Tetraclitidae	*Tesseropora rosea*	BC											**0.001**
Brachyura	Unidentified brachyuran	BC						0.008	0.040		22.159	0.107	**0.041**
	Unidentified brachyuran megalopa	PC											**0.054**
	Unidentified brachyuran zoea	PC						0.008	0.638	0.019	0.504	0.025	**0.009**
Grapsidae	Unidentified grapsid	BC									0.926	0.004	**0.001**
Leucosiidae	*Ebalia intermedia*	BC									2.580	0.012	**0.004**
Majidae	Unidentified majid	BC											**0.000**
Portunidae	*Ovalipes australiensis*	BC			0.022		0.021			0.024		0.003	**0.082**
	Ovalipes sp.	BC											**0.001**
Caridea	*Macrobrachium* sp.	BC						0.004	0.129	0.029	3.961	0.028	**0.010**
Cladocera	Unidentified cladoceran	PC							0.173			0.004	**0.001**
Copepoda	Unidentified calanoid	PC						0.040	0.091	0.340	8.040	0.117	**0.041**
	Unidentified copepod	PC						0.012	2.104	0.686	1.412	0.150	**0.052**
Diogenidae	*Diogenes senex*	BC											**0.004**
Euphausiacea	*Nyctiphanes australis*	PC							73.266	0.024	0.296	1.504	**0.528**

Family (or higher taxon)	Prey	Category	Victoria					Tasmania					Total
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall	
	Unidentified euphausiid	PC											**0.006**
Isopoda	*Ligia australiensis*	BC								0.001		0.000	**0.000**
	Paritodea ungulata	BC									3.339	0.015	**0.005**
	Zuzara venosa	BC								0.005		0.001	**0.000**
	Unidentified valvifera	BC								0.003	1.867	0.009	**0.003**
	Unidentified isopod	BC		3.734	0.002		0.046		0.031	0.001	0.046	0.001	**0.034**
Luciferidae	*Lucifer hanseni*	PC							0.027			0.001	**0.000**
Mysidae	*Paramesopodopsis rufa*	PC						0.002	6.299	0.219	1.169	0.165	**0.058**
	Unidentified mysid	PC		0.448			0.005	0.008	0.003		1.254	0.012	**0.011**
Palaemonidae	*Palaemon intermedius*	BC	20.964	2.689			0.121						**0.003**
Penaeidae	*Penaeus* sp.	BC											**0.001**
Sergestidae	Unidentified sergestid	PC							1.395	0.036	1.548	0.040	**0.014**
Stomatopoda	Unidentified squillid	BC									1.320	0.006	**0.002**
	Unidentified stomatopod larvae	PC									1.867	0.008	**0.004**
Thalassinidae	*Biffarius ceramicus*	BC							3.455	0.031		0.075	**0.026**
	Unidentified thalassinid	BC						0.024	0.352	0.077	0.789	0.041	**0.015**
Upogebiidae	Unidentified upogebiid	BC											**0.000**
Crustacea	Unidentified crustacean remains	BC		1.120			0.013	0.000	0.395	0.003	0.501	0.011	**0.005**
Plantae													
Alariaceae	*Ecklonia radiata*	P											**0.002**
Algae	Unidentified algae	P											**0.002**
Bonnemaisoniaceae	*Asparagopsis* sp.	P											**0.000**
Chlorophyta	Unidentified chlorophyte	P											**0.001**
Casuarinaceae	Unidentified casuarinaceae	P											**0.000**
Caulerpaceae	*Caulerpa filiformis*	P											**0.016**
Dictyotaceae	*Dictyopteris muelleri*	P											**0.000**
	Dictyota dichotoma	P											**0.005**
	Padina fraseri	P											**0.000**
Magnoliophyta	Unidentified magnoliophyte	P						0.001		0.005		0.001	**0.000**

Family (or higher taxon)	**Prey**	**Category**	**Victoria**					**Tasmania**					**Total**
			Sp	**Su**	**Au**	**Wi**	**Overall**	**Sp**	**Su**	**Au**	**Wi**	**Overall**	
Phaeophyta	Unidentified phaeophyte	P								0.026		0.003	**0.002**
Rhodophyta	Unidentified rhodophyte	P			0.001		0.001						**0.000**
Sargassaceae	*Cytsophora moniliformis*	P											**0.000**
	Sargassum sp.	P											**0.003**
Tracheophyta	Unidentified tracheophyte	P			0.020		0.020						**0.001**
Zosteraceae	*Zostera capricorni*	P											**0.013**
Plantae	Unidentified plant remains	P											**0.000**
Miscellaneous													
Aphroditidae	*Aphrodite australis*	Misc		34.205			0.407						**0.011**
Onuphidae	*Australonuphis teres*	Misc											**0.003**
Bryozoa	Unidentified bryozoan	Misc			0.014		0.014						**0.001**
Chondrillidae	*Chondrilla australiensis*	Misc											**0.005**
Insecta	Unidentified insect	Misc						0.000	0.023		0.030	0.001	**0.000**
Nematoda	Unidentified nematode	Misc											**0.004**
Serpulidae	*Galeolaria caespitosa*	Misc											**0.000**
Sipuncula	Unidentified sipunculid	Misc											**0.001**
Teleostei	Fish eggs	Misc							0.003			0.000	**0.000**
	Fish scales	Misc								0.052		0.007	**0.002**
Zooplankton	Unidentified gelatinous zooplankton	Misc											**0.071**
Charcoal		Misc											**0.000**
Fishing hook		Misc											**0.002**
Rock		Misc			0.163		0.161						**0.023**
Sediment		Misc						0.003	0.040	0.034	0.015	0.008	**0.003**
Wood		Misc											**0.000**
Unidentified	Unidentified material	Misc			2.101		2.067		0.060	0.001		0.001	**0.796**
Total wet weight (g)			4.8	13.4	1108.	0.0	1126.4	12401.	301.0	1937.4	65.9	14705.4	**41928.3**
Number of prey taxa consumed			2	11	17	0	26	34	27	32	34	62	**135**

Family (or higher taxon)	Prey	Category	Victoria					Tasmania					Total
			Sp	Su	Au	Wi	Overall	Sp	Su	Au	Wi	Overall	
Number of stomachs examined			19	43	181	0	243	721	670	799	848	3048	**5109**
Number of empty stomachs			16	28	99	0	143	180	78	125	301	684	**1955**
Average wet weight (g) of prey consumed per fish			1.590	0.893	13.51	0.000	11.264	22.923	0.508	2.874	0.120	6.247	**13.294**

Table 7.3. Percentage contribution (in terms of wet weight) of eight prey categories to the diet of eastern Australian salmon in northern NSW, southern NSW, Victoria and Tasmania.

Prey Category	Northern NSW	Southern NSW	Victoria	Tasmania	Overall
Pelagic fishes	95.641	83.070	96.513	95.003	**93.863**
Demersal fishes	2.584	13.298	0.392	2.412	**3.810**
Molluscs	0.028	0.167	0.213	0.012	**0.045**
Cephalopods	0.402	0.176	0.000	0.010	**0.225**
Benthic crustaceans	0.044	0.822	0.209	0.516	**0.312**
Pelagic crustaceans	0.038	0.389	0.005	2.025	**0.778**
Plants	0.041	0.184	0.020	0.005	**0.046**
Miscellaneous	1.222	1.895	2.648	0.017	**0.922**

7.3.2. Regional comparisons

The number of prey taxa consumed was similar in northern NSW (54 taxa), southern NSW (56 taxa) and Tasmania (62 taxa), but was less in Victoria (26 taxa). The relative importance of each prey category was similar for all three regions examined (Tables 7.1, 7.2 & 7.3). Pelagic fishes were by far the largest contributor to the diet in terms of WW in northern NSW, southern NSW, Victoria and Tasmania (95.6, 83.1, 96.5 & 95.0% respectively) (Table 7.3). The importance of each species to this group did however, vary substantially between locations. In northern NSW the Australian sardine made up almost half (46.3%) of all prey by WW, approximately a quarter (26.8%) of the diet in Tasmania, but only 18.0% in southern NSW and was not found in the stomachs of any fish sampled from Victoria. In contrast, scads were extremely important prey in Victoria (53.9%), Tasmania (40.5%) and southern NSW (38.5%), but made up only 19.6% by WW of the diet in northern NSW. The small schooling baitfishes sandy sprats and Australian anchovy combined were much more important prey in northern NSW (13.0% WW) than in southern NSW (3.0%), Victoria (0.3%) or Tasmania (1.7%). Blue mackerel were found to be of similar importance in northern NSW (8.2%), southern NSW (8.7%) and Victoria (10.1%), but did not appear in the diet of fish collected from Tasmania. Demersal fishes (mainly eastern school whiting) contributed 13.3% by WW to the diet in southern NSW, but made a much smaller contribution in northern NSW (2.6%), Victoria (0.4%) and Tasmania (2.4%).

Some species occurred in one region only. For example, the eastern sea garfish *Hyporhamphus australis* and sand whiting *S. ciliata* occurred in northern NSW only (0.7% & 0.3% by WW overall respectively) and the southern silverbelly *Parequula melbournensis* (0.84%), redbait *Emmelichthys nitidis* (0.6%) and barracouta *Thyrsites atun* (0.3%) in Tasmania only. Pelagic crustaceans contributed very little to the diet in northern NSW (0.04%), southern NSW (0.4%) or Victoria (0.01%), but made up 2.0% of the diet by WW in Tasmania (Table 7.3). This was mainly due to the importance of the pelagic euphausiid *Nyctiphanes australis*, which contributed 1.5% by WW to the diet in Tasmania (0.5% overall) (Tables 7.2 & 7.5). All other prey categories contributed < 1.0% by WW across S.E. Australia, except miscellaneous organisms/items (0.02 – 2.7%) (Table 7.3).

The non-metric multi-dimensional scaling (nMDS) ordination (Fig. 7.2) and one-way ANOSIM of diet biomass showed significant differences in the taxonomic composition of the diet between regions (Global R = 0.446, P = 0.001). Pairwise comparisons revealed that the diet of eastern Australian salmon collected from Tasmania to be significantly different (P = 0.001 in each case) to the diet of fish from northern NSW, southern NSW and Victoria (which were similar). SIMPER revealed that the average dissimilarity in diets between Tasmania and the other three regions was high (98.8 – 99.0%). These differences were primarily due to dissimilarities in the abundances of unidentified teleosts, *Trachurus* sp. and Australian sardines between Tasmania and the other three regions.

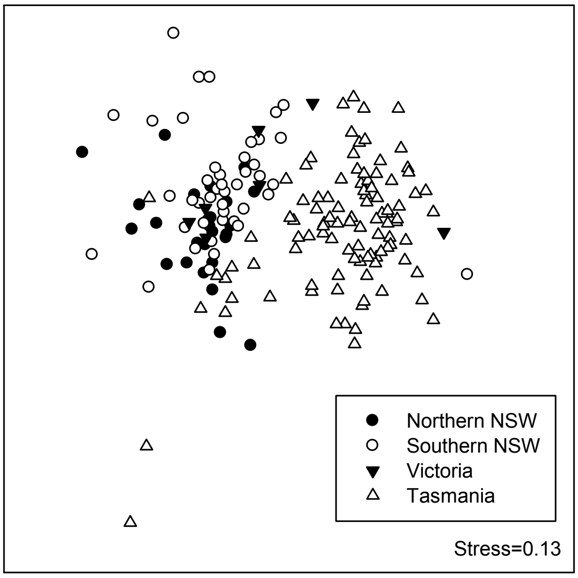


Figure 7.2. Non-metric multidimensional scaling ordination of diet biomass for eastern Australian salmon caught from northern NSW (●), southern NSW (○), Victoria (▼) and Tasmania (Δ) between October 2006 and January 2010. Stress value is shown.

7.3.3. Seasonal comparisons

The number of prey taxa consumed was similar between seasons (Tables 7.1 & 7.2). Overall the diet was most diverse in summer (69 taxa) and least diverse in spring and winter (62 taxa each). There were 64 taxa present in the diet in autumn. Pelagic fishes were by far the largest contributor to the diet across all seasons in all locations in terms of WW (average for all locations: spring 97.8%, summer 95.6%, autumn 86.8%, winter 88.3%). Benthic fishes were the second largest contributor to the diet in terms of WW in all seasons (except summer) and were much more important in autumn (10.8%) and winter (7.4%) than in spring (1.3%) and summer (0.9%). Pelagic crustaceans were more important to the diet in summer (2.4%) than in any of the other seasons (mean WW 0.3%). Similarly, cephalopods were more important in winter (1.5%) than in any of the other seasons (mean 0.03%).

When the data for all locations were combined, the nMDS ordination (Fig. 7.3) and one-way ANOSIM showed that there was a significant difference in seasonal diet composition overall (Global R = 0.052, P = 0.001). Pairwise comparisons revealed that the diet differed significantly between summer and winter (P = 0.001), autumn and winter (P = 0.003) and spring and summer (P = 0.018). SIMPER confirmed these differences with average dissimilarity in diets between these seasons ranging from 95.4 to 96.1%. These differences were again revealed to be a result of the high dissimilarities in the abundances of the three most abundant species: unidentified teleosts, *Trachurus* sp. and Australian sardines.

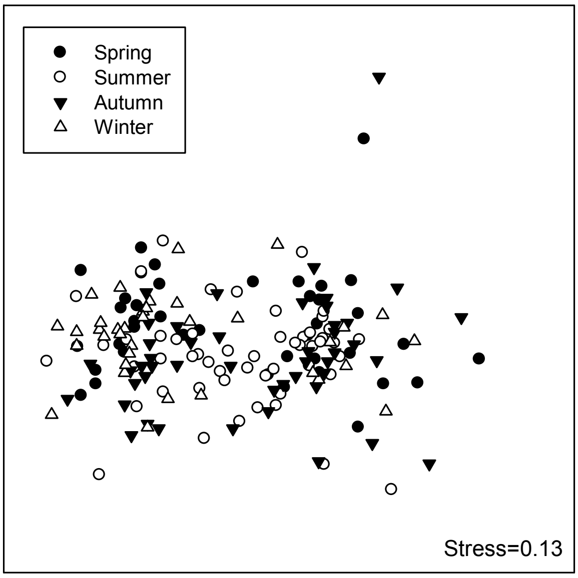


Figure 7.3 Non-metric multidimensional scaling ordination of diet biomass for eastern Australian salmon caught in each of the four seasons; spring (●), summer (○), autumn (▼) and winter (Δ) between October 2006 and January 2010 for all regions combined in south-east Australia. Stress value is shown.

Seasons between regions

The pattern of seasonal variation also varied considerably by region. In northern NSW, the fish had the most diverse diet in spring and winter (24 & 29 taxa respectively) and the least diverse diet in summer and autumn (16 & 15 taxa respectively) (Table 7.1). In contrast, fish from southern NSW had the most diverse diet in summer and autumn (42 & 31 taxa respectively) and the least diverse diet in spring and winter (18 & 10 taxa respectively). Fish from Victoria showed a similar pattern to that of southern NSW with the most diverse diet found in summer and autumn (11 & 17 taxa respectively) and the least diverse diet in spring (2 taxa) (Table 7.2). Eastern Australian salmon collected from Tasmania had the most diverse diet in winter (62 taxa) and a similar, but less diverse diet in spring, summer and autumn (27, 32 & 34 taxa, respectively).

The importance of each species to the diet in each season also varied considerably between regions. In northern NSW, Australian sardines were found in stomachs in all seasons (average 34.8% WW) and were most important in summer (89.5%), whereas in southern NSW it was found in summer (11.6%) and autumn (27.9%) only and in Tasmania in spring (31.8%) only (Tables 7.1 & 7.2). Australian sardines were not found in the stomachs of any fish sampled from Victoria. *Trachurus* sp. were found in stomachs in all seasons in southern NSW (average 46.0%) and three out of four seasons in northern NSW (average 27.7%) (Table 7.2). In southern NSW, they were most important in winter (61.8%), whereas in northern NSW they were not found at all in summer and were most important in spring (37.1%) (Table 7.1). In Victoria and Tasmania however, *Trachurus* sp. were only found in one season in each region; autumn (54.8%) and spring (45.9%), respectively (Table 7.2). Largest WWs for the small clupeid sandy sprat occurred in northern NSW (51.0%) and southern NSW (5.9%) in autumn, but occurred in summer in Victoria (24.8%) and not at all in Tasmania (Table 7.2). Blue mackerel occurred in the diet in three out of four seasons in northern NSW and was most important in spring (18.4%) and winter (16.1%) (Table 7.1). Similarly in southern NSW, it again occurred in three out of four seasons and was also most important in spring (50.2%). However, it only occurred in autumn in Victoria (10.2%) and not at all in Tasmania (Table 7.2). Australian anchovy occurred in each of northern NSW, southern NSW and Tasmania, but in a different season for each region: winter in northern NSW (19.7%), autumn in southern NSW (0.04%) and spring in Tasmania (1.9%) (Tables 7.1 & 7.2). Eastern school whiting were found in stomachs in three of four seasons in northern NSW (average 2.2%) and were most important in winter (5.7%) (Table 7.1). In southern NSW, they were also present in three out of four seasons (average 9.3%), but were most important in autumn (25.3%). In Victoria, they were found only in autumn (0.2%) and were not found at all in Tasmania (Table 7.2).

Larval brachyurans (megalopa and zoea) were present in the diet in all seasons in southern NSW and Tasmania, autumn and winter in northern NSW, but not at all in Victoria (Tables 7.1 & 7.2). Euphausiids were not present in the diet in northern NSW or Victoria, only in summer in southern NSW (0.1%), but in three out of four seasons in Tasmania, including 73.3% of the diet in summer (Tables 7.1 & 7.2).

<u>Seasons within regions</u>

The only region for which ANOSIM detected significant variation in diet with season was Tasmania (Global R = 0.079, P = 0.002). Pairwise comparisons revealed that the diet in Tasmania differed significantly between all seasons except autumn and summer (P = 0.262) (Fig. 7.4). SIMPER confirmed these differences with average dissimilarity in diets between these seasons ranging from 84.4 to 89.9%. These differences were the result of the high dissimilarities in the abundances of the most important prey items for each season: unidentified copepods in autumn, unidentified amphipods in spring, unidentified teleosts in summer and unidentified exoedicerotid amphipods in winter. In contrast, there was no significant overall seasonal variability in diet detected by ANOSIM for northern NSW (Global R = 0.091, P = 0.077), southern NSW (Global R = -0.028, P = 0.675) or Victoria (Global R = 0.600, P = 0.333). Despite the lack of significant differences in overall diet between seasons in northern NSW, pairwise comparisons revealed that the diet in summer was significantly different to the diet in winter (P = 0.001). The average dissimilarity between diets was 93.4% and this was due mainly to high abundances of Australian sardines in the diet in summer and high abundances of *Trachurus* sp. in the diet in winter.

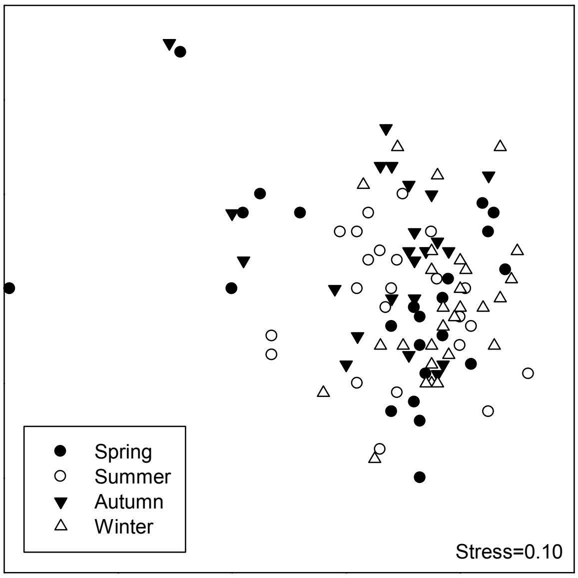


Figure 7.4. Non-metric multidimensional scaling ordination of diet biomass for eastern Australian salmon caught in each of the four seasons; spring (●), summer (○), autumn (▼) and winter (Δ) between August 2008 and January 2010 from Tasmania. Stress value is shown.

7.3.4. Size-related comparisons

Overall, large fish had the most diverse diet (77 taxa) with small (58 taxa) and medium-sized fish (59 taxa) possessing less diverse diets (Tables 7.4 & 7.5). This pattern was consistent in both northern NSW and southern NSW with large fish having the most diverse diet (51 & 38 taxa respectively), while small fish had the least diverse diet (2 & 19 taxa respectively) (Table 7.4). However, the opposite pattern was found for eastern Australian salmon collected from Tasmania with small fish possessing the most diverse diet (40 taxa) and large fish the least diverse (14 taxa) (Table 7.5). In the diet of fish from Victoria, the number of prey taxa consumed was similar regardless of size class (11, 10 & 10 taxa for S, M & L fish respectively).

Overall, pelagic teleosts were the most important dietary group for fish of all size classes, however they became progressively more important to the diet with increasing size class. They made up only 37.1% by WW of the diet in small fish, but made up the majority of the diet in medium-sized (88.4%) and large (94.8%) fish (Tables 7.4 & 7.5). Demersal fishes were more important for small fish (10.5%) than for medium (4.2%) or large fish (3.7%). Pelagic and benthic crustaceans were also considerably more important dietary items for small fish (28.2 & 20.0% respectively) than for medium (4.9 & 1.2% respectively) or large fish (0.2 & 0.1% respectively).

The nMDS ordination (Fig. 7.5) and one-way ANOSIM showed significant differences in the taxonomic composition of the diet of different size classes of fish (Global *R* = 0.408, *P* = 0.001). Pairwise comparisons revealed that the diets of all three size classes were significantly different to one another (*P* = 0.001 to 0.003). SIMPER revealed that the average dissimilarity in diets between each size class was high (91.1 – 99.2%). These differences were primarily due to dissimilarities in the abundances of unidentified teleosts, *Trachurus* sp. and Australian sardines.

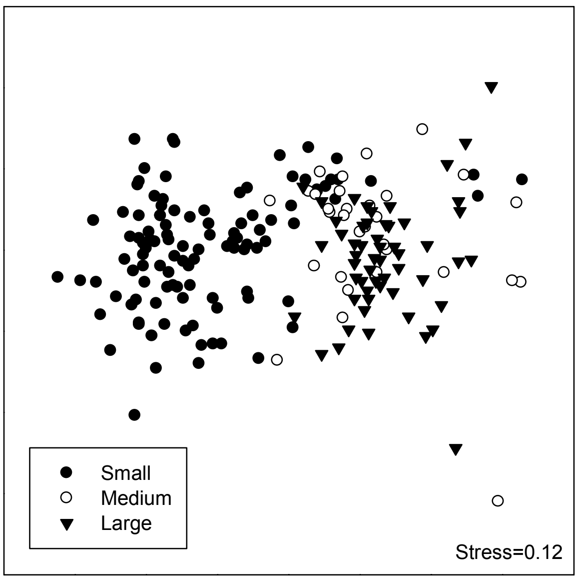


Figure 7.5. Non-metric multidimensional scaling ordination of diet biomass for small (●, 0 – 20 cm FL), medium (○, 20 – 40 cm FL) and large (▼, > 40 cm FL) eastern Australian salmon caught between October 2006 and January 2010 for all regions combined in south-east Australia. Stress value is shown.

Table 7.4. Prey taxa consumed (% wet weight) by small (< 20 cm FL), medium (20 – 40 cm FL) and large (> 40 cm FL) eastern Australian salmon in northern and southern NSW between October 2006 and March 2009. Fish with empty stomachs were not included in the analysis. Prey categories are PF – pelagic fishes, DF – demersal fishes, M – molluscs, C – cephalopods, PC – pelagic crustaceans, BC – benthic crustaceans, P – plants, Misc – miscellaneous.

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	Medium	Large	Overall	Small	Medium	Large	Overall
Teleosts										
Ambassidae	*Ambassis jacksoniensis*	PF								
Atherinidae	*Atherinason hepsetoides*	PF								
	Atherinosoma presbyteroides	PF								
	Kestratherina brevirostris	PF								
	Unidentified atherinid	PF								
Arripididae	*Arripis trutta*	PF								
Carangidae	*Trachurus declivis*	PF			0.412	0.405				
	Trachurus novaezelandiae	PF			1.330	1.306				
	Trachurus sp.	PF		13.142	17.960	17.868	1.336	37.369	39.535	38.457
Clupeidae	*Hyperlophus vittatus*	PF	30.284	7.809	7.614	7.624	19.26	23.278		2.960
	Sardinops sagax	PF		7.420	47.003	46.280	2.422	1.069	20.459	17.950
	Spratelloides robustus	PF					3.422	1.238		0.210
	Sprattus novaehollandiae	PF								
	Unidentified sprat	PF								
	Unidentified clupeid	PF		7.294	0.105	0.233	5.629	0.872		0.219
Dinolestidae	*Dinolestes lewini*	PF			0.190	0.186				
Engraulidae	*Engraulis australis*	PF			5.480	5.380		0.159		0.017
Emmelichthyidae	*Emmelichthys nitidus*	PF								
Galaxiidae	*Galaxias cleaveri*	PF								
	Galaxias maculatus	PF								
	Unidentified galaxiid	PF								
Gempylidae	*Thyrsites atun*	PF								
Gerreidae	*Parequula melbournensis*	DF								
Gobiidae	Unidentified gobiid	DF								

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	Medium	Large	Overall	Small	Medium	Large	Overall
Hemiramphidae	*Hyporhamphus australis*	PF		9.523	1.292	1.440				
Leptoscopidae	*Lesueurina platycephala*	DF								
Mugilidae	*Myxus elongatus*	PF					5.319			0.117
Pomatomidae	*Pomatomus saltatrix*	PF			0.086	0.084				
Scombridae	*Scomber australasicus*	PF		35.805	7.688	8.190		0.593	9.907	8.674
Scorpididae	*Atypichthys strigatus*	PF			0.065	0.064				
Sillaginidae	*Sillago ciliata*	DF			0.531	0.521				
	Sillago flindersi	DF		1.492	1.813	1.807	23.98	2.545	14.149	13.102
	Sillago sp.	DF		1.744	0.229	0.256		1.795		0.195
Teleostei	Unidentified teleost remains		69.716	13.014	6.445	6.582	24.68	24.417	12.955	14.462
Molluscs										
Calyptraeidae	*Sigapatella calyptraeformis*	M			0.003	0.003			0.002	0.002
Mactridae	*Spisula trigonella*	M							0.004	0.003
Marginellidae	*Austroginella muscaria*	M								
Naticidae	Unidentified naticid	M			0.001	0.001				
Trochidae	*Bankivia fasciata*	M		0.003	0.005	0.005			0.035	0.030
	Phasianotrochus sp.	M								
Turritellidae	*Gazameda gunnii*	M							0.068	0.059
Volutidae	Unidentified volutid	M							0.000	0.000
Gastropoda	Unidentified gastropod	M			0.000	0.000			0.003	0.003
	Unidentified gastropod remains	M			0.002	0.002				
Donacidae	*Donax deltoides*	M			0.001	0.001				
Glycymerididae	*Glycymeris striatularis*	M			0.003	0.003				
	Glycymeris sp.	M			0.000	0.000				
	Unidentified glycymeridid	M							0.007	0.006
Mytilidae	*Mytilus edulis*	M							0.030	0.026
	Unidentified mytilid	M			0.001	0.001			0.008	0.007
Nuculidae	*Nucula obliqua*	M			0.001	0.001				
Bivalvia	Unidentified bivalve	M								

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	**Medium**	**Large**	**Overall**	**Small**	**Medium**	**Large**	**Overall**
	Unidentified bivalve remains	M			0.010	0.010			0.017	0.015
Mollusca	Unidentified mollusc	M							0.010	0.008
	Unidentified mollusc remains	M			0.000	0.000		0.075		0.008
Loliginidae	*Photololigo* sp.	C			0.408	0.401				
Sepiolidae	*Euprymna tasmanica*	C						0.087	0.043	0.047
Teuthida	Unidentified Teuthida	C					1.690		0.068	0.096
Cephalopoda	Unidentified cephalopod remains	C			0.002	0.002			0.037	0.032
Crustaceans										
Amphipoda	*Gammaridea* sp.	BC								
	Unidentified corophioid	BC								
	Unidentified eusirid	BC								
	Unidentified exoedicerotid	BC								
	Unidentified hyalellid	BC								
	Unidentified paracalliopid	BC								
	Unidentified amphipod	BC								
Balanidae	*Austromegabalanus nigrescens*	BC			0.002	0.002				
	Balanus trigonus	BC						0.003	0.000	0.001
Tetraclitidae	*Tesseropora rosea*	BC							0.007	0.006
Brachyura	Unidentified brachyuran	BC			0.007	0.007				
	Unidentified brachyuran megalopa	PC		0.260	0.030	0.034	4.440	0.773	0.127	0.292
	Unidentified brachyuran zoea	PC								
Grapsidae	Unidentified grapsid	BC								
Leucosiidae	*Ebalia intermedia*	BC								
Majidae	Unidentified majid	BC						0.009		0.001
Portunidae	*Ovalipes australiensis*	BC			0.004	0.004		3.663	0.257	0.622
	Ovalipes sp.	BC		0.115		0.002				
Caridea	*Macrobrachium* sp.	BC								
Cladocera	Unidentified cladoceran	PC								
Copepoda	Unidentified calanoid	PC								

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	Medium	Large	Overall	Small	Medium	Large	Overall
	Unidentified copepod	PC								
Diogenidae	*Diogenes senex*	BC			0.008	0.008				
Euphausiacea	*Nyctiphanes australis*	PC								
	Unidentified euphausiid	PC					2.043			0.045
Isopoda	*Ligia australiensis*	BC								
	Paritodea ungulata	BC								
	Zuzara venosa	BC								
	Unidentified valvifera	BC								
	Unidentified isopod	BC			0.021	0.021	0.431		0.191	0.176
Luciferidae	*Lucifer hanseni*	PC								
Mysidae	*Paramesopodopsis rufa*	PC								
	Unidentified mysid	PC					0.701	0.337		0.052
Palaemonidae	*Palaemon intermedius*	BC								
Penaeidae	*Penaeus* sp.	BC						0.072		0.008
Sergestidae	Unidentified sergestid	PC								
Stomatopoda	Unidentified squillid	BC								
	Unidentified stomatopod larvae	PC		0.174		0.003				
Thalassinidae	*Biffarius ceramicus*	BC								
	Unidentified thalassinid	BC								
Upogebiidae	Unidentified upogebiid	BC							0.000	0.000
Crustacea	Unidentified crustacean remains	BC					0.474			0.010
Plantae										
Alariaceae	*Ecklonia radiata*	P						0.134		0.015
Algae	Unidentified algae	P			0.002	0.002			0.007	0.006
Bonnemaisoniaceae	*Asparagopsis* sp.	P						0.002		0.000
Chlorophyta	Unidentified chlorophyte	P						0.087		0.009
Casuarinaceae	Unidentified casuarinaceae	P							0.000	0.000
Caulerpaceae	*Caulerpa filiformis*	P			0.033	0.033				
Dictyotaceae	*Dictyopteris muelleri*	P							0.002	0.002

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	Medium	Large	Overall	Small	Medium	Large	Overall
	Dictyota dichotoma	P							0.042	0.036
	Padina fraseri	P			0.000	0.000				
Magnoliophyta	Unidentified magnoliophyte	P								
Phaeophyta	Unidentified phaeophyte	P			0.001	0.001		0.012	0.003	0.004
Rhodophyta	Unidentified rhodophyte	P								
Sargassaceae	*Cytsophora moniliformis*	P							0.000	0.000
	Sargassum sp.	P			0.003	0.003		0.066	0.001	0.008
Tracheophyta	Unidentified tracheophyte	P								
Zosteraceae	*Zostera capricorni*	P			0.000	0.000				
Plantae	Unidentified plant remains	P			0.001	0.001	0.112	0.045	0.111	0.104
Miscellaneous										
Aphroditidae	*Aphrodite australis*	Misc								
Onuphidae	*Australonuphis teres*	Misc					1.164			0.026
Bryozoa	Unidentified bryozoan	Misc			0.000	0.000			0.000	0.000
Chondrillidae	*Chondrilla australiensis*	Misc			0.010	0.010				
Insecta	Unidentified insect	Misc								
Nematoda	Unidentified nematode	Misc					0.009	0.178	0.016	0.033
Serpulidae	*Galeolaria caespitosa*	Misc			0.001	0.001		0.002		0.000
Sipuncula	Unidentified sipunculid	Misc					0.276			0.006
Teleostei	Fish eggs	Misc								
	Fish scales	Misc								
Zooplankton	Unidentified gelatinous zooplankton	Misc			0.145	0.143				
Charcoal		Misc							0.004	0.004
Fishing hook		Misc			0.003	0.003				
Rock		Misc			0.027	0.026		0.359	0.010	0.048
Sediment		Misc								
Wood		Misc			0.001	0.001				
Unidentified	Unidentified material	Misc		2.205	1.018	1.039	2.603	0.759	1.886	1.779

Family (or higher taxon)	Prey	Category	Northern NSW				Southern NSW			
			Small	Medium	Large	Overall	Small	Medium	Large	Overall
Total wet weight (g)			6.3	373.3	20452.8	20832.4	116.0	573.3	4575.1	5264.4
Number of prey taxa consumed			2	14	51	53	19	28	38	56
Number of stomachs examined			5	71	716	792	171	213	652	1036
Number of empty stomachs			2	41	398	441	105	132	450	687
Average wet weight (g) of prey consumed per fish			2.113	12.443	64.317	59.352	1.758	7.078	22.649	15.084

Table 7.5. Prey taxa consumed (% wet weight) by small (< 20 cm FL), medium (20 – 40 cm FL) and large (> 40 cm FL) eastern Australian salmon in Victoria and Tasmania between February 2007 and January 2010 and for all regions combined (bold). Fish with empty stomachs were not included in the analysis. Prey categories are PF – pelagic fishes, DF – demersal fishes, M – molluscs, C – cephalopods, PC – pelagic crustaceans, BC – benthic crustaceans, P – plants, Misc – miscellaneous.

Family (or higher taxon)	Prey	Category	Victoria				Tasmania				Total
			Small	Medium	Large	Overall	Small	Medium	Large	Overall	
Teleosts											
Ambassidae	*Ambassis jacksoniensis*	PF	7.764			0.125					**0.003**
Atherinidae	*Atherinason hepsetoides*	PF					0.207			0.002	**0.001**
	Atherinosoma presbyteroides	PF					0.961			0.010	**0.004**
	Kestratherina brevirostris	PF						0.058		0.007	**0.003**
	Unidentified atherinid	PF	2.863			0.046	3.532	0.437		0.094	**0.034**
Arripididae	*Arripis trutta*	PF						0.131		0.017	**0.006**
Carangidae	*Trachurus declivis*	PF							1.951	1.679	**0.790**
	Trachurus novaezelandiae	PF									**0.649**
	Trachurus sp.	PF		42.575	65.812	53.890		5.573	44.116	38.682	**28.721**
Clupeidae	*Hyperlophus vittatus*	PF	18.282			0.295					**4.168**
	Sardinops sagax	PF						3.543	30.630	26.815	**34.653**
	Spratelloides robustus	PF									**0.026**
	Sprattus novaehollandiae	PF							0.154	0.133	**0.047**
	Unidentified sprat	PF						24.134	4.040	6.580	**2.308**
	Unidentified clupeid	PF						0.709	9.276	8.074	**2.975**
Dinolestidae	*Dinolestes lewini*	PF									**0.092**
Engraulidae	*Engraulis australis*	PF						10.364	0.348	1.632	**3.248**
Emmelichthyidae	*Emmelichthys nitidus*	PF							1.923	1.655	**0.580**
Galaxiidae	*Galaxias cleaveri*	PF					0.402			0.004	**0.002**
	Galaxias maculatus	PF					4.569			0.049	**0.017**
	Unidentified galaxiid	PF					0.478			0.005	**0.002**
Gempylidae	*Thyrsites atun*	PF							1.008	0.867	**0.304**
Gerreidae	*Parequula melbournensis*	DF						5.409	1.983	2.402	**0.842**
Gobiidae	Unidentified gobiid	DF	11.013			0.178					**0.005**

Family (or higher taxon)	**Prey**	**Category**	**Victoria**				**Tasmania**				**Total**
			Small	**Medium**	**Large**	**Overall**	**Small**	**Medium**	**Large**	**Overall**	
Hemiramphidae	*Hyporhamphus australis*	PF									**0.715**
Leptoscopidae	*Lesueurina platycephala*	DF					0.943			0.010	**0.004**
Mugilidae	*Myxus elongatus*	PF									**0.015**
Pomatomidae	*Pomatomus saltatrix*	PF			3.503	1.809					**0.090**
Scombridae	*Scomber australasicus*	PF			19.546	10.095					**5.429**
Scorpididae	*Atypichthys strigatus*	PF									**0.032**
Sillaginidae	*Sillago ciliata*	DF									**0.259**
	Sillago flindersi	DF		0.458		0.214					**2.549**
	Sillago sp.	DF									**0.152**
Teleostei	Unidentified teleost remains		23.018	53.218	9.695	30.252	4.518	40.047	4.066	8.698	**8.949**
Molluscs											
Calyptraeidae	*Sigapatella calyptraeformis*	M									**0.002**
Mactridae	*Spisula trigonella*	M									**0.000**
Marginellidae	*Austroginella muscaria*	M		0.009		0.004					**0.000**
Naticidae	Unidentified naticid	M									**0.001**
Trochidae	*Bankivia fasciata*	M									**0.006**
	Phasianotrochus sp.	M						0.004		0.000	**0.000**
Turritellidae	*Gazameda gunnii*	M									**0.007**
Volutidae	Unidentified volutid	M									**0.000**
Gastropoda	Unidentified gastropod	M		0.002		0.001					**0.001**
	Unidentified gastropod remains	M					0.135			0.001	**0.001**
Donacidae	*Donax deltoides*	M									**0.000**
Glycymerididae	*Glycymeris striatularis*	M									**0.002**
	Glycymeris sp.	M									**0.000**
	Unidentified glycymeridid	M									**0.001**
Mytilidae	*Mytilus edulis*	M									**0.003**
	Unidentified mytilid	M									**0.001**
Nuculidae	*Nucula obliqua*	M									**0.000**
Bivalvia	Unidentified bivalve	M			0.002	0.001					**0.000**

Family (or higher taxon)	Prey	Category	Victoria				Tasmania				Total
			Small	Medium	Large	Overall	Small	Medium	Large	Overall	
	Unidentified bivalve remains	M		0.141		0.066	0.008	0.079		0.010	**0.012**
Mollusca	Unidentified mollusc	M									**0.001**
	Unidentified mollusc remains	M			0.273	0.141					**0.005**
Loliginidae	*Photololigo* sp.	C									**0.199**
Sepiolidae	*Euprymna tasmanica*	C									**0.006**
Teuthida	Unidentified Teuthida	C									**0.012**
Cephalopoda	Unidentified cephalopod remains	C					0.025	0.072		0.010	**0.008**
Crustaceans											
Amphipoda	*Gammaridea* sp.	BC						0.044		0.006	**0.002**
	Unidentified corophioid	BC					0.791			0.009	**0.003**
	Unidentified eusirid	BC					1.753			0.019	**0.007**
	Unidentified exoedicerotid	BC					11.979			0.130	**0.045**
	Unidentified hyalellid	BC					0.327			0.004	**0.001**
	Unidentified paracalliopid	BC					0.252			0.003	**0.001**
	Unidentified amphipod	BC	0.441			0.007	3.097		0.001	0.034	**0.012**
Balanidae	*Austromegabalanus nigrescens*	BC									**0.001**
	Balanus trigonus	BC									**0.000**
Tetraclitidae	*Tesseropora rosea*	BC									**0.001**
Brachyura	Unidentified brachyuran	BC					3.638	0.523		0.107	**0.041**
	Unidentified brachyuran megalopa	PC									**0.054**
	Unidentified brachyuran zoea	PC					2.283			0.025	**0.009**
Grapsidae	Unidentified grapsid	BC						0.032		0.004	**0.001**
Leucosiidae	*Ebalia intermedia*	BC						0.090		0.012	**0.004**
Majidae	Unidentified majid	BC									**0.000**
Portunidae	*Ovalipes australiensis*	BC			0.041	0.021	0.295			0.003	**0.082**
	Ovalipes sp.	BC									**0.001**
Caridea	*Macrobrachium* sp.	BC					1.893	0.056		0.028	**0.010**
Cladocera	Unidentified cladoceran	PC					0.327			0.004	**0.001**
Copepoda	Unidentified calanoid	PC					10.773			0.117	**0.041**

Family (or higher taxon)	Prey	Category	Victoria				Tasmania				Total
			Small	Medium	Large	Overall	Small	Medium	Large	Overall	
	Unidentified copepod	PC					13.821			0.150	**0.052**
Diogenidae	*Diogenes senex*	BC									**0.004**
Euphausiacea	*Nyctiphanes australis*	PC					1.141	8.243	0.502	1.504	**0.528**
	Unidentified euphausiid	PC									**0.006**
Isopoda	*Ligia australiensis*	BC					0.013			0.000	**0.000**
	Paritodea ungulata	BC						0.116		0.015	**0.005**
	Zuzara venosa	BC					0.057			0.001	**0.000**
	Unidentified valvifera	BC					0.038	0.065		0.009	**0.003**
	Unidentified isopod	BC	2.753	0.004		0.046	0.083			0.001	**0.034**
Luciferidae	*Lucifer hanseni*	PC					0.050			0.001	**0.000**
Mysidae	*Paramesopodopsis rufa*	PC					15.224			0.165	**0.058**
	Unidentified mysid	PC	0.330			0.005	1.132			0.012	**0.011**
Palaemonidae	*Palaemon intermedius*	BC	7.489			0.121					**0.003**
Penaeidae	*Penaeus* sp.	BC									**0.001**
Sergestidae	Unidentified sergestid	PC					3.079	0.054		0.040	**0.014**
Stomatopoda	Unidentified squillid	BC						0.046		0.006	**0.002**
	Unidentified stomatopod larvae	PC						0.065		0.008	**0.004**
Thalassinidae	*Biffarius ceramicus*	BC					6.912			0.075	**0.026**
	Unidentified thalassinid	BC					3.514	0.027		0.041	**0.015**
Upogebiidae	Unidentified upogebiid	BC									**0.000**
Crustacea	Unidentified crustacean remains	BC	0.826			0.013	0.993			0.011	**0.005**
Plantae											
Alariaceae	*Ecklonia radiata*	P									**0.002**
Algae	Unidentified algae	P									**0.000**
Bonnemaisoniaceae	*Asparagopsis* sp.	P									**0.002**
Chlorophyta	Unidentified chlorophyte	P									**0.001**
Casuarinaceae	Unidentified casuarinaceae	P									**0.000**
Caulerpaceae	*Caulerpa filiformis*	P									**0.016**
Dictyotaceae	*Dictyopteris muelleri*	P									**0.000**

Family (or higher taxon)	Prey	Category	Victoria				Tasmania				Total
			Small	Medium	Large	Overall	Small	Medium	Large	Overall	
	Dictyota dichotoma	P									**0.005**
	Padina fraseri	P									**0.000**
Magnoliophyta	Unidentified magnoliophyte	P						0.011		0.001	**0.000**
Phaeophyta	Unidentified phaeophyte	P							0.004	0.003	**0.002**
Rhodophyta	Unidentified rhodophyte	P			0.002	0.001					**0.000**
Sargassaceae	*Cytsophora moniliformis*	P									**0.000**
	Sargassum sp.	P									**0.003**
Tracheophyta	Unidentified tracheophyte	P		0.042		0.020					**0.001**
Zosteraceae	*Zostera capricorni*	P									**0.013**
Plantae	Unidentified plant remains	P									**0.000**
Miscellaneous											
Aphroditidae	*Aphrodite australis*	Misc	25.220			0.407					**0.011**
Onuphidae	*Australonuphis teres*	Misc									**0.003**
Bryozoa	Unidentified bryozoan	Misc		0.030		0.014					**0.001**
Chondrillidae	*Chondrilla australiensis*	Misc									**0.005**
Insecta	Unidentified insect	Misc					0.088			0.001	**0.000**
Nematoda	Unidentified nematode	Misc									**0.004**
Serpulidae	*Galeolaria caespitosa*	Misc									**0.000**
Sipuncula	Unidentified sipunculid	Misc									**0.001**
Teleostei	Fish eggs	Misc					0.006			0.000	**0.000**
	Fish scales	Misc						0.053		0.007	**0.002**
Zooplankton	Unidentified gelatinous zooplankton	Misc									**0.071**
Charcoal		Misc									**0.000**
Fishing hook		Misc									**0.002**
Rock		Misc			0.311	0.161					**0.023**
Sediment		Misc					0.545	0.016		0.008	**0.003**
Wood		Misc									**0.000**
Unidentified	Unidentified material	Misc		3.522	0.815	2.067	0.119			0.001	**0.796**

Family (or higher taxon)	Prey	Category	Victoria				Tasmania				Total
			Small	Medium	Large	Overall	Small	Medium	Large	Overall	
Total wet weight (g)			18.2	526.5	581.8	1126.4	159.1	1891.1	12654.9	14705.	**41928**
Number of prey taxa consumed			11	10	10	26	40	28	14	62	**135**
Number of stomachs examined			47	127	69	243	2442	375	221	3038	**5109**
Number of empty stomachs			29	63	51	143	482	172	30	684	**1955**
Average wet weight (g) of prey consumed per fish			1.009	8.226	32.320	11.264	0.081	9.316	66.256	6.247	**13.294**

Size differences within regions

In northern NSW and Victoria, there were no differences between the diets of fish of different size classes detected by ANOSIM (northern NSW; Global R = -0.016, P = 0.554, Victoria; Global R = -0.200, P = 0.667).

There were however, significant differences between the diets of fish of different size classes in both southern NSW (Global R = -0.110, P = 0.027, Fig. 7.6) and Tasmania (Global R = -0.748, P = 0.001, Fig. 7.7). For southern NSW, this difference was driven by the separation of the diet of small and large fish (P = 0.013) with SIMPER revealing that the average dissimilarity (80.1%) in diets was primarily due to high abundances of unidentified teleosts in the diet of small fish and *Trachurus* sp. in the diet of large fish.

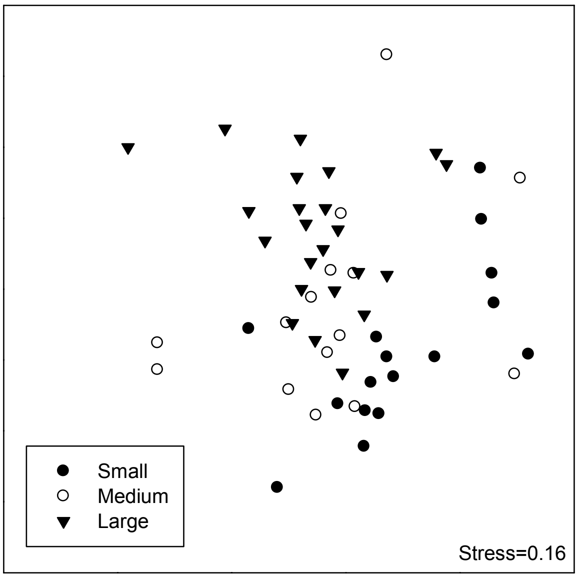


Figure 7.6. Non-metric multidimensional scaling ordination of diet biomass for small (●, 0 –20 cm FL), medium (○, 20 – 40 cm FL) and large (▼, > 40 cm FL) eastern Australian salmon caught between October 2006 and December 2009 from southern NSW. Stress value is shown.

For Tasmania, pairwise comparisons revealed that the diet of small eastern Australian salmon differed significantly from the diets of large and medium-sized fish (P = 0.001 in each case). SIMPER confirmed these differences with average dissimilarity in diets between these size classes ranging from 99.5 to 100.0%. These differences were the result of the high abundances of *Trachurus* sp., unidentified sprats, unidentified teleosts and krill *Nyctiphanes australis* in the diets of large and medium-sized eastern Australian salmon.

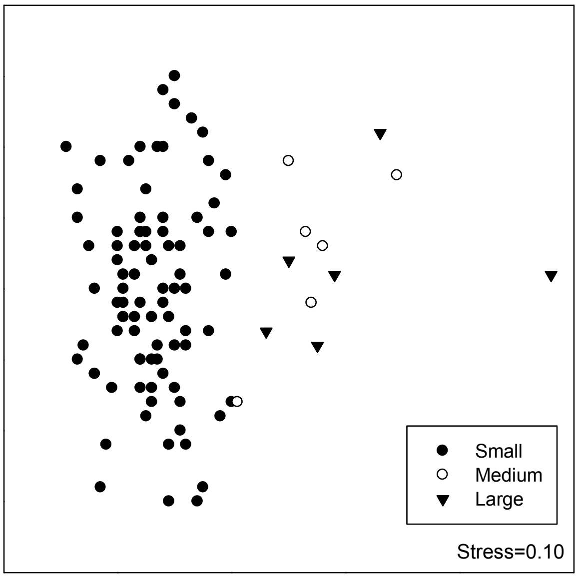


Figure 7.7. Non-metric multidimensional scaling ordination of diet biomass for small (●, 0 – 20 cm FL), medium (○, 20 40 cm FL) and large (▼, > 40 cm FL) eastern Australian salmon caught between August 2008 and January 2010 from Tasmania. Stress value is shown.

7.3.5. Prey size

Eastern Australian salmon sampled in NSW and Victoria consumed teleost prey ranging in size from 2.5 to 24.5 cm SL (Figs 7.8 & 7.9). The majority (94.7%) of prey were represented in two modes in the prey size distribution: the first mode (60.2% of the total) between 5 and 9 cm SL consisted mainly of the small pelagic fish sandy sprats, Australian anchovy and scads; and a second smaller mode between 10 and 16 cm SL comprising a further 34.5% was dominated primarily by Australian sardines (Fig. 7.8). Scads were mainly consumed at sizes of 6 to 9 cm SL, although scads of all size classes up to 21.7 cm SL were consumed. Similarly for blue mackerel, most were consumed at a size of 8 to 11 cm SL up to a maximum of 22 cm SL. Of the largest (> 17 cm SL) prey items consumed 20.0% were eastern sea garfish, 28.6% blue mackerel and 40.0% scads.

There was a significant positive correlation between fish size and prey size (r = 0.346, P < 0.0001; Fig. 7.11). Small and medium-sized fish consumed prey of distinct size and type. Small fish mainly consumed eastern school whiting, sandy sprats and unidentified larval/juvenile teleosts between 2.5 and 7.5 cm SL. Medium-sized fish consumed only sandy sprats and scads between 5 and 9 cm SL. However, large fish consumed a diverse group of prey of all sizes from 4.5 to 24.5 cm SL. A small number of large prey (< 20 cm SL) – primarily scads, blue mackerel and eastern sea garfish – were consumed only by large eastern Australian salmon (Fig. 7.9).

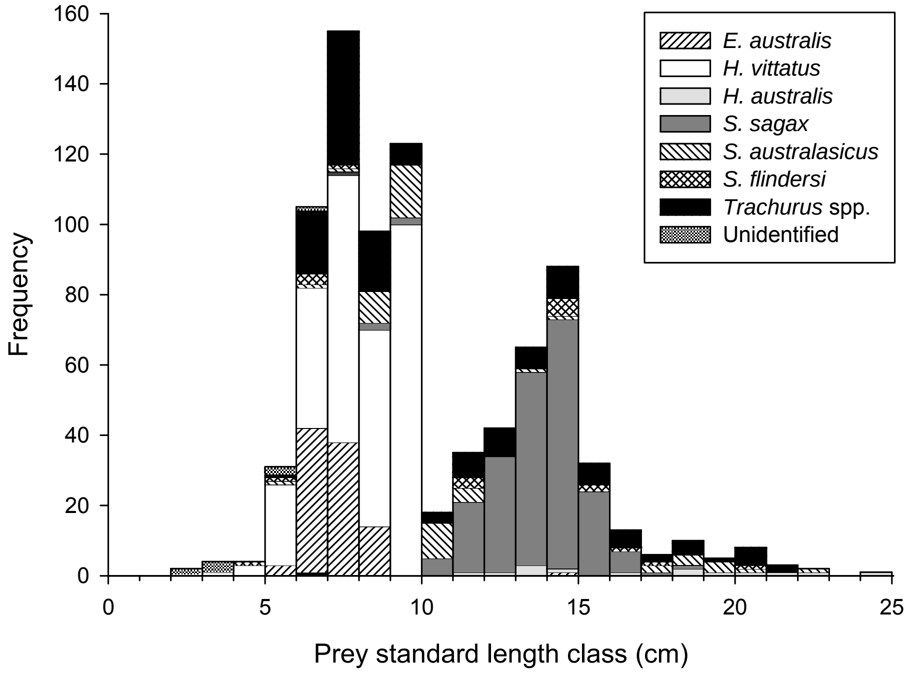


Figure 7.8. Size-frequency histogram showing the standard length (in 1 cm length classes) of prey consumed by eastern Australian salmon caught between October 2006 and March 2009 in northern NSW, southern NSW and Victoria.

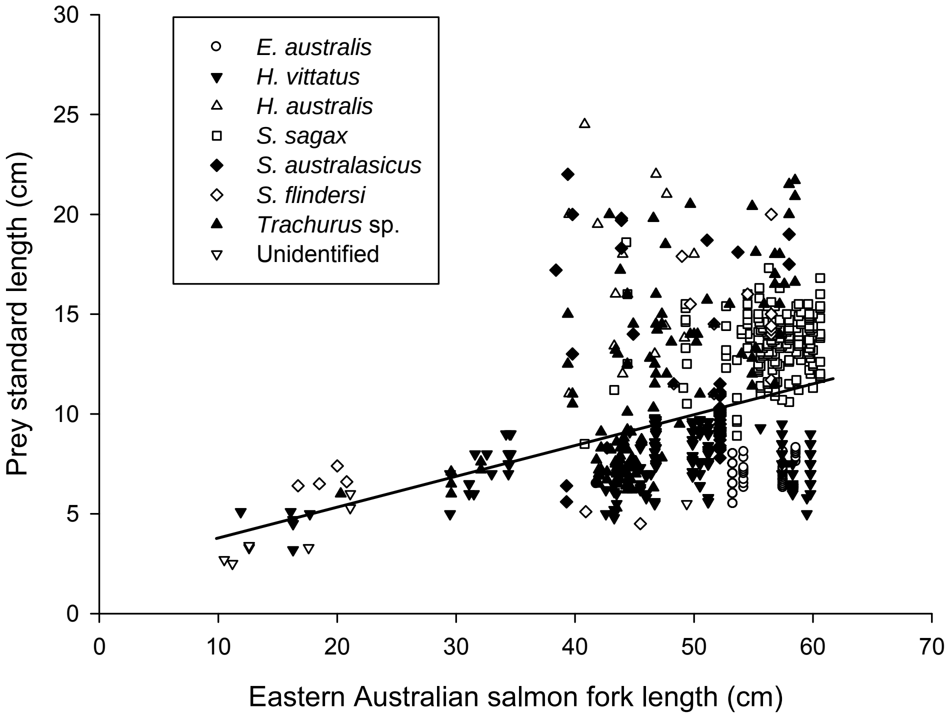


Figure 7.9. Scatter plot showing the relationship between eastern Australian salmon fork length (cm) and the standard length (cm) of prey consumed by eastern Australian salmon caught between October 2006 and March 2009 in northern NSW, southern NSW and Victoria.

7.3.6. Small juvenile diet

For analytical purposes, small juvenile eastern Australian salmon captured by research beach seine in Tasmanian waters were grouped into two size classes, namely ≤ 80 mm and > 80 mm FL. The > 80 mm group included individuals of up to 180 mm FL, although 98.5% were 150 mm or smaller.

Regionally (see Fig. 2.9), there was variability in feeding intensity (GCI) for ≤ 80 mm eastern Australian salmon, with the highest intensities in the NEC and EC samples and the lowest intensities in the SEC and NWC samples (Fig. 7.10). The situation for the > 80 mm group differed, with lowest feeding intensity for fish from the NEC and greatest intensities for the SEC, EC and NWC samples. There was a strong seasonal pattern in feeding intensity for the > 80 mm group, with significantly higher GCIs in summer and autumn than at other times of the year (Fig. 7.10). While feeding intensity was low in winter for ≤ 80 mm group, there was less variability in GCIs by season. Feeding intensities for the > 80 mm group were markedly higher in moderate compared with high exposure sites but were similar between habitats for smaller size class (Fig. 7.10).

The diet of juvenile eastern Australian salmon was dominated by amphipods, copepods, mysids, polychaetes, and teleosts (Table 7.6). Some of the more commonly consumed prey species within these groups were exoedicerotid amphipods, calanoid copepods, *Paramesopodopsis rufa* (Mysidae), and unidentified crab zoea (Decapoda). Amphipods were common in diets in most regions, whereas copepods and mysids tended to be more common in the EC and NEC and teleosts more prevalent in the NWC and WC regions (Fig. 7.11). Seasonal trends indicated that amphipods were common at most times of the year whereas copepods appeared to be more common between spring and autumn (Fig. 7.11). In terms of the relative importance (IRI), copepods were the most dominant prey item between seasons, particularly in small, recruiting individuals (≤ 80 mm), followed by amphipods, mysids, decapods and polychaetes, with the later prey items becoming increasingly important in the diet of larger juvenile eastern Australian salmon (Fig. 7.12).

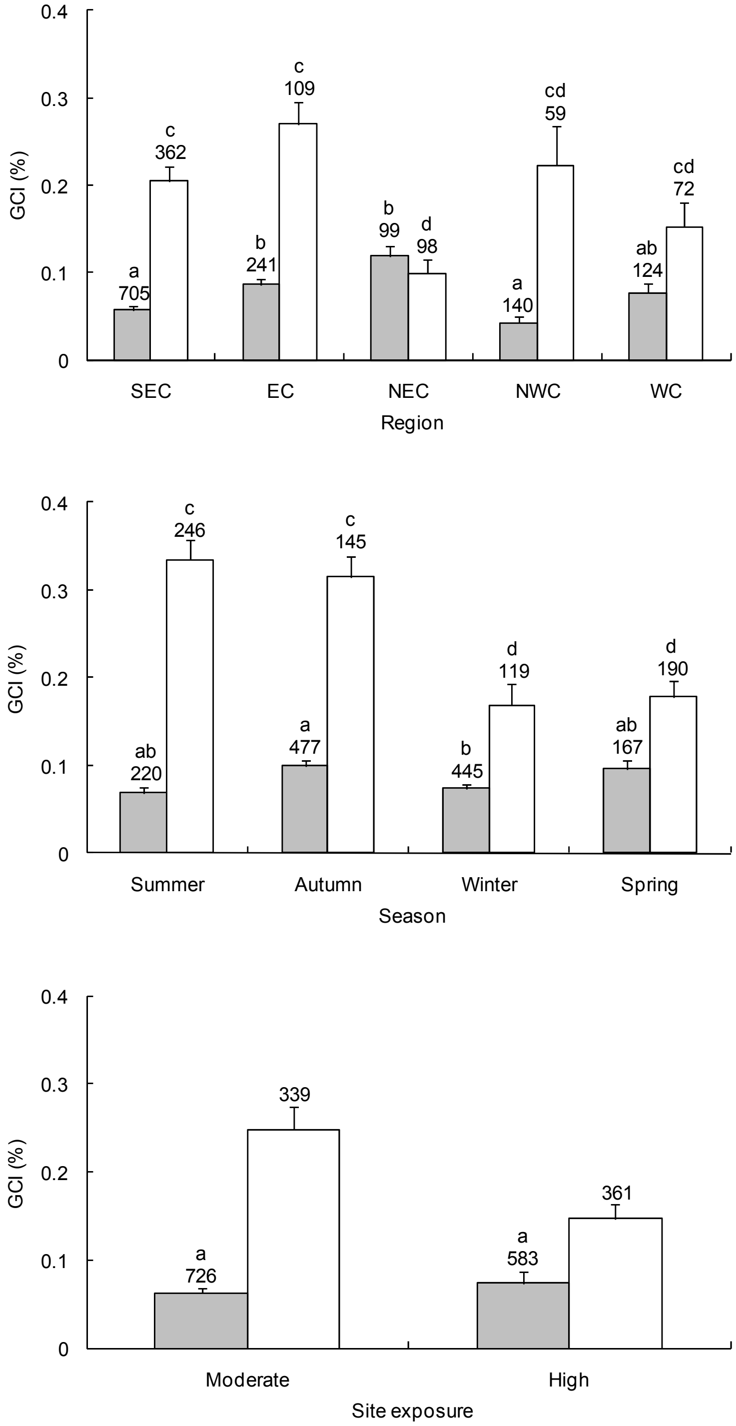


Figure 7.10. Regional, seasonal and site exposure feeding intensity (mean GCI ± S.E.) of juvenile eastern Australian salmon ≤ 80 mm FL (open) and > 80 mm FL (shaded) in Tasmanian inshore waters between January 2009 and January 2010. Post-hoc Tukey Kramer tests of no significant differences between factors for each size class ($P > 0.05$) are denoted by the same letter. The number of individual stomachs assessed is also given above each bar.

Table 7.6. Contribution of prey items to the diet of eastern Australian salmon by %N: percent number; %WW: percent weight; %F: frequency of occurrence; and %IRI: percent index of relative importance. Higher order taxonomic groupings used to examine dietary similarities are in bold. Samples have been pooled by region and season. * denotes contributions < 0.01%.

Prey taxa	**≤80 mm FL**				**> 80 mm FL**				**Combined**			
	%N	**%WW**	**%F**	**%IRI**	**%N**	**%WW**	**%F**	**%IRI**	**%N**	**%WW**	**%F**	**%IRI**
Amphipods	**11.38**	**26.76**	**37.03**	**11.82**	**5.11**	**9.05**	**25.72**	**5.61**	**8.94**	**13.84**	**32.97**	**9.89**
Corophioidae	0.9	1.31	1.85	0.09	0.29	0.34	1.29	0.04	0.66	0.6	1.65	0.08
Eusiridae	0.03	0.65	0.24	*	0.16	1.59	1.72	0.03	0.08	1.33	0.77	*
Exoedicerotidae	9.72	21.92	22.17	11.27	1.69	4.36	9.63	1.94	6.6	9.11	17.67	8.51
Hyalellidae	0.04	0.23	0.16	*	0.19	0.26	1.15	0.03	0.1	0.25	0.52	*
Paracalliopiidae	*	0.04	0.08	*	0.14	0.25	0.57	0.01	0.06	0.19	0.26	*
Unidentified	0.7	2.61	12.53	0.46	2.64	2.26	11.35	3.56	1.45	2.36	12.11	1.28
Bivalves	**0.01**	**0.02**	**0.16**	*					**0.01**	**0.01**	**0.1**	*
Unidentified	0.01	0.02	0.16	*					0.01	0.01	0.1	*
Cephalopods					*	**0.03**	**0.14**	*	*	**0.02**	**0.05**	*
Unidentified					*	0.03	0.14	*	*	0.02	0.05	*
Cladocerans	**0.82**	**0.92**	**1.77**	**0.08**					**0.5**	**0.25**	**1.13**	**0.04**
Unidentified	0.82	0.92	1.77	0.08					0.5	0.25	1.13	0.04
Copepods	**84.02**	**41.27**	**37.35**	**87.32**	**55.15**	**10.34**	**17.1**	**55.51**	**72.82**	**18.7**	**30.09**	**82.73**
Calanidae	29.35	17.04	14.62	22.42	25.76	4.91	9.05	27.56	27.96	8.19	12.62	25.7
Unidentified	54.67	24.22	22.73	64.91	29.39	5.43	8.05	27.95	44.86	10.51	17.47	57.04
Crustaceans (unidentified)	**0.01**	**0.18**	**0.48**	*	**0.7**	**0.97**	**2.16**	**0.18**	**0.28**	**0.76**	**1.08**	**0.02**
Decapods	**0.95**	**8.52**	**6.51**	**0.13**	**3.88**	**16.54**	**13.07**	**2.2**	**2.09**	**14.37**	**8.86**	**0.49**
Biffarius ceramicus	*	0.71	0.08	*	0.05	6.94	2.01	0.02	0.02	5.26	0.77	*
Brachyura	*	0.05	0.08	*	0.02	0.89	1.01	*	0.01	0.66	0.41	*
Crab zoea	0.32	1.45	2.81	0.05	3.59	1.84	5.03	2.14	1.59	1.74	3.61	0.42
Lucifer hanseni	*	0.14	0.08	*				*	*	0.04	0.05	*
Macrobrachium spp	0.01	0.95	0.64	*	0.03	1.62	1.58	0.01	0.02	1.44	0.98	*
Ovalipes australiensis					*	0.31	0.14	*	*	0.22	0.05	*
Sergestidae	0.01	0.88	0.32	*	0.05	2.88	2.01	0.01	0.02	2.34	0.93	*
Thalassinidae	0.6	4.33	2.49	0.08	0.14	2.06	1.29	0.02	0.42	2.67	2.06	0.06
Euphausids	**0.08**	**1.09**	**1.69**	**0.01**	**0.13**	**0.79**	**1.44**	**0.02**	**0.1**	**0.87**	**1.6**	**0.01**
Nyctiphanes australis	0.08	1.09	1.69	0.01	0.13	0.79	1.44	0.02	0.1	0.87	1.6	0.01
Gastropods	*	**0.38**	**0.16**	*					*	**0.1**	**0.1**	*
Unidentified	*	0.38	0.16	*					*	0.1	0.1	*
Insects	**0.03**	**0.12**	**0.24**	*	*	**0.05**	**0.14**	*	**0.02**	**0.07**	**0.21**	*
Unidentified	0.03	0.12	0.24	*	*	0.05	0.14	*	0.02	0.07	0.21	*
Isopods	**0.06**	**0.39**	**1.2**	*	**0.01**	**0.05**	**0.57**	*	**0.05**	**0.14**	**0.98**	*
Ligia australiensis	0.03	0.22	0.88	*	*	0.01	0.14	*	0.02	0.06	0.62	*
Valvifera	*	0.02	0.08	*	*	0.01	0.14	*	*	0.01	0.1	*
Zuzara venosa					0.01	0.04	0.29	*	*	0.03	0.1	*
Unidentified	0.04	0.16	0.24	*					0.02	0.04	0.15	*
Mysids	**2.46**	**6.13**	**6.67**	**0.61**	**33.39**	**14.77**	**14.37**	**34.86**	**14.47**	**12.44**	**9.43**	**6.54**
Paramesopodopsis rufa	2.37	5.65	4.82	0.6	32.58	13.77	8.91	34.34	14.1	11.58	6.29	6.46
Unidentified	0.1	0.48	1.85	0.01	0.81	1	5.46	0.53	0.38	0.86	3.14	0.09
Polychaetes	**0.14**	**10.25**	**5.3**	**0.04**	**0.52**	**35.76**	**17.53**	**1.34**	**0.29**	**28.86**	**9.69**	**0.24**
Unidentified	0.14	10.25	5.3	0.04	0.52	35.76	17.53	1.34	0.29	28.86	9.69	0.24
Teleosts	**0.03**	**3.96**	**1.37**	*	**0.5**	**11.53**	**7.47**	**0.27**	**0.21**	**9.49**	**3.55**	**0.03**
Atherinason hepsetoides	*	0.58	0.08	*	*	0.79	0.14	*	*	0.73	0.1	*
Atherinidae	*	0.53	0.08	*	*	0.22	0.14	*	*	0.3	0.1	*
Atherinosoma sp. sp.sp.*presbyteroides*	*	0.58	0.08	*					*	0.16	0.05	*
Galaxias cleaveri					0.01	0.42	0.29	*	*	0.31	0.1	*
Galaxias maculatus	0.01	1.45	0.48	*	0.09	4.22	1.29	0.02	0.04	3.47	0.77	*
Galaxias spp.					0.01	0.5	0.29	*	*	0.36	0.1	*
Lesueurina platycephala					*	0.98	0.14	*	*	0.72	0.05	*
Unidentified	0.01	0.81	0.64	*	0.38	4.41	5.17	0.24	0.16	3.44	2.27	0.03
Fish eggs					0.59	0.01	0.14	0.01	0.23	*	0.05	*
Unidentified taxa	*	**0.02**	**0.08**	*	*	**0.12**	**0.14**	*	*	**0.09**	**0.1**	*
Total number of stomachs	**1309**				**700**				**2009**			
Percentage of stomachs with food	**78.9**				**74.1**				**77.3**			

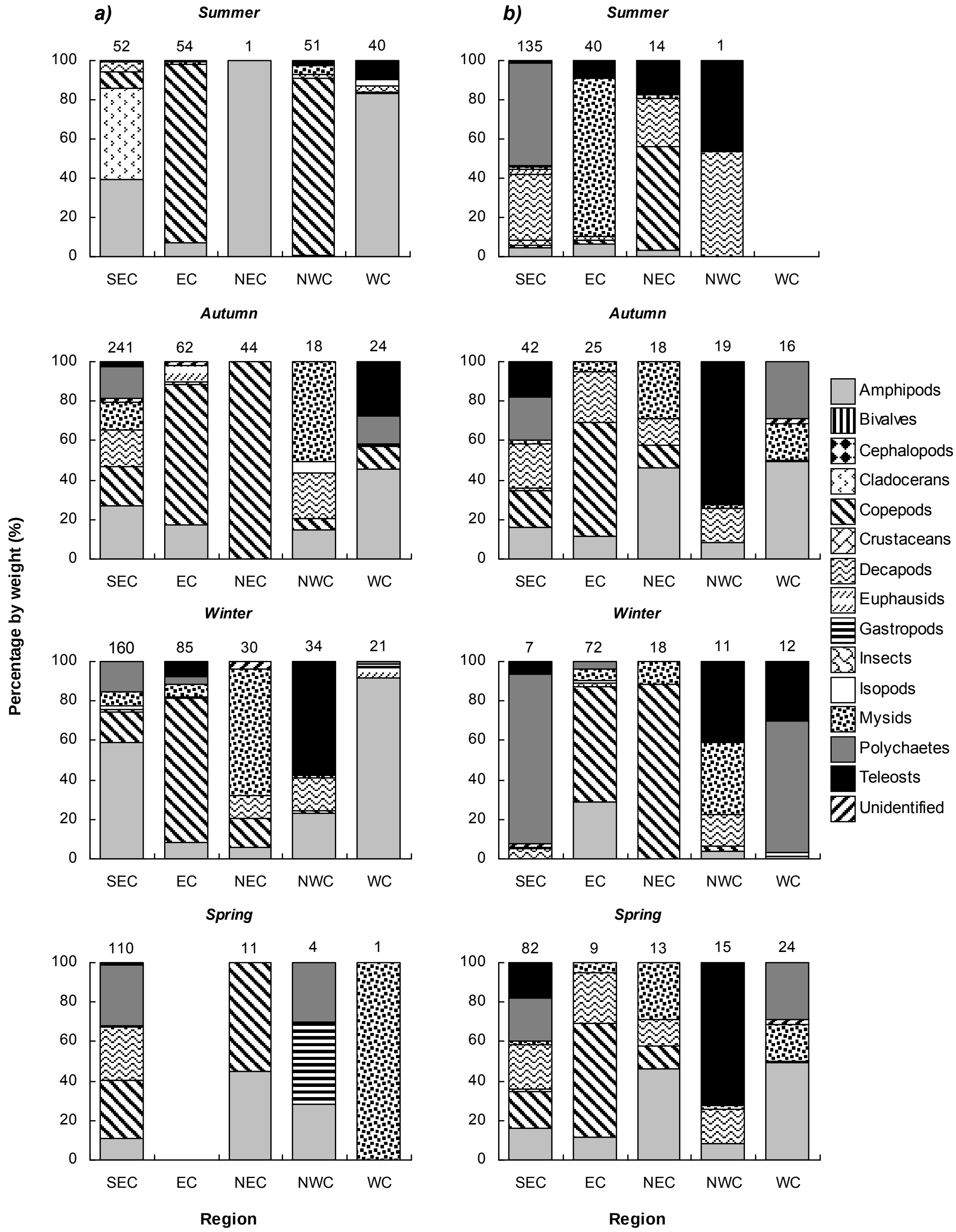


Figure 7.11. Percentage contribution, by weight, to the diets of a) ≤ 80 mm and b) > 80 mm FL eastern Australian salmon for each region within each season. Number of individuals containing prey in their stomachs which were examined is given above each bar.

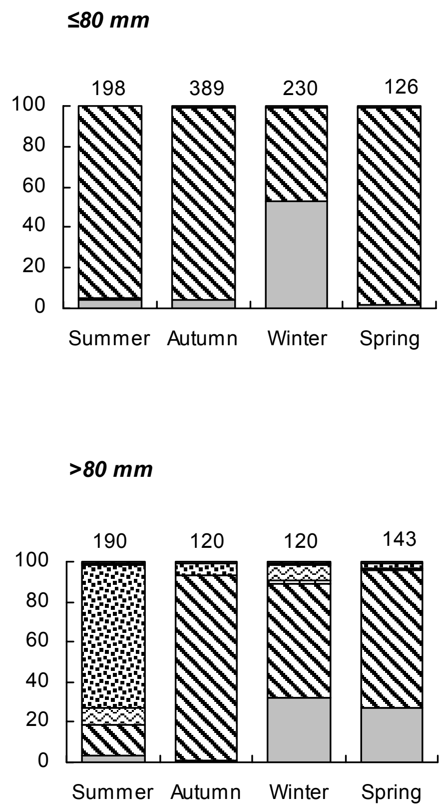


Figure 7.12. Percent index of relative importance (IRI) of prey items to the seasonal dietary composition of juvenile eastern Australian salmon. Refer Fig. 7.13 for key.

One-way ANOSIM revealed the greatest variation in overall diet composition occurred between size classes (Global R = 0.154, P = 0.001), followed by site exposure (Global R = 0.062, P = 0.001), region (Global R = 0.061, P = 0.002), and season (Global R = 0.034, P = 0.001). SIMPER demonstrated that the diet of ≤ 80 mm fish differed to that for the > 80 mm individuals due to the greater consumption of copepods and amphipods in the former and a more diverse diet comprising polychaetes, decapods, mysids, and teleosts in the latter group.

As size was considered to have the greatest influence on the dietary composition, each size class was separated and ANOSIM and SIMPER analysis were used to examine the influence of site exposure, region, and season on their diet.

7.3.6.1. ≤ 80 mm size class

Two-way crossed ANOSIM and MDS ordination indicated that the diet of ≤ 80 mm eastern Australian salmon was influenced most by region (Global R = 0.105, P = 0.003), followed by season (Global R = 0.103, P = 0.001) and, to a minor extent, by site exposure (Global R = 0.025, P = 0.001) (Fig. 7.13).

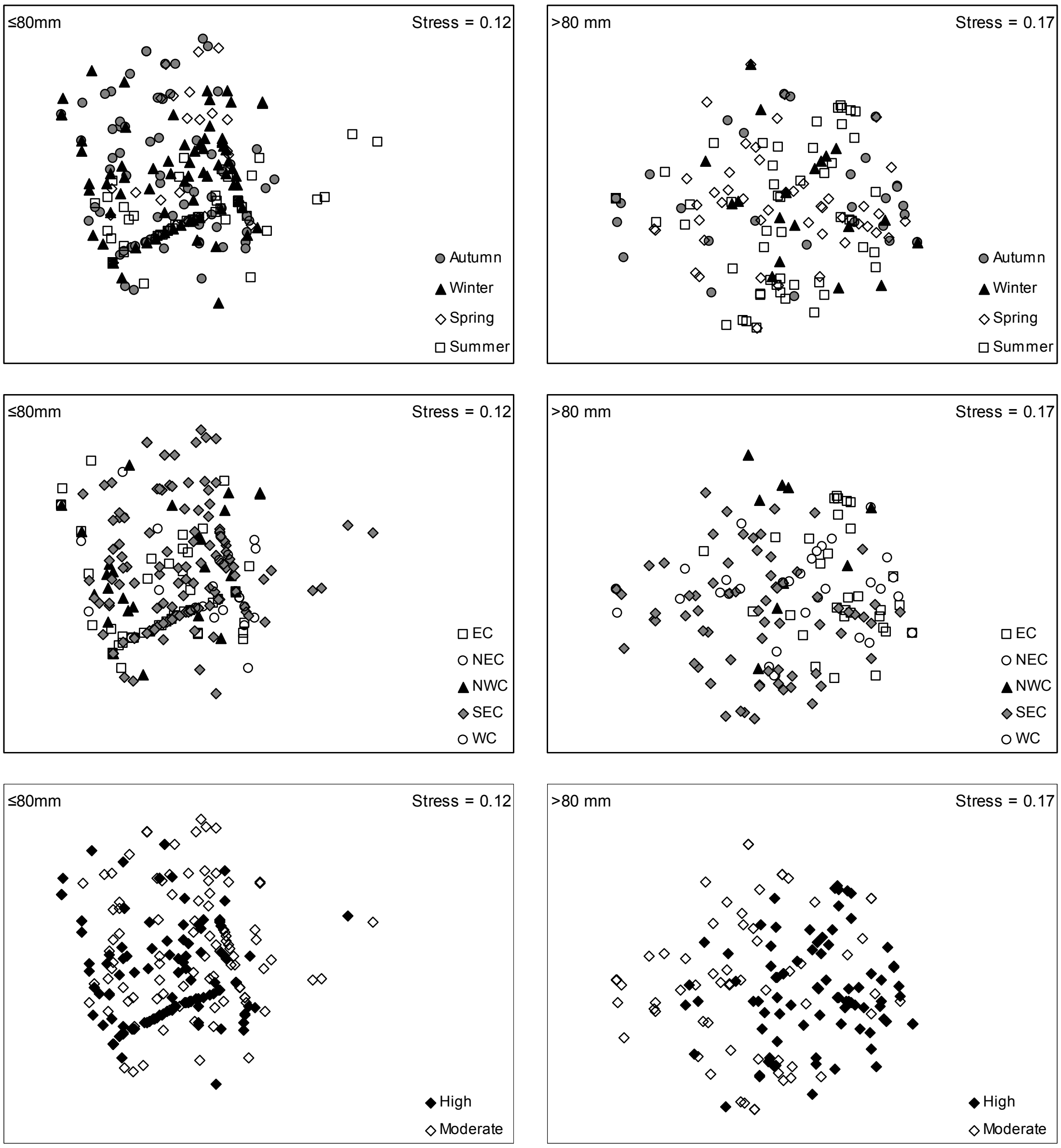


Figure 7.13. MDS ordination of the percentage contributions of the various dietary groups, by weight, to the diet of eastern Australian salmon a) ≤ 80 mm and b) > 80 mm FL coded for region, season and site exposure.

Pair-wise comparisons revealed significant regional differences (P < 0.05) in all but the SEC-WC and NEC-EC comparisons. The WC was distinguished from most other regions based on the greater reliance on amphipods, the NWC was separated mainly due to the greater proportion of copepods and decapods in the diet, while the higher level of predation on amphipods and polychaetes by SEC fish distinguished this region from the EC and NEC. The lack of difference between the SEC and WC was influenced mainly by the large quantities of amphipods consumed in both regions whereas copepods contributed heavily to the diets in both EC and NEC fish.

Pair-wise comparisons also demonstrated significant differences ($P < 0.05$) in diet between all seasonal comparisons, apart from the spring-autumn comparison. During summer amphipods and copepods were the most common food items consumed by this size class. Differences between winter and spring and, to a lesser extent, autumn were influenced mainly by the reliance on amphipods and mysids during winter. During autumn and spring, amphipods, copepods and decapods were the most important prey items consumed in both seasons.

Dietary differences between moderate and high exposure sites showed the least variation (R = 0.025, P = 0.001) with differences attributed to the consumption of more amphipods and copepods in highly exposed sites compared to decapods in more sheltered sites.

7.3.6.2. > 80 mm size class

Two-way crossed ANOSIM and MDS ordination demonstrated that the greatest influences on diet of > 80 mm juvenile eastern Australian salmon was site exposure (R = 0.240, P = 0.001), followed by region (Global R = 0.210, P = 0.001) and to a small extent by season (Global R = 0.083, P = 0.002) (Fig. 7.13).

Differences due to site exposure were attributed to a higher level of predation on amphipods and copepods in highly exposed sites whereas in sheltered waters polychaetes and decapods comprised a larger part of the diet.

Pair-wise comparisons showed diets differed significantly ($P < 0.05$) between most regions other than the SEC and WC, where the diets were predominately comprised of polychaetes, decapods and amphipods. EC fish differed to those from the other regions due mainly to the greater proportions of copepods and mysids in the diet. Similarly, the diet in the NEC was distinguished from the other regions mainly as a result of greater reliance on copepods and mysids but separated from the EC by the presence of decapods. Fish from the NWC were distinguished from the remaining regions due to the greater reliance on teleosts and mysids.

Seasonal variation in diet was mostly attributed to differences between autumn and summer, and autumn and winter. Whereas in autumn, polychaetes and copepods were the more important prey items, amphipods and decapods were consumed in greater amounts during summer and winter. There were no significant differences in diet between remaining seasonal comparisons.

7.3.6.3. Juvenile diurnal feeding pattern

Feeding intensity (based on CGI values) indicated more intense feeding activity in the late afternoon and evening and again around sunrise, with apparently low activity during other daylight hours. Typically, feeding intensity was greatest at sunset for the larger fish (GCI = 1.9) and at sunrise and sunset for smaller individuals (GCI = 2.9 and 2.5, respectively) (Fig. 7.14). During the day, particularly between mid morning and mid afternoon, feeding intensity for both size classes was markedly lower than at other times (GCI < 1.5). In most cases, smaller fish tended to feed more intensely than larger fish throughout the 24-hour period. One-way ANOVA indicated there were significant differences in feeding intensity between day and night for both ≤ 80 mm ($F_{1,169}$ = 7.153, $P < 0.05$) and > 80 mm individuals ($F_{1,137}$ = 5.069, $P < 0.05$). There was no correlation between tidal height and feeding intensity for either size class (small: $F_{1,6}$ = 1.910, P = 0.216; large: $F_{1,6}$ = 0.402, P = 0.550).

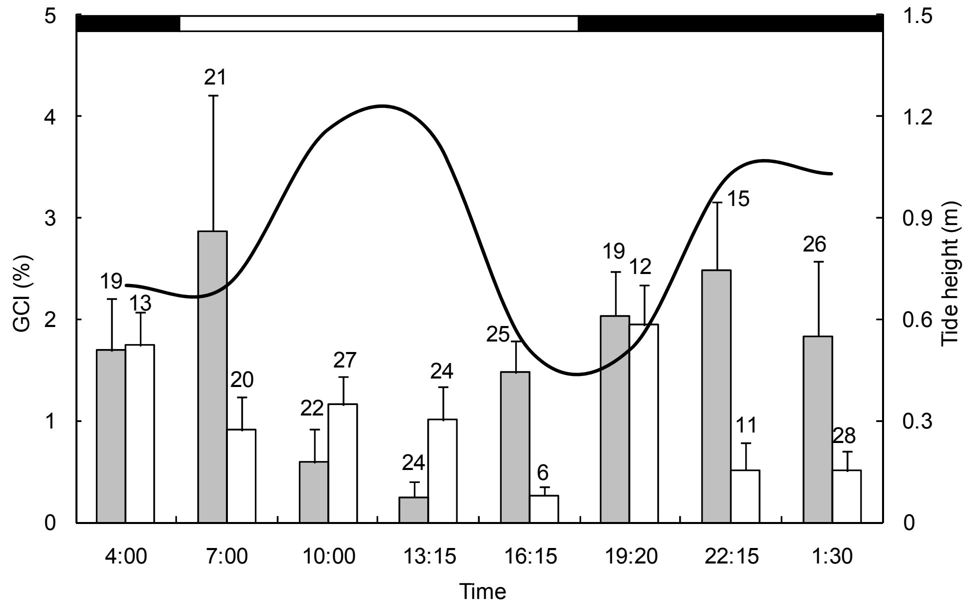


Figure 7.14. Diurnal pattern of feeding activity (mean GCI ± S.E.) of eastern Australian salmon ≤ 80 mm (shaded) and > 80 mm FL (open) during a 24-hour period in February 2009. Tidal height is indicated (solid line) and the number of stomachs examined is given above the bars for each time period. Horizontal black and white bars indicate periods of night and day, respectively.

Teleosts were the most common prey item consumed by both size classes during the 24-hour period and were particularly dominant during the early morning hours and late at night (Fig. 7.15). Mysids and decapods were also common dietary items, especially late in the afternoon and early morning hours. To a minor extent, polychaetes tended to be more important during the middle of the day.

Two-way crossed ANOSIM indicated that there were minor differences in diet composition between day and night (Global $R = 0.042$, $P = 0.002$) and between size classes (Global $R = 0.042$, $P = 0.002$). One-way ANOSIMs demonstrated that within size class differences occurred between day and night ($R = 0.038 – 0.050$, $P = 0.001 – 0.008$) whereas between size class differences were only apparent during the day ($R = 0.058$, $P = 0.001$). SIMPER indicated that dietary differences between day and night were attributed to marginally more polychaetes being consumed during the day and teleosts, decapods and mysids at night. Differences between size classes during the day were mostly attributed to the consumption of more teleosts and polychaetes by the larger fish as opposed to decapods by smaller individuals.

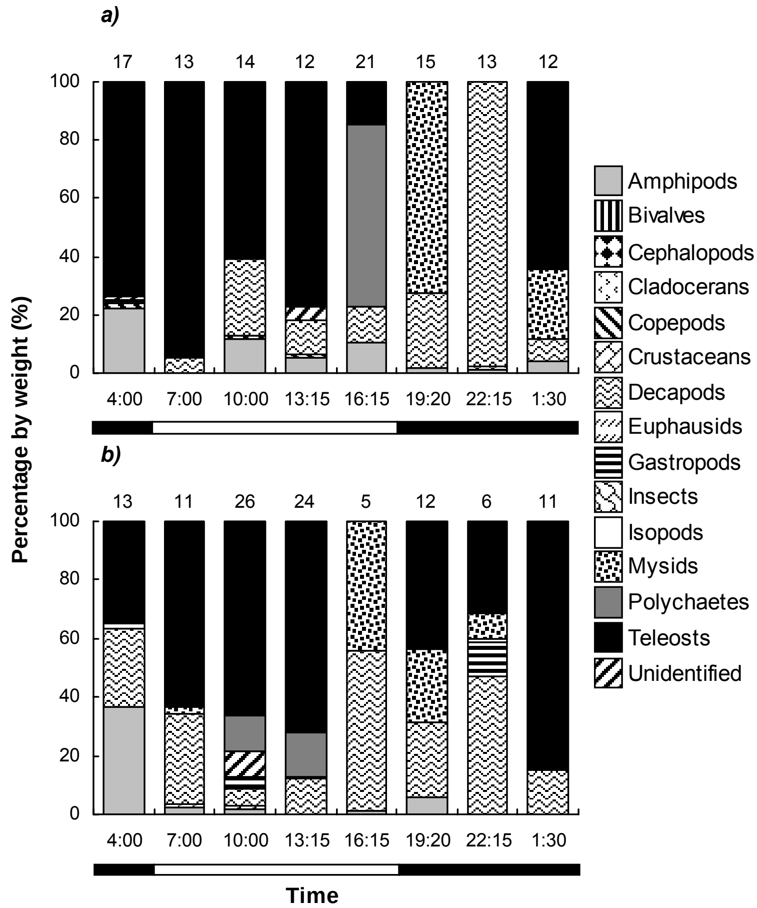


Figure 7.15. Percentage contributions (by weight, during a 24-hour cycle during summer) to the diets of a) ≤ 80 mm and b) > 80 mm FL eastern Australian salmon. Number of individuals containing prey in their stomachs is given above the bar for each time period. Horizontal black and white bars indicate periods of night and day, respectively.

7.3.7. Regurgitation of stomach contents

The total weight of regurgitated food from the 50 t purse seine catch of eastern Australian salmon caught at Bermagui on 14 November 2007 was 61.9 kg. Of the 30 fish subsample taken from this catch, 13 individuals had food in their stomachs weighing a total of 765.6 g consisting mainly of the teleost *Trachurus* sp. along with cephalopods, molluscs and crustaceans. Averaged over the whole subsample (including fish with empty stomachs), this was equivalent to a mean stomach contents weight of 25.5 g/fish. The mean body weight of these 30 fish was 1,177.53 g. If these mean values are scaled up to the entire catch, the catch therefore consisted of an estimated 42,462 individuals containing 1,083.6 kg of stomach contents. The amount of regurgitated food was therefore estimated to be ~ 5.4% of the stomach contents contained in the entire catch and thus not considered likely to result in a loss of information or to bias subsequent estimates of diet composition, feeding periodicity, or rates of food consumption and gastric evacuation.

Mean stomach fullness of eastern Australian salmon collected using beach hauling (276 samples) was not significantly different to that of fish collected by purse seine (also 276 samples) (ANOVA, $F_{1,\ 550} = 3.542$, $P > 0.05$). Collection method was therefore not considered in subsequent diet analyses. In addition, observations of the appearance of empty stomachs generally did not show any distension which could indicate that they had been full of food prior to capture.

7.3.8. Daily ration and prey consumption rates

7.3.8.1. Gastric evacuation experiments

On each occasion the experimental eastern Australian salmon became satiated after approximately 2.5 minutes of feeding. Experimental parameters and results are given in Table 7.7. At ~15ºC, experimental fish consumed 8.2 kg of sardines (mean weight 40.4 ± 0.4 g). Sixty-three percent of fish sampled contained labelled food remains (mean meal weight 102.0 ± 11.6 g). Time for complete digestion took 50.1 h and A_i was estimated to be 22.59 (Fig. 7.16). At ~20ºC, 87% of fish sampled had consumed an average sardine meal of 82.3 ± 8.1 g out of the 7.3 kg offered (mean weight 25.8 ± 0.3 g per sardine). Time for complete digestion was 39.34 h and A_i was estimated to be 17.10 (Fig. 7.16).

Table 7.7. Experimental parameters [temperature (ºC), fish size (fork length (FL – cm) and weight – g), food weight (total and mean – g)] and results [sample sizes, experimental meal weight (g), time for complete digestion (h) and A_i estimates] for eastern Australian salmon gastric evacuation experiments.

Temperature mean ± S.E. (range) (ºC)	Fish FL mean ± S.E. (range) (cm)	Fish weight mean ± S.E. (range) (g)	Total food weight (g)	Food weight mean ± S.E. (range) (g)	No. fish	No. fish that ate	Meal weight mean ± S.E. (range) (g)	Time to complete digestion (h)	A_i
15.1 ± 0.1 (14.5 – 15.5)	51.3 ± 0.3 (47.6 – 55.7)	2481 ± 54 (1912 – 3281)	8197.3	40.38 ± 0.36 (23.94 – 57.02)	45	28	102.02 ± 11.62 (23.94 – 207.32)	50.10	22.59
19.4 ± 0.1 (17.9 – 20.9)	53.7 ± 0.2 (50.5 – 56.9)	3032 ± 47 (2600 – 3782)	7331.5	25.81 ± 0.33 (12.21 – 39.21)	38	33	82.31 ± 8.11 (23.37 – 206.06)	39.34	17.10

Using the evacuation rate (A_i) estimates above, daily ration for eastern Australian salmon of various sizes and at the two experimental temperatures was calculated (Table 7.8). The estimated mean daily consumption averaged across fish of all sizes (4.7 – 64.6 cm FL, 1593.31 ± 21.53 g) was 13.97 ± 0.19 g at ~15ºC and 18.45 ± 0.25 g at ~20ºC. This equated to a daily ration of 0.88 ± 0.01 and 1.16 ± 0.02 % of body weight per day (BW/d) at ~ 15 and ~ 20ºC respectively. Daily ration was similar for small (1.01 ± 0.04 and 1.33 ± 0.05% BW/d at ~ 15 and ~ 20ºC respectively) and large fish (0.89 ± 0.01% and 1.18 ± 0.01% BW/d) and was lowest for medium-sized fish (0.58 ± 0.01% and 0.77 ± 0.01% BW/d). Estimated annual consumption rates increased with both fish size and temperature from 0.24 ± 0.01 kg/year for small fish at ~ 15ºC to 9.13 ± 0.01 kg/year for large fish at ~ 20ºC. The amount of food ingested in a year (Q) by eastern Australian salmon of all sizes combined expressed as a fraction of their biomass (B) was therefore calculated to be 3.20 ± 0.04 at ~ 15ºC and 4.23 ± 0.06 at ~ 20ºC (Table 7.8).

Table 7.8. Fork length, mean body weight (± S.E.), daily consumption (± S.E.), daily ration (± S.E.), annual prey consumption (± S.E.) and *Q/B* estimate (food consumed/biomass) for small, medium and large eastern Australian salmon pooled for northern NSW, southern NSW and Victoria at the two gastric evacuation experimental temperatures (~15 & ~20ºC) for which A_i was estimated.

Size class	Length range (FL cm)	Body weight (g)	Experimental temperature (ºC)	Daily consumption (g/day)	Daily ration (% BW/day)	Annual consumption (kg/year)	*Q/B*
Small	4.7 – 20.0	66.62 (2.30)	15.1 (0.1)	0.67 (0.02)	1.01 (0.04)	0.24 (0.02)	
			19.4 (0.1)	0.88 (0.03)	1.33 (0.05)	0.33 (0.02)	
Medium	20.0 – 40.0	656.59 (12.31)	15.1 (0.1)	3.81 (0.07)	0.58 (0.01)	1.39 (0.05)	
			19.4 (0.1)	5.03 (0.09)	0.77 (0.01)	1.84 (0.07)	
Large	40.0 – 64.6	2119.26 (19.29)	15.1 (0.1)	18.93 (0.17)	0.89 (0.01)	6.91 (0.13)	
			19.4 (0.1)	25.02 (0.23)	1.18 (0.01)	9.13 (0.17)	
Overall	4.7 – 64.6	1593.31 (21.53)	15.1 (0.1)	13.97 (0.19)	0.88 (0.01)	5.10 (0.14)	3.20 (0.04)
			19.4 (0.1)	18.45 (0.25)	1.16 (0.02)	6.74 (0.18)	4.23 (0.06)

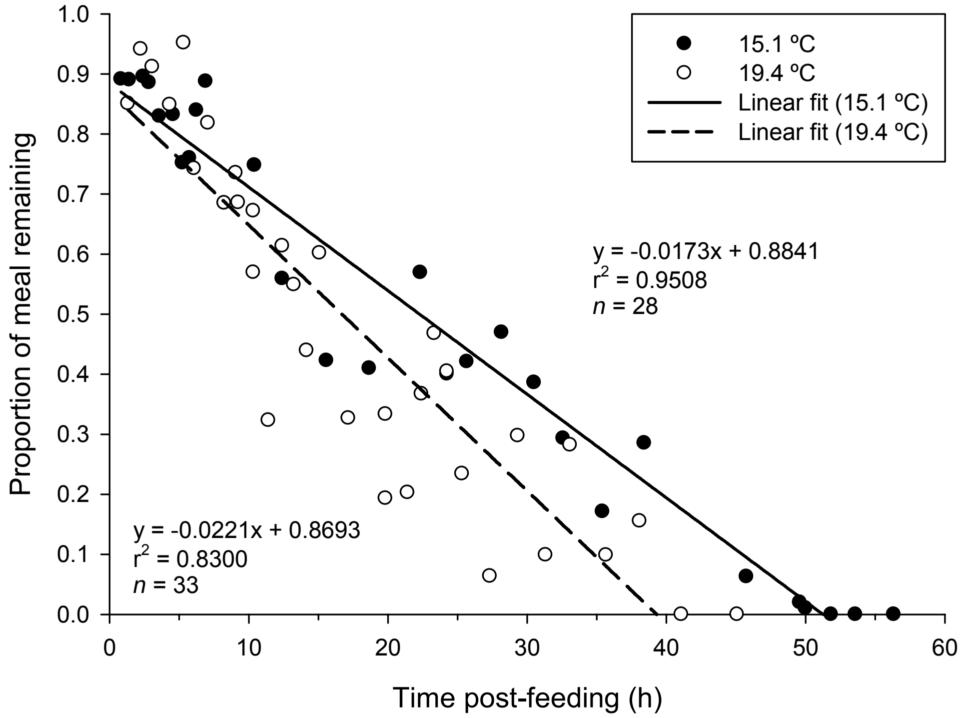


Figure 7.16. Proportion of initial wet mass of Australian sardines recovered from the stomachs of captive experimental eastern Australian salmon versus time post-feeding (h) at 15.1°C (●) and 19.4°C (○). *n* is sample size.

7.3.8.2. Bioenergetics modelling

Using the bioenergetics model simulations described above, daily ration for eastern Australian salmon of various sizes was calculated for the two experimental temperatures (Table 7.9). The estimated mean daily consumption averaged across fish of all sizes (2.20 to 60.27 cm FL) was 12.55 ± 0.74 g at 15ºC and 19.01 ± 1.00 g at 20ºC. This equated to a daily ration of 1.01 ± 0.06 and 1.36 ± 0.07 % of body weight per day (BW/d) at 15 and 20ºC respectively. Daily ration was higher for small (2.61 ± 0.03% and 3.63 ± 0.05% BW/d at 15 and 20ºC respectively) and medium-sized fish (1.36 ± 0.01 and 1.90 ± 0.02% BW/d) and was lowest for large fish (0.92 ± 0.01 and 1.28 ± 0.01% BW/d). Estimated annual consumption rates increased with both fish size and temperature from 0.41 ± 0.01 kg/year for small fish at 15ºC to 10.83 ± 0.12 kg/year for large fish at 20ºC. This was equivalent to an overall Q/B for eastern Australian salmon in S.E. Australia of 3.67 ± 0.22 at 15ºC and 4.98 ± 0.26 at 20ºC (Table 7.9).

Table 7.9. Fork length (FL – cm), mean body weight (g ± S.E.), daily consumption (g/day ± S.E.), ration (%BW/day ± S.E.), annual prey consumption (kg/year ± S.E.) and *Q/B* estimate (food consumed/biomass) for small, medium and large eastern Australian salmon using simulations of the bioenergetics model at 15 and 20ºC.

Size class	Length range (FL cm)	Body weight (g)	Simulation temperature (ºC)	Daily consumption (g/day)	Daily ration (% BW/day)	Annual consumption (kg/year)	*Q/B*
Small	2.20 – 20.0	43.57 (0.54)	15	1.12 (0.01)	2.61 (0.03)	0.41 (0.01)	
			20	1.60 (0.02)	3.63 (0.05)	0.58 (0.01)	
Medium	20.0 – 40.0	542.97 (5.31)	15	7.32 (0.07)	1.36 (0.01)	2.67 (0.03)	
			20	10.42 (0.10)	1.90 (0.02)	3.80 (0.04)	
Large	40.0 – 60.27	2301.08 (25.53)	15	21.04 (0.24)	0.92 (0.01)	7.68 (0.09)	
			20	29.69 (0.33)	1.28 (0.01)	10.83 (0.12)	
Overall	2.20 – 60.27	1320.79 (73.07)	15	12.55 (0.74)	1.01 (0.06)	4.58 (0.27)	3.67 (0.22)
			20	19.01 (1.00)	1.36 (0.07)	6.94 (0.36)	4.98 (0.26)

7.3.8.3. Empirical multiple regression model

There was substantial variability in eastern Australian salmon caudal fin aspect ratio (AR) for fish of all sizes (12.9 to 61.5 cm FL) and ranged from 1.775 to 3.143 (Fig. 7.17). AR was not significantly correlated with fish size (r = 0.030, P = 0.340, n = 189) and therefore the average AR for fish of all sizes (2.366 ± 0.022) was used in the multiple regression model. W_∞ was calculated by converting the L_∞ value estimated in Chapter 3 (67.72 cm FL) to weight using the length-weight relationship for eastern Australian salmon ($Wt = 0.0192(FL)^{2.9666}$, $r^2 = 0.994$, n = 2300). W_∞ was therefore calculated to be 4100.27 g. Using the multiple regression model of Palomares & Pauly (1989, 1998), the overall *Q/B* for eastern Australian salmon was estimated to be 4.02 at 15ºC and 5.25 at 20ºC.

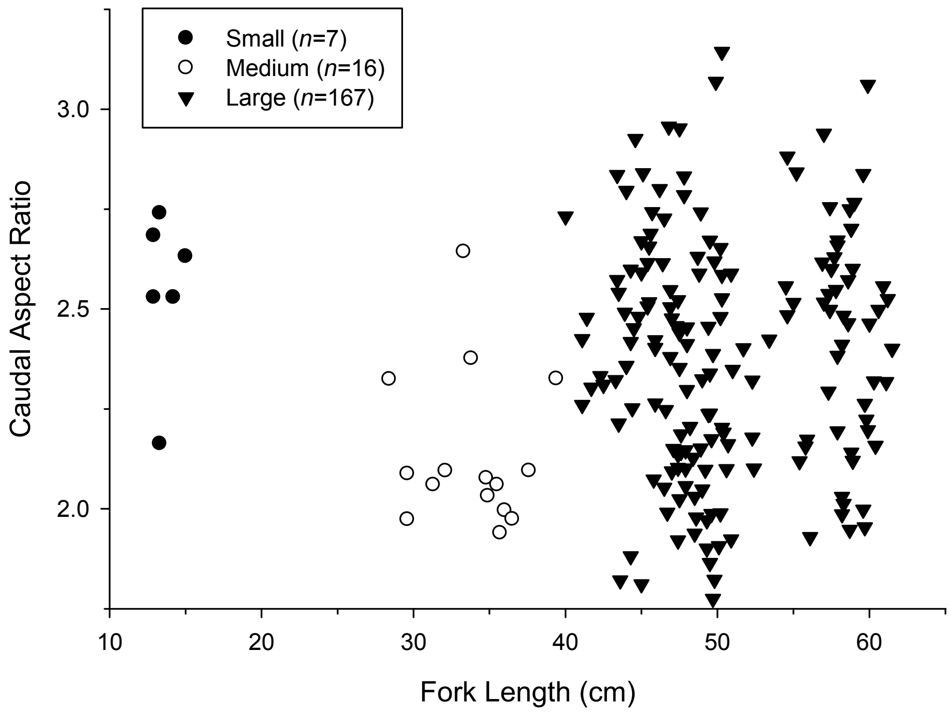


Figure 7.17. Caudal fin aspect ratio versus fork length (cm) for small (●, 0 – 20 cm FL), medium (○, 20 – 40 cm FL) and large (▼, > 40 cm FL) eastern Australian salmon. *n* is sample size.

7.3.9. Annual prey consumption

The *Q/B* estimates calculated from the gastric evacuation experiments, the bioenergetics model and the multiple regression model (Table 7.10) were averaged to give an overall *Q/B* value at 15ºC of 3.63 ± 0.24 and 4.82 ± 0.31 at 20ºC. These values of *Q/B* equate to between 3.63 and 4.82 kg (overall mean 4.22 kg) of prey being consumed annually for each 1 kg of eastern Australian salmon biomass.

Table 7.10. Annual food consumed per biomass (*Q/B*) for eastern Australian salmon estimated using three techniques: gastric evacuation experiments, bioenergetics model simulations and a multiple regression model at 15ºC and 20ºC.

Estimation Method	**Temperature (ºC)**	
	15	**20**
Gastric Evacuation Experiments	3.20	4.23
Bioenergetics Modelling	3.67	4.98
Multiple Regression Modelling	4.02	5.25
Mean (S.E.)	3.63 (0.24)	4.82 (0.31)
Total (S.E.)	**4.22 (0.32)**	

7.4. Discussion

Small juveniles

The research done on the diet of juvenile and adult eastern Australian salmon clearly demonstrates an ontogenetic change in diet. The research on two size-classes of small juveniles shows a progressive decline in the contribution of smaller prey items (such as copepods) with increasing size. The onset of piscivory occurred when individuals were < 80 mm FL, but as fish grew larger there was an increasing reliance on teleost prey. These findings are consistent with those observed in other populations of eastern Australian salmon in Australian and New Zealand (NZ) waters, where larger prey such as teleosts became increasingly important as individuals reach about 100 mm FL (Malcolm 1959, Baker 1971, Robertson 1982). Similar ontogenetic shifts in diet composition have been noted for other similar-sized pelagic fish; mackerel tuna (*E. affinis*; Griffiths *et al.* 2009), the little tunny *E. alleteratus* (Bahou *et al.* 2007) and bluefish/tailor *Pomatomus saltatrix* (Marks & Conover 1991) with small fish primarily consuming small crustaceans and larger fish progressively more (and larger) teleost prey.

Small juvenile (0+ and 1+) eastern Australian salmon consumed a wide variety of benthic and pelagic prey items, including amphipods, copepods, mysids and teleosts. Individual stomachs were generally dominated by a single prey species (often multiple individuals) with relatively few other prey taxa present. This feeding mode implies that the fish tend to gorge on prey that is concentrated or aggregated rather than selective or continuous feeding. Similar feeding behaviours have been reported for adult eastern Australian salmon in NZ which tend to feed on large concentrations of a single teleost species (Baker 1971). Juvenile eastern Australian salmon collected from Botany Bay (NSW) were also found to consume mainly small fish (47% of the diet), as well as polychaetes (mainly nereids) and crustaceans (mainly amphipods) (Pease *et al.* 1981). The diet of juvenile western Australian salmon is reportedly similar to that presented here for eastern Australian salmon, the most important prey items reported by Robertson (1982) to be demersal fish (39.4%) and by Hindell *et al.* (2000, 2001, 2002) to be pelagic crustaceans (42%) and demersal teleosts (22%).

Multivariate analysis demonstrated that the diet of juvenile eastern Australian salmon was influenced by fish size along with regional and seasonal factors. For example, copepods comprised a large proportion of diet of small (< 80 mm FL) individuals during summer, particularly in highly exposed areas along the north and east coasts of Tasmania, whereas teleosts (particularly whitebait *Galaxias* spp.) formed a major component of the diet of larger juveniles (> 80 mm FL) in the north-west during autumn and spring. At other times of the year these two size groups tended to feed on more benthic prey such as amphipods and polychaetes. The observed seasonal variability in the diet is consistent with the presence of greater densities of zooplankton along the east coast in late summer to winter (Harris *et al.* 1991, Slotwinski 2008) and whitebait during winter/spring in north-west Tasmania (Inland Fisheries Service 2006). Similar patterns have also been observed in other populations of eastern Australian salmon where zooplankton prey such as copepods are more important during summer and benthic crustaceans, fish and cephalopods during winter when zooplankton become less abundant (Baker 1971, Robertson 1982, Hoedt and Dimmlich 1994).

Small eastern Australian salmon in Tasmanian waters feed on a much wider range of prey items than medium or large fish, whereas in NSW this pattern was reversed. The diversity of diet clearly varies depending on factors such as geographical location, prey availability and habitat (e.g., estuarine seagrass cf. ocean beach).

Feeding periodicity in juvenile eastern Australian salmon peaked in the late afternoon-early evening and again at around sunrise to mid-morning. During these peak periods, fish fed mainly on pelagic prey such as teleosts and mysids, some individuals gorging themselves until almost complete fullness. Through the middle part of the day, feeding intensity was lower and mainly directed at benthic prey such as polychaetes. This feeding pattern, including changes in the composition of the diet, may reflect diurnal variation in the availability of preferred prey species and/or changes in the schooling behaviour by eastern Australian salmon (e.g., wide dispersal during the day and formation of schools in the evening and early morning). Indeed, it has previously been shown that schooling behaviour increases the feeding success of juvenile eastern Australian salmon when preying on swarming prey such as mysids (Foster *et al.* 2001).

<u>Large juveniles and adults</u>

The dietary analyses on larger juvenile and adult eastern Australian salmon demonstrated that, in contrast to the diet of the small juveniles, the diet of large (> 40 cm FL) individuals was dominated (~ 65% by WW) by the pelagic fishes Australian sardines and scads. Teleosts ranging between 4.5 and 24.6 cm SL were observed to have been consumed by large eastern Australian salmon. The diet of medium-sized (20 to 40 cm FL) fish exhibited features of the diets of both small and large fish. Medium-sized fish between 35 and 40 cm FL consumed similar prey taxa to that of large fish consisting of blue mackerel, scads and eastern sea garfish of a similar size range (5.5 – 22.2 cm SL). The diet of subadult western Australian salmon in Western Port was similar to that of medium-sized fish in this study (93% pelagic fish) and consisted exclusively of the pelagic teleosts Australian anchovy, Australian sardine and sandy sprat (Hoedt & Dimmlich 1994).

Overall, large fish had the most diverse diet (77 taxa) with small (58 taxa) and medium-sized fish (59 taxa) possessing less diverse diets. Large and small fish were sampled in similar numbers (2,042 and 2,668 respectively), whereas fewer (786) stomachs were examined from medium-sized fish. It is therefore possible that the number of prey taxa observed in each size class was influenced by the sample sizes of fish collected, and a larger sample of medium-sized fish may have increased the observed dietary breadth of this size class of fish.

Prey size significantly increased with fish size, the largest prey recorded being a 24.6 cm SL eastern sea garfish consumed by a 40.8 cm FL eastern Australian salmon. Although eastern Australian salmon are clearly capable of consuming large prey items, the vast majority (94%) of the 2,215 prey items recovered and measured in this study were < 16 cm SL.

<u>Overall diet</u>

The results presented in this chapter demonstrate that eastern Australian salmon consume a diverse range of predominantly small pelagic schooling fish, in particular the clupeids Australia sardines and sandy sprats, the carangids jack mackerel, yellowtail scad and unidentified scads (hereafter all three species: scads), the scombrid blue mackerel and the engraulid Australian anchovy. In contrast to the results of this work, previous diet studies of eastern Australian salmon in Australian waters have reported the most important prey item to be the pelagic euphausiid crustacean *Nyctiphanes australis* (krill) (Malcolm 1966a) with the Australian anchovy and squid being of relatively minor importance (Stanley 1980). Euphausiid crustaceans were found in the diet of eastern Australian salmon in the present study, but only in relatively small quantities (< 0.1% WW).

Eastern Australian salmon in NZ offshore waters were reported to feed exclusively on pelagic crustaceans, especially krill in winter, however inshore schools preyed mainly on a suite of small pelagic fish (including clupeids (Australian sardine), engraulids (Australian anchovy), mugilids, hyporhamphids and carangids (jack mackerel)) similar to those found abundant in the diet of eastern Australian salmon in this study (Baker 1971, Hartill & Walsh 2005). The diet observed for eastern Australian salmon in S.E. Australia in this study is similar to that reported for the closely related congeneric species, the west Australian salmon in WA waters which consisted predominantly of Australian sardines along with sandy sprats and scads (Malcolm 1966a, M. Cappo pers. comm. in Hoedt & Dimmlich 1994). One model to explain the apparent shift in diet of Australian salmon in S.E. Australia from mainly krill during the 1960s (Malcolm 1966a) to mainly small telesosts during the present study, is that the availability of these prey species have changed. Potentially, there has been a regime shift from a cold water dominated pelagic system rich in krill, to a more warm water dominated system that supports lower abundance of krill.

It has been previously been suggested that the differing number of gill rakers possessed by eastern Australian salmon (33 to 40) and west Australian salmon (25 to 31) reflect the different feeding habits of the two species with the eastern species large number of comparatively fine rakers adapted to straining small (< 12 mm) krill from the water column. The west Australian salmon purportedly feeds predominantly on the much larger pelagic baitfish Australian sardine, do not need as fine a straining mechanism and hence the fewer number of short, stubby gill rakers observed (Malcolm 1959, 1966a). The results of this work do not lend any support to this suggestion.

Small pelagic schooling fishes are a common feature of the diets of nearshore pelagic predatory fish throughout the world (e.g., Begg & Hopper 1997, Buckel *et al.* 1999, Griffiths *et al.* 2007, 2009, Overton *et al.* 2008). The contribution of pelagic fishes to the diets of the coastal scombrid species longtail tuna *Thunnus tonggol* and mackerel tuna *Euthynnus affinis* in tropical Australian waters were similar (in terms of WW) to the diet of eastern Australian salmon presented here (Griffiths *et al.* 2007, 2009). Indeed, in the region of eastern Australia where the ranges of eastern Australian salmon, longtail tuna and mackerel tuna overlap in northern NSW-southern Queensland, important prey items for all three species included Australian sardines, engraulids, blue mackerel and scads (Griffiths *et al.* 2007, 2009).

Eastern Australian salmon also consumed demersal fishes (primarily *Sillago spp*.) as well as small numbers of other benthic prey (crustaceans and molluscs) indicating that some feeding occurs on or near the seabed. The presence of demersal teleost, crustacean and mollusc prey in eastern Australian salmon stomachs has also previously demonstrated that demersal feeding occurs in NZ waters (Graham 1956, Moreland 1960, Baker 1971, Penlington 1988). Demersal fishes were also consumed in similar proportion to that for eastern Australian salmon (4.6% by weight) by longtail tuna (4.2%) and in much greater proportion by mackerel tuna (18.8%) in eastern Australia (Griffiths *et al.* 2007, 2009). It has been suggested that the high proportion of demersal prey in the diet of these small scombrid species may be a result of their preference for the shallow neritic waters of the continental shelf where slower moving demersal prey may be easily targeted when pelagic prey are unavailable or scarce (Griffiths *et al.* 2007, 2009).

Regional and seasonal comparisons

Eastern Australian salmon played a similar ecological role in all four regions in S.E. Australian coastal waters as a predator of small pelagic fish. Whilst the overall diversity and composition of the diet was similar among regions and seasons, there were some important spatial and temporal variations. The temperate coastal waters of S.E. Australia are a relatively uniform environment with comparatively subtle seasonal variations in nearshore water temperatures (Ridgway & Godfrey 1997). It is therefore unlikely that variation in nearshore water temperature is significant enough to produce large variation in prey diversity as would be seen between true tropical and temperate waters (Blaber 2002, Griffiths *et al.* 2007). Despite pelagic fish being by far the most important prey category in all four regions, demersal fishes were substantially more important in southern NSW than in the other regions. The majority of this difference was due to the consumption of large numbers of eastern school whiting in southern NSW waters. The two main commercial fisheries for eastern school whiting in S.E. Australia are Danish seining in Victoria (Port Philip Bay to Lakes Entrance) and trawling in NSW (Kailola *et al.* 1993). It is possible that the relative importance of eastern school whiting to the diet in southern NSW is a reflection of the higher relative abundance of this species in southern NSW waters compared with those of northern NSW, Victoria and Tasmania.

The most important pelagic prey species also varied between locations with the clupeids Australian sardines, sandy sprats and Australian anchovy consumed in much greater numbers in northern NSW (59.3%) than in southern NSW (20.9%), Victoria (0.3%) or Tasmania (0%). Australian sardines, sandy sprats and Australian anchovy were also consumed in significant quantities by both longtail tuna and mackerel tuna in northern NSW waters (Griffiths *et al.* 2007, 2009). Similarly, scads were consumed by salmon in much greater quantities in Victoria (53.9%), southern NSW (38.5%) and Tasmania (38.7%) than in northern NSW (19.6%). This pattern is possibly explained by the abundance and distribution of the two species making up the "scads" group. The jack mackerel is the main species found in Victorian and southern NSW waters in large enough numbers to support a significant commercial purse seine fishery, whilst the scad consumed by eastern Australian salmon in northern NSW are mainly yellowtail scad which are most abundant in NSW waters (Kailola *et al.* 1993). Both longtail tuna and mackerel tuna consumed scads in northern NSW, mackerel tuna in similar quantities (17%) to those reported here for eastern Australian salmon in northern NSW (19.6%) (Griffiths *et al.* 2007, 2009). Blue mackerel was of similar importance to the diet of eastern Australian salmon in both NSW regions and Victoria (8.2 to 10.1%) but was not recorded in stomachs of fish sampled in Tasmania.

Australian sardines were found in eastern Australian salmon stomachs in all seasons in northern NSW and made up, on average, approximately one third of the diet, but was easily most important in summer when ~ 90% of the prey consumed was Australian sardines. Australian sardines were also found in summer and autumn in southern NSW and autumn in Victoria but was much less important overall (~ 10%) and not found in Tasmania at all. It has previously been shown that some Australian sardines migrate into southern Queensland during winter to spawn before moving southwards after the spawning season (Ward & Staunton-Smith 2002). Eastern Australian salmon in northern NSW may therefore be feeding on Australian sardine shoals as they move southwards along the east coast after spawning in spring-summer, whilst eastern Australian salmon in the more temperate waters of southern NSW consume Australian sardines which aggregate in surface schools to spawn in summer-autumn in this region (Ward *et al.* 2001). A similar explanation can be suggested to explain the high importance of Australian anchovies to the diet in winter in northern NSW (20%): Australian anchovies have been shown to migrate into the warmer waters of S.E. Queensland to spawn in winter (Ward *et al.* 2003). In southern NSW, scads were the prey species found in all seasons where they made up a considerable component of the diet (~ 26 to 62%). It was also an important prey item in northern NSW and was found in salmon stomachs in three out of four seasons contributing 13 to 37% of the diet with the highest contribution occurring in spring. Jack mackerel was found in the stomachs of mackerel tuna in all months in northern NSW and was also most important to the diet in spring (Griffiths *et al.* 2009). The season in which scads were absent from the diet of eastern Australian salmon was summer when the diet consisted almost exclusively of Australian sardines.

Prey consumption rates and daily ration

The consumption estimates presented as part of this study were calculated using three diverse but well founded techniques, two empirical and one experimental. Previous studies have used either a single estimation technique (Elliot & Persson 1978), multiple similar techniques (Buckel & Conover 1997), or applied experimental results derived for one species to other comparable species based on physiological similarities (Olson & Galvan-Magana 2002, Griffiths *et al.* 2007, 2009). In addition, estimation of consumption rates using gastric evacuation rate experiments on captive fish in controlled laboratory conditions has been attempted previously for very few other pelagic fish species (e.g., yellowfin tuna *T. albacares*: Olson & Boggs 1986, striped bass *Morone saxatilis*: Hurst & Conover 2001). The similarity of values determined using each of these techniques suggests that the resulting estimates may be reasonably accurate.

The estimates of eastern Australian salmon consumption using gastric evacuation experiments may be conservative. One of the few other studies that has successfully used gastric evacuation experiments to estimate the consumption of a fish species showed that for yellowfin tuna, gastric evacuation rates were inversely correlated with total lipid content of four food organisms (Olson & Boggs 1986). In this study, the experimental food organism fed to eastern Australian salmon and hence used for used for the calculation of consumption rates and daily ration was Australian sardines. Australian sardines are likely to be the prey item with the highest lipid content in the diet of eastern Australian salmon. Gastric evacuation rates for all other items in the diet of eastern Australian salmon will therefore be faster than for Australian sardines and thus overall actual consumption rates and daily ration for eastern Australian salmon in S.E. Australia may be higher than the estimates resulting from the gastric evacuation experiments.

Daily ration estimates for eastern Australian salmon of all sizes (0.9 to 1.4% BW/day) were lower than for other similar-sized (~ 1.5 kg) primarily piscivorous temperate pelagic fish species striped bass (~ 5% BW/day) and tailor (~ 6% BW/day) estimated using bioenergetics modelling in Chesapeake Bay (Hartman & Brandt 1995a). The considerable difference in daily ration between these species and eastern Australian salmon is difficult to explain, but the water temperatures used in the Chesapeake Bay model were generally much higher than those used to estimate eastern Australian salmon daily ration in this study (15 to 20ºC). Decreased water temperatures can result in decreased gastric evacuation rates (Temming *et al.* 2002) and metabolic rates (Korsmeyer & Dewar 2001) in pelagic fishes. Both striped bass and tailor are found in waters as warm as ~ 30ºC on the east coast of the United States (Hartman & Brandt 1995a, 1995b), whereas eastern Australian salmon in S.E. Australian waters rarely tolerate temperatures > ~ 23ºC (Malcolm 1966a, pers. obs.). Daily ration for eastern Australian salmon was also lower than those for the mainly tropical scombrids longtail tuna (1.3 to 2.3% BW/day: Griffiths *et al.* 2007), mackerel tuna (2.0 to 4.1% BW/day: Griffiths *et al.* 2009), skipjack tuna *Katsuwonis pelamis* (5.5 to 9.9% BW/day: Menard *et al.* 2000, Essington 2003), albacore *T. alalunga* (3.8% BW/day: Essington 2003), juvenile bigeye tuna *T. obesus* (4.8% BW/day: Menard *et al.* 2000) and juvenile yellowfin tuna (2.3 to 6% BW/day: Olson & Boggs 1986, Maldeniya 1996). The difference in daily ration between these species and many temperate species (including eastern Australian salmon) is due to the influences of both the extremely high metabolic rates possessed by scombrids (Palomares & Pauly 1998) in addition to the higher temperatures of the mainly tropical waters in which they are found, on prey evacuation rates and hence daily ration (Durbin *et al.* 1983). Indeed, even within the family Scombridae, temperate species like southern bluefin tuna *T. maccoyii* and Atlantic bluefin tuna *T. thynnus* have daily ration estimates (0.89 to 1.01 & 1 to 2% BW/day respectively) much lower than for tropical species and similar to those for eastern Australian salmon presented here (Young *et al.* 1997, Essington *et al.* 2001).

Eastern Australian salmon daily ration decreased with increasing fish size from 1.01 to 3.63 % BW/day for small fish (< 20 cm FL) to 0.89 to 1.28 % BW/day for large fish (> 40 cm FL). This pattern has been similarly noted for other pelagic species longtail tuna (Griffiths *et al.* 2009), mackerel tuna (Griffiths *et al.* 2007), tailor (Buckel & Conover 1997) and yellowfin tuna (Maldeniya 1996). It has been previously suggested that (for longtail tuna) the decline in daily ration with size may be the result of decreased metabolic demand at sizes greater than that at which the growth rate begins to slow (Griffiths *et al.* 2007). As a result, larger fish may require relatively smaller amounts of food to meet their metabolic requirements than smaller fish. Decreasing growth rate with increasing size (Chapter 3) likely reflects this decrease in metabolic demand and hence daily ration in eastern Australian salmon.

Thirty-eight percent of the 5,109 eastern Australian salmon collected in this study had empty stomachs. In addition, the predominance of single prey taxa in the stomachs of juvenile fish observed during the present study and direct observations of feeding behaviour (pers. obs.), suggests that this species is a ‘gorging’ feeder. Such feeding behaviour together with time for complete gastric evacuation of ~ 40 to 50 h means that within a given shoal of fish, most individuals will either contain stomach contents (if feeding has occurred < 40 to 50 h ago) or will be empty (if feeding > 40 to 50 h ago). Similar results have been found for striped bass, which has also been suggested to be a gorging feeder in the Hudson River (USA) with 66% of fish collected having empty stomachs (Hurst & Conover 2001).

Ecosystem and fishery implications

The estimates of prey consumption rates and daily ration presented here suggest that eastern Australian salmon play an important role in structuring the nearshore pelagic ecosystem in S.E. Australia by consuming approximately between 3.6 and 4.8 times their own biomass annually (*Q/B*). The majority (93%) of this prey consists of pelagic fishes, all of which are economically important species.

The *Q/B* estimates presented here are well within the range for some temperate pelagic marine fish species (e.g., 1.52 for European seabass *Dicentrarchus labrax* and 4.08 for marine coho salmon *Oncorhynchus kisutch*: Palomares & Pauly 1998), but are low compared with similar sized primarily piscivorous pelagic species from temperate waters (18.3 for striped bass & 21.9 for tailor; estimated from Hartman & Brandt 1995a) and up to an order of magnitude lower than for species with the highest energy demands recorded like scombrids (e.g., skipjack tuna 32.4, yellowfin tuna 19.8, albacore 13.4; Essington 2003). This means that, although the eastern Australian salmon population in S.E. Australian waters probably have a substantial impact through consumption of large amounts of prey, their 'predatory impact' relative to their biomass appears to be comparatively low compared with that of other species which occupy similar trophic positions in this region. Populations of primarily piscivorous pelagic schooling species in this region like tailor, yellowtail kingfish *Seriola lalandi*, Australian bonito *Sarda australis*, skipjack tuna and *Thunnus* spp. all possess (or would be expected to posses) *Q/B*s at least double, and up to ~ 8 times larger than that of eastern Australian salmon.

The predatory impact of the eastern Australian salmon stock is not accurately known, but these results suggest that it may be lower other species. For example, Griffiths *et al.* (2007) found that a 4,800 t population of longtail tuna consumed 148,200 t/year of prey in the Gulf of Carpentaria, of which 82% were pelagic teleosts and 16% demersal teleosts, including 599 t/year of economically important penaeid prawns. Similarly, a mackerel tuna biomass of 2,100 t was estimated to consume 25,000 t of prey annually in northern NSW and southern Queensland, of which 80% were pelagic teleosts and 14% demersal teleosts (Griffiths *et al.* 2009). At the higher end of the scale, it was estimated that the yellowfin tuna population consumed 2.2 to 3.2 million t of prey each year between 1970 and 1972 in the eastern Pacific Ocean and Watanabe *et al.* (2004) estimated that albacore were capable of consuming 145,000 to 206,000 t/day of migrating Japanese anchovies *Engraulis japonicus* in the northern Pacific. Such large predation rates highlight the resilience of these small pelagic fish species (like clupeids and engraulids) to such apparently high 'predatory impact'. Small clupeoid fishes in particular are known to have extremely fast growth rates (Rogers & Ward 2007a, b) and high reproductive output (Plaza *et al.* 2002, Dimmlich *et al.* 2009) and it is these two features which allow them to maintain large populations in the face of enormous predation pressure from a vast suite of predators throughout the worlds oceans.

In conclusion, and recognizing that the biomass of eastern Australian salmon in S.E. Australia is unknown, they do have the potential to consume a substantial biomass of teleost fish annually. All of the species consumed in the greatest quantities were of economic importance to commercial and recreational fisheries: Australian sardines, scads, blue mackerel, sandy sprats, Australia anchovies and eastern school whiting. Pelagic species, as discussed above, are adapted to be resilient to intense predation pressure and it is thus considered unlikely that predation by eastern Australian salmon in S.E. Australia would pose any significant risk to the health of these stocks.

8. THE TOTEMIC AND CULTURAL SIGNIFICANCE OF AUSTRALIAN SALMON TO THE ABORIGINAL PEOPLE OF NSW

OBJECTIVES ADDRESSED

This chapter addresses objective 8 of the original Project No. 2006/018 to "Describe the totemic and cultural significance of Australian salmon to the Aboriginal people of NSW".

The objective was addressed through a B. Env Sci (Honours) thesis by Mr Jesse Waddell through Southern Cross University. A summary report from this thesis is attached as Appendix 5.

8.1. Introduction

The report in Appendix 1 documents research findings of a recent cultural study undertaken within Indigenous communities on the south coast of New South Wales (NSW). Focussing on eastern Australian salmon, the study initially explored the customary values and uses surrounding marine resources for Indigenous people by way of a literature review. Historical accounts and archaeological findings on midden analysis found that salmon have long represented customary importance, primarily as a staple food, to the local Yuin people of southern NSW. In the absence of any specific information on salmon use within contemporary Indigenous culture, qualitative research methods such as key informant interviewing provided a means to locating knowledge specific to local fishing practice and cultural uses of salmon.

During consultation with Indigenous communities along the south coast of NSW, a number of issues surrounding marine use and access to cultural resources were uncovered. Specific to salmon, contemporary values and use of this species were found to include commercial value, communal values (staple cultural food), and totemic significance. Traditional ecological knowledge was also found to be important to modern Indigenous fishing practices for salmon, with environmental cues such as the flowering of a tree used as an indicator to resource availability. An example of the ongoing importance of salmon to Indigenous fishers is given in the small but well managed beach haul fishery that has provided local Indigenous fishers with income and livelihood for many decades.

In light of these findings, a number of considerations to future management of the species are discussed in the report. Primarily:

- Salmon continue to bring commercial value as an important economic resource for Indigenous beach-haul fishers;
- Many indigenous fishers practice a subsistence harvest and resource sharing regime which, if limited, can severely impact on standard of living and quality of life;
- Further commercialisation of this resource will negatively affect Indigenous use and values;
- Resource allocation and fisheries planning of salmon and other marine resources must take account of a range of needs, uses and values within Indigenous communities;
- Spiritual and belief values, such as totem significance of the fish, are a significant value to be considered by managers; and
- Traditional ecological knowledge should be employed in achieving ecologically sustainable use of marine resources.

9. CROSS-JURISDICTIONAL CO-OPERATION TO ENSURE SUSTAINABLE FISHING FOR EASTERN AUSTRALIAN SALMON

OBJECTIVES ADDRESSED

This chapter addresses objective 5 of the expanded Project No. 2008/056 to "Use eastern Australian salmon as a case study in developing a model of co-operative multi-jurisdictional management of shared-stock fisheries to ensure global harvest sustainability".

9.1. Introduction

A discussion paper submitted to the Australian Fisheries Management Forum in 2003 (AFMF Meeting 4, July 2003) identified that there was no nationally agreed framework for co-operative management of fisheries based on stocks that straddle jurisdictional boundaries and that are used by competing sectors both within and between jurisdictions. Identified potential risks that this situation posed for sustainable and efficient management of such fisheries included:

1. Lack of drivers for resource assessment work focussed at the stock level;
2. Potential for over-fishing at key points in the range of the stock;
3. Difficulties in achieving structural reform at state level if fishing effort on the same stock remained uncontrolled elsewhere;
4. Assessment complications arising from differing harvest strategies applied to different life history stages of the fish;
5. Potential for particular jurisdictions/sectors to assume "ownership" of significant portions of sustainable yield to the detriment of other participants in the fishery;
6. Lack of mechanisms for structural adjustment strategies to operate across jurisdictional boundaries; and
7. Potential for conflict over shifts in spatial allocation of effort to achieve optimum harvest strategies (e.g., move effort away from smaller fish to larger fish to optimise yield).

The discussion paper also identified that any cross-jurisdictional arrangements designed to mitigate these risks would need to include as a minimum:

- Agreement on the cross-jurisdictional management unit – preferably (or usually) set at the exploitable stock level;
- Ability to obtain a credible estimate of sustainable yield for the stock;
- Ability to estimate total fishing mortality imposed by each jurisdiction and its relationship to the estimated global sustainable yield; and

- Identification of appropriate tools to vary overall and proportional mortality to explicitly link the catch in each jurisdiction with global sustainable yield and with any agreed sectoral or jurisdictional shares of this yield.

National guidelines for cross-jurisdictional co-operation to address biological sustainability, resource allocation, economic and/or social objectives for fisheries management are being developed as part of a separate national Harvest Strategy project being conducted under the auspices of the Australian Fisheries Management Forum.

9.2. Eastern Australian salmon

Objective No. 5 for the second stage of the current project identifies the need to use information obtained on eastern Australian salmon stock status and the characteristics of fisheries across three state jurisdictions as a case study in developing a model of cross-jurisdictional co-operation to address global harvest sustainability objectives. This chapter therefore focuses on the steps needed to develop cross-jurisdictional arrangements for sustainable harvest of eastern Australian salmon, and in particular how the findings of this project can inform selection of appropriate monitoring programs, assessment approaches and performance indicators to address sustainability objectives for eastern Australian salmon fisheries.

In general, the steps needed to develop co-operative cross-jurisdictional arrangements include:

- Relevant jurisdictions (New South Wales (NSW), Tasmania and Victoria) to conduct a joint risk assessment to determine whether or not current separate jurisdictional management and lack of a co-ordinated monitoring and assessment regime poses unacceptable risks to the global sustainability of eastern Australian salmon fisheries.
- If risks associated with current arrangements are unacceptable and a co-ordinated approach to ensuring global sustainability is required, jurisdictions and relevant stakeholder representatives to jointly identify and evaluate cost effective monitoring regimes and appropriate assessment approaches that facilitate the development of performance indicators and reference points to demonstrate the sustainability of global harvest levels for eastern Australian salmon.
- Participants to negotiate and agree on the development of global harvest decision rules and management responses, and on the roles of individual jurisdictions or stakeholder groups in contributing to global monitoring and assessment programs.

As described in Chapter 2, the fisheries for eastern Australian salmon in NSW, Victoria and Tasmania have the following characteristics:

- All fisheries are based on a single stock of eastern Australian salmon, with the known spawning areas being in coastal waters of NSW and eastern Victoria, and juvenile nursery areas in bays, inlets and sheltered coastal waters around Tasmania, eastern Victoria and southern NSW.
- Commercial catches have been at historically high levels in recent years (~ 1,900 t/yr) and in each state are dominated by high volume catches by a small number of large vessels using haul seines and purse seines in coastal waters. These catches are generally marketed at relatively low prices for bait or pet food, and targeted fishing is strongly influenced by market demand. The remainder of state commercial catches are taken in small quantities by a substantial number of commercial operators as part of diversified fishing businesses.
- Commercial fisheries in each state exploit different life history stages of the eastern Australian salmon population. Tasmanian catches are primarily juvenile and sub-adult (2 to 4 years old) fish that are generally < 45 cm FL. Catches from eastern Victorian coastal waters contain both juvenile and adult (2 to 5 years old) fish. Smaller commercial catches from Victorian bays and inlets are likely to consist mostly of juvenile fish. Catches from southern NSW contain sub-

adult and adult (3 to 7 years old) fish, while catches from northern NSW are dominated by adult (3 to 10 years old) fish.

- Eastern Australian salmon are also targeted by shore-based and boat-based recreational fishers in all three states, and available evidence suggests that the size composition of recreational catches is similar to that observed for commercial catches from the same waters. Estimates of total recreational catch from the 2000/01 National Recreational Fishing Survey and from a Tasmanian state survey in 2007/08 indicate that recreational catches have accounted for 15 – 35% by weight of total annual state harvests of Australian salmon.
- Commercial fisheries in all three states are managed primarily using input (effort) controls including limited entry and equipment restrictions, although some secondary catch controls such as size limits, area closures and trip limits are also used. Tasmania has applied a total annual commercial catch limit of 120% of average annual catches in recent years (equivalent to 435 t) as a limit reference point to trigger a review of the adequacy of existing management arrangements. Recreational salmon fisheries are managed using size and individual catch limits, and equipment restrictions in some cases.

9.3. Monitoring of fisheries

All commercial fisheries for eastern Australian salmon are routinely monitored through mandatory catch and effort logbook programs. These programs provide a time series of catch and effort information by fishing method and area.

The usefulness of these data as indicators of fishery or stock status is constrained by the following factors:

- Uncertainty regarding the species composition of commercial Australian salmon catches – particularly in some Victorian and Tasmanian waters. Eastern and western Australian salmon species are not routinely identified and reported separately in logbooks.
- The strong influence of market demand on the amount of targeted effort expended by large operators.
- The skewed distribution of overall commercial catch rates because of the large contributions to total state catches of a few large individual catches.
- Uncertainty regarding the relationship between purse seine/beach seine catch rates and stock abundance because of inadequate recording of search time as a unit of effort.

Routine sampling of commercial catches to provide a time series of information on the size and age structure of the recruited part of the eastern Australian salmon population is feasible, and has been carried out by some, but not all, jurisdictions. Given that a small number of large operators contribute the majority of the total commercial catch in each jurisdiction, it is appropriate that catch sampling should focus to some extent on the landings of this group.

However, the regional differences in the size and age composition of eastern Australian salmon catches, in addition to the sporadic, market driven nature of the major landings, makes representative sampling of the overall fishery difficult and potentially costly. Gaining representative samples in northern NSW is complicated further where the commercial fishery is limited to a by-catch allowance and a relatively small daily trip limit for some fishers to allow retention of salmon for use as bait.

Any future systematic sampling of eastern Australian salmon commercial catches will require dedicated staff in each jurisdiction to co-ordinate the work, and a good working relationship with the major salmon fishers to enable sampling to be organized at times and places where large catches are expected. This strategy worked well during the present study in NSW and Tasmania, where the researchers had a good rapport with industry.

Monitoring of recreational fishing for Australian salmon in all relevant jurisdictions is limited in terms of both geographical and temporal coverage. State-wide estimates of total recreational fishing effort and catch are only obtained occasionally, and the only time that NSW, Tasmania and Victoria have obtained concurrent estimates was during the 2000/01 National Recreational Fishing Survey. Some jurisdictions have conducted periodic on-site creel surveys of recreational fishing in selected waters, or have recruited volunteer angler diarists to target Australian salmon to provide a time series of catch rate and size/age composition data. These data provide valuable information on fishery trends and the status of Australian salmon stocks in localised areas, but may not be representative of the situation state-wide or across the distribution of the species as a whole.

9.4. Assessment approaches and performance indicators

The need for clear fishery management objectives and for both quantitative and qualitative methods for measuring, assessing and monitoring the sustainability of wild stock fisheries has been increasingly recognised in recent years (Garcia and Staples 2000). A range of both model-derived and empirical performance indicators and reference points have been identified which may help to improve decision making to demonstrate the sustainability of finfish fisheries (Caddy and Mahon 1995, Caddy 1998).

The main variables that have been used to monitor fishery/stock status and as a basis for setting target or limit reference points are catch, fishing effort, fishing mortality and stock biomass. Other less used variables include size/age/maturity composition of catches; recruitment patterns and ‘escapement’ of fish to contribute to reproduction. The variable(s) chosen and the methods used to measure these variables for any given fishery will depend on the characteristics of the fishery and the stock. In general the variables chosen must be affordable to measure given the size/value of the fisheries; must be measurable with sufficient accuracy and precision to form the basis of clear management advice; and must be tailored to suit the biology of the species and the structure of the fisheries.

Determining suitable assessment approaches, performance indicators and reference points for cross-jurisdictional management of eastern Australian salmon fisheries requires extensive collaborative management strategy evaluation by all relevant jurisdictions, and is beyond the scope of this project. However, the findings of this project, together with an examination of existing assessment approaches for Australian salmon fisheries, provide some guidance for such a process.

9.4.1. Catch/Effort/Catch Rate trends

South Australia has used historical trends and fluctuations in commercial Australian salmon catches, targeted commercial fishing effort, and targeted commercial catch rates, to set upper and lower limit reference points which, if breached, trigger management review processes (Fowler *et al.* 2008). Tasmania has set a reference point of 120% of average annual commercial catches from 1996/97 to 2006/07 which, if exceeded, will trigger a management review processes. Western Australia has set a target catch range for the commercial Australian salmon fishery based on autoregressive moving average analysis of 37 years of catch data up to 2000. The upper limit of this range has recently been reduced to a more precautionary level to maintain export accreditation for the fishery under EPBC Act requirements. Western Australia also monitors targeted Australian salmon commercial catch rates as part of a “weight of evidence” approach to assessment and management decision making, but has not set reference points for this variable (Fletcher and Santoro 2009, 2010).

There appears to be some scope to use these fishery-related indicators and associated limit reference points in eastern Australian salmon fisheries as an 'early warning' of possible sustainability issues that require closer investigation or management response. The utility of these indicators in a cross-jurisdictional management framework will, however be influenced by:

- The extent of uncertainties regarding the relationship between these indicators and the abundance of eastern Australian salmon (as described above), and the ability to reduce some of these uncertainties (e.g. by improving catch/effort reporting and/or species identification in Australian salmon catches);
- Agreement by relevant jurisdictions on which indicators (catch, effort, catch rate) and associated reference points could be applied across all eastern Australian salmon fisheries to assist in developing a global harvest strategy;
- Agreement by relevant jurisdictions as to what decision rules/management responses will apply if limit reference points are breached; and
- What other types of performance indicators are available to assess sustainability and inform management decisions.

9.4.2. Biomass and fishing mortality indicators

In the past some Australian jurisdictions conducted regular aerial surveys of schooling Australian salmon in near-shore coastal waters. Such surveys could be used to estimate standing stock biomass in coastal waters and could be compared with reported commercial catches (and in some cases estimates of recreational catches) to obtain estimates of exploitation rates. While some large commercial operators use aircraft to spot schooling fish, systematic surveys of Australian salmon schools ceased in the 1990s. Aerial survey has in the past been considered as a tool for providing an index of abundance for some New Zealand kahawai (*Arripis trutta*) fisheries, but was not adopted because of uncertainties regarding the relationship between observed schooling fish and overall stock abundance.

Western Australia has used a biomass dynamic model to estimate the long term average annual harvest (both commercial and recreational) of spawning run western Australian salmon that is considered sustainable. This estimate falls in the upper part of the target catch range derived from analysis of historic commercial catch trends. Available data indicate that total annual catches have been below this reference point in recent years and are therefore considered sustainable.

In the 1990s assessments of kahawai stocks in several New Zealand fishery management areas were based on monitoring of the size/age composition of commercial catches to generate catch curve estimates of total mortality (*Z*) (NZ Ministry of Fisheries, May 2009 Plenary Report). This approach was discontinued because of difficulties in interpreting catch curve analyses for a schooling pelagic fish species such as kahawai. Problems included: (a) the cost and logistic difficulties in obtaining a large enough representative sample of size/age data to reliably describe the age structure of the stock – particularly where different life history stages are geographically separated and are targeted by different fishery sectors; (b) uncertainty regarding what portion of total mortality (*Z*) consists of natural mortality (*M*); and (c) lack of contrast in the data if exploitation rates are not changing.

More recently an age structured stock assessment model has been applied in the largest kahawai fishery management area (KAH1). This model uses commercial catch and commercial and recreational catch rate and size/age composition data, together with a range of possible values for natural mortality and recreational catch, to estimate current biomass as a proportion of unfished biomass and as a proportion of the biomass that produces maximum sustainable yield (MSY). These outputs, together with yield per recruit analyses for various scenarios, enable calculation of a range of MSY catch values which can then be used to set or review a global TAC for the stock. It should be noted that this stock assessment approach has not been applied to the smaller and less data rich kahawai fishery management areas, and there is currently no credible assessment of the stocks on which these fisheries are based

Application of any of these approaches to the eastern Australian salmon stock will require cross-jurisdictional evaluation and agreement that the approach is cost effective and that the resulting estimates of biomass and/or fishing mortality are sufficiently accurate and precise to form the basis of credible management advice.

9.4.3. Other indicators

9.4.3.1. Size composition

Some jurisdictions routinely or periodically monitor the size composition of commercial and/or recreational Australian salmon catches. Such data can be used to estimate total mortality, or (together with associated age data) as an input to age-structured assessment models. They can also be used more directly to provide a less sophisticated indicator of stock status. For example, mean length/weight of fish in catches may be monitored and compared with reference points that define optimum yield per recruit or minimum acceptable egg production capacity. The usefulness of this approach for eastern Australian salmon will need to be carefully evaluated given the latitudinal gradient in the size/age composition of catches for this stock.

9.4.3.2. Recruitment patterns

The relative abundance of juvenile Australian salmon in key western Australian nursery areas has been routinely monitored through fishery independent surveys since the mid 1990s (Fletcher and Santoro 2009, 2010). Such information provides an indication of future recruitment to fisheries and can be used as an 'early warning' of fluctuations in recruited stock abundance due to either fishing or environmental impacts on reproductive success and juvenile survival. Available WA monitoring data indicate contrasting Australian salmon recruitment trends in South Coast and West Coast waters linked to the differing influence of the Leeuwin Current, and demonstrate the potential for this tool to provide information on the impacts of climate change on distribution and productivity of Australian salmon, as well as contributing to fishery management decision making.

Tasmania has conducted fishery independent surveys of juvenile Australian salmon as part of this FRDC-funded project, but there has otherwise been no routine pre-recruit monitoring for eastern Australian salmon fisheries. The usefulness of this approach as a performance indicator for eastern Australian salmon fisheries will depend on:

- Identification of key juvenile nursery areas in sheltered marine and estuarine waters of Tasmania, eastern Victoria and southern NSW and cross-jurisdictional agreement on a cost-effective monitoring program;
- Evaluation of the strength of the relationship between juvenile abundance in key nursery areas and recruitment to the adult spawning stock.

9.4.3.3. 'Escapement' of sub-adults to participate in spawning

South Australian commercial catches of Australian salmon have been subject to an annual Total Allowable Catch (TAC) of 1000 tonnes since the mid 1980s. This TAC was introduced to allow adequate numbers of sub-adult Australian salmon derived from South Australian nursery areas to contribute to spawning aggregations in Western Australian waters, and was set based on the results of tagging studies that indicated significant westward migration of sub-adults.

The ability to determine appropriate levels of 'escapement' of eastern Australian salmon from fisheries based on sub-adult fish in Tasmania, Victoria and southern NSW in order to ensure adequate recruitment to the spawning stock will depend on:

- Understanding of the relative contributions of sub-adults from different regions to spawning aggregations;
- The ability to estimate total fishing mortality imposed by each jurisdiction and its relationship to the estimated global sustainable yield.

Finally, it should be noted that development of effective cross-jurisdictional management arrangements to ensure global sustainability of eastern Australian salmon fisheries involves more than just identification and evaluation of appropriate fishery monitoring and stock assessment approaches, performance indicators that are robust to uncertainty, and reference points that indicate desired fishery or stock conditions. An effective global harvest strategy will also require the pre-negotiation and agreement by all stakeholders on clear decision rules and management responses should undesirable fishery or stock conditions arise.

10. BENEFITS

The new information on the biology, life-history, stock structure and fisheries for eastern Australian salmon presented in this report will directly benefit future management and assessment of this species in all states. Beneficiaries of this new information will include fisheries managers within the NSW Department of Industry & Investment (NSW I&I), the Department of Primary Industries Victoria (PIRVIC) and the Department of Primary Industries, Parks, Water and the Environment (DPIPWE) Tasmania. The information presented in this report may assist when developing management strategies for this species and in consideration of issues such as resource sharing, catch limits, size and bag limits. Prior to the current study, scientific assessment of eastern Australian salmon stocks were reasonably rudimentary. The detailed information on the biology of this species, in addition to the landings composition in each state jurisdiction, should improve these assessments. For example, as a direct result of the work presented in this report the assessment level for Australian salmon in NSW has been increased from a class 3 to a class 2 level and the status of the stock changed from ‘uncertain’ to ‘fully-fished’. It is anticipated that the ultimate beneficiaries of the improvements in scientific assessments and management understanding of this species will be commercial and recreational fishers.

Much of the new information on Australian salmon will benefit broader scientific studies and management issues. For example, the information on the diet and food consumption rates of eastern Australian salmon are already being used in an ecosystem model (ECOPATH) of south-east Queensland by CSIRO scientists. Fin-clips from eastern Australian salmon were also provided to a PhD student investigating evolution within the family Arripidae.

The information on the importance of Australian salmon to the Indigenous people of NSW should directly benefit these people. An improved understanding of Indigenous values and cultural uses should result in better consultation between the management agencies and Indigenous people and incorporation of their needs and interests in the management of salmon. The NSW Aboriginal Fishing Advisory Council (AFAC) will be the main vehicle for consultation and dissemination into the wider community.

The cross-jurisdictional collaborative nature of this study should improve dissemination of the results amongst relevant stakeholders. Outcomes from the study will be made available through various methods, including the final report (available as hard copy, electronically and through the fisheries agencies websites), port meetings and seminars. The study has been widely publicised throughout with numerous media reports, an episode on the television show ‘Escape with ET’ and through editorials in the main recreational fishing magazines ‘Modern Fishing’ and ‘Fishing World’.

11. FURTHER DEVELOPMENT

While the results of the current study have greatly improved our knowledge and understanding of eastern Australian salmon in south-eastern Australia, there remain areas that require further investigation. Although this species has been determined to comprise one stock, there is clearly some fine-scale population structuring in some areas. Further otolith chemistry studies, using a broader selection of age classes, would help in identifying this fine-scale population structuring. Understanding such fine-scale population structuring may be important in future management arrangements. In addition, the movement patterns towards the northern end of the species range remain unclear and have to date been inferred from commercial landings and anecdotal evidence. A tag/recapture study in northern NSW would provide insight into the seasonal patterns of movement of the oldest fish in the population.

More work on determining the importance of different spawning areas to recruitment of juveniles in each state is needed. The results in the current study have shed some light on the potential dispersal of salmon eggs and larvae, but our understanding would benefit from incorporating more detailed oceanographic processes into a model of dispersal. In particular, the importance of spawning areas in northern and southern NSW and also Victoria to recruitment patterns in each state will be important when assessing future impacts such as changes in fishing pressure and the effects of climate change.

This study has demonstrated the difficulty in representatively sampling a species that has a strong life-history driven latitudinal gradient in ages, sizes and reproductive condition across 4 state jurisdictions (Tas, Vic, NSW & Qld), each with different fisheries and management regimes. Future work on how to representatively sample such stocks, and how to minimise bias in the interpretation of the results, would benefit their assessments and management.

Much of the new information on eastern Australian salmon will be written and published in the international scientific literature. Dissemination of these results will increase exposure of the project's outcomes to the scientific community.

12. PLANNED OUTCOMES

Through achieving all of the stated objectives this study has succeeded in its planned outcomes. The honours thesis on the importance of salmon to Indigenous people of NSW has met the planned outcome of "Improved understanding of the cultural significance of Australian salmon to Aboriginal people". The improvements in understanding of the biology and fisheries for salmon directly addressed the planned outcome of "Improved assessments of stock status and the impact of management decisions" by being the basis for a change in this species stock status in NSW from 'uncertain' to 'fully fished' in 2010. It is hoped that the development of a model for cross-jurisdictional monitoring and assessment of this species will contribute to improved assessments and ultimately management of the stock.

13. CONCLUSIONS

The results from this study represent the most comprehensive research to date into the biology, life-history, stock structure and fisheries for eastern Australian salmon. This detailed current information allows a conceptual model of the dynamics of this species in south-eastern Australia.

The northwards movement of juveniles from Tasmanian to Victorian waters and then to NSW revealed by tag/recapture data, in combination with the observed latitudinal gradient in age structure (Chapter 2), and lack of any distinct otolith chemical signatures from fish from different locations (Chapter 6) support the hypothesis that eastern Australian salmon belong to a single well-mixed stock. This single stock is characterized by immature fish less than 5 years old in Tasmanian waters with fish growing and maturing as they move northwards. The largest, oldest (> 7 years old) fish are found at the northernmost end of their range (northern NSW and southern Queensland) (Chapter 2). Sexual maturation occurs at between 30 and 40 cm fork length and spawning occurs in inshore, coastal waters between October and March (Chapter 3). The resulting eggs and larvae are transported southwards by the east Australian current, with most juveniles settling towards the southern end of their distribution (Tasmania and Victoria). Small juveniles inhabit inshore and estuarine waters where they feed mainly on small crustaceans. Larger juveniles switch to eating mainly fish and adults eat a wide variety of piscivorous prey which varies depending on their relative abundance in time and location. The diet of adult fish is dominated by schooling 'baitfish' species such as Australian sardines, anchovies, blue mackerel and scads. Adult salmon consume between 3.6 and 4 times their own body weight annually (Chapter 7). Juveniles grow quite quickly, attaining ~ 16 cm fork length after 1 year and ~ 27 cm fork length after 2 years. Fish grow faster in more northerly locations and the oldest fish sampled was estimated to be 12 years old (Chapter 3).

Australian salmon are targeted by commercial and recreational fisheries across their entire distribution in south-eastern Australia (Chapter 2). These fisheries are similar in each state, being characterized by relatively high volume, low market price commercial net operations, whilst eastern Australian salmon are also important recreational targets. Most of the commercial catch in each state is taken by only a few fishers operating large vessels that can handle large catches. These large operators use either purse-seine or haul nets, and generally fish only to market requirements. Many smaller fishing operations harvest salmon as part of their diversified businesses. Anecdotally the stock of eastern Australian salmon in south-eastern Australia has expanded in recent years, both in biomass and in its distribution with fish being observed as far north as southern Queensland every winter. This anecdotal evidence is supported by commercial landings that are currently at historically high levels (Chapter 2).

As well as being important to commercial and recreational fishers, Australian salmon have cultural significance to Indigenous communities (Chapter 8). Contemporary values and uses of this species include commercial value, as a staple food and also some totemic significance. It is important that Indigenous people are consulted and that their needs and interests are incorporated into future management of this species.

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15. APPENDICES

15.1. Appendix 1 – Intellectual Property

No patentable inventions or processes were developed as part of this work. The work presented in this report remains the intellectual property of the authors, and they should be acknowledged when citing this work.

15.2. Appendix 2 – Staff

Staff who directly worked on this project:

Dr John Stewart – Research Scientist
Mr Julian Hughes – Fisheries Technician
Mr Jerom Stocks – Fisheries Technician
Dr Jeremy Lyle – Research Scientist
Mr Jaime McAllister – Fisheries Technician
Dr Murray Macdonald – Fisheries Manager

15.3. Appendix 3 – Historical References to Abundance of Australian Salmon in New South Wales

This report was provided to the NSW Advisory Council on Recreational Fishing in 2008. The report is an extract from the following publication: Pepperell Research & Consulting Pty Ltd. 2009. THE GOOD OLD DAYS? HISTORICAL INSIGHTS INTO NEW SOUTH WALES COASTAL FISH POPULATIONS AND THEIR FISHERIES. Report to The NSW Recreational Fishing Trusts Expenditure Committee, http://www.dpi.nsw.gov.au/fisheries/recreational/publications/general/historic.

Historical References to Abundance of Australian Salmon in New South Wales

Julian Pepperell

December 2007

The following historical observations on Australian salmon off NSW have been collated as part of a larger project, funded by the NSW Recreational Fishing Trusts, entitled "Historical insights into coastal NSW fish populations and their fisheries". The source material for this information is shown for each.

First Arrival and Settlement

Captain James Cook was the first European to visit eastern Australia and record some observations on fish life. His ship, the HMS Endeavour, spent 8 days in Botany Bay between 28 April and 6 May 1770 during which time the crew hauled unidentified fish on several occasions, and also caught several very large sting rays.

Eighteen years later, on January 20 1788, the first fleet, captain by Arthur Phillip also arrived in Botany Bay, and on 26 January, established the colony at Sydney Cove in Port Jackson. At the time, and in the next few years, Phillip himself, as well as a number of other personnel with the first fleet, wrote accounts of daily life in the colony, including numerous mentions of catching fish for sustenance. The method used was almost exclusively seine net, although there are also references to the use of hook and line. The accounts of fishing and fish do not mention the actual kinds of fish very often, and when they do, it is sometimes not clear which species are being referred to. In accounts of all writers where specific mention of kinds of fish is made, a large catch of Australian salmon (Arripis trutta) is clearly described in one entry in the diary of Lieutenant–Colonel David Collins. In September 1789 he writes:

"The day preceding the governor's visit, the fishing boats had the greatest success which had yet been met with; near four thousand of a fish, named by us, from its shape only, the salmon, being taken at two hauls of the seine. Each fish weighed on an average about five pounds; they were issued to this settlement, and to that at Rose Hill; and thirty or forty were sent as a conciliating present to Bennillong and his party on the north shore."

This catch equates to about 8 tonnes, which is substantial. While there are other accounts of large hauls of fish, because the names of the fish are not used, it is not possible to ascribe them to any particular species.

Royal Commission, 1880

The historic literature regarding fish catches after the First Fleeters is very patchy, and specific references to Australian salmon (or most other species) are few. Australian salmon are mentioned several times during the Royal Commission into the fisheries of New South Wales, held in January/February 1880. The Commission called many persons to testify, including Government boatmen, fishing tackle retailers and commercial net fishermen who had usually had extensive experience fishing on the NSW coast. The following excerpts of transcripts from the Commission are the most pertinent to considerations of abundance of Australian salmon. Questions asked by the Commissioners are in italics:

19 January, 1880

Mr Michael Solomon, Government boatman

The salmon is a fish that sometimes comes in large numbers?

Yes.

In what season does it come?

At all times we have seen them.

Wednesday 28 January 1880

Mr George Newton, fisherman

The salmon are very numerous now?

Yes, all along the coast.

Monday 9 February, 1880

Mr George Eastway, tackle retailer

You have seen them [Australian salmon] *in shoals?*

Yes; I know where they are now – any amount of them

They are more of a surface fish?

Yes.

You do not take the trouble to fish for them, do you?

Oh yes, I have seen fifty or sixty people down at Bondi catching them on a Saturday.

Large-sized salmon?

About 18 inches.

What do they do with them – they are not very bad?

Certainly not; I do not think there is any fish bad to eat; I think even leather-jackets are good.

Did you ever see the salmon salted?

No.

Did you ever know any person suffer from illness or fish-poisoning through eating salmon?

No; when being caught in a boat, and the moon allowed to shine on them, I believe that will spoil fish.

11 February, 1880

Mr Philip Cohen

In what other part of the Colony have you been acquainted with the fish?

Newcastle, Port Stephens, the Manning River, the Hasting, and the Macleay.

I suppose you have often observed the movements of fish when they school in shoals?

Oh yes.

What have you observed – can you mention any instances of large shoals that you have seen?

They school in different times of the year. For instance, in about six weeks or two months now the shoals of mullet will come, but they are not of so extensive a character as they were many years ago.

That is to say they do not come into the harbours – that they do not appear to come into Sydney Harbour in such numbers?

Yes; no doubt they are in greater quantities down the coast.

You have observed they always pass up in a northerly direction?

They come from the south, and go north.

Have you encountered the shoals out at sea?

Yes, about a mile off the coast.

Are they very thick?

Oh, very thick.

What other fish have you seen pass that way in shoals – have you seen the mackerel?

Yes, but there is nothing that comes in such immense quantities as the mullet, except the salmon.

The salmon come in equally large shoals?

Larger if anything, or quite as large.
Have you ever seen the salmon put to any use?

No; they are very coarse.

Would they do for salting?

No, I have tried them; they are a very coarse, unsavoury fish.

In summary, at this time (the second half of the 19th century), salmon were regarding as being extremely common, occurring in very large schools, at least in the Sydney area. It is also interesting to note that the species was a target of recreational anglers at Bondi, which would probably not be the case today. It is also clear that salmon were not generally considered a good eating fish and there were even reliable reports that food poisoning could occur from eating salmon. These latter reports appear to have had their origin in the writings of Professor Frederick McCoy, an eminent Victorian zoologist. He stated that poisoning (or allergic reactions?) even occurred when perfectly fresh fish were consumed.

Fisheries Accounts

The next sources of available information on Australian salmon off NSW, in an historic context, are several books by professional fisheries scientists of the day. These date from 1882 to 1916 and were collations of taxonomic and biological information on fishes, either of New South Wales, or more ambitiously, of Australia. They provide useful references to abundance of the more important (or common) species, particularly since they are presented as factual information by objective experts: Quotes regarding salmon are presented under each reference:

Tenison-Woods, 1882. ***Fish and Fisheries of New South Wales*****. Sydney, Govt Printer.**

"This is the most common of all Victorian fishes"… "It seems to 'school' about the latter end of summer, when shoals of astonishing magnitude annually visit our shores" (the first sentences was quoting Frederick McCoy, while the second sentence refers to the situation in New South Wales).

Ogilby, J. Douglas (1893). ***Edible fishes and crustaceans of New South Wales*****. Sydney, Govt Printer.**

"Common as the salmon is along the greater part of the coast line of New South Wales, but little is known as to where or when it breeds;"… "at Port Macquarie and the Clarence Heads the spawning season is respectively given as November and October." (this is the earliest reference to the occurrence of salmon as far north as the Clarence River – although it is most likely in error regarding spawning).

"During the warmer months of the year Salmon make their appearance along our shores in shoals of marvellous magnitude, and are taken in large numbers by the seine, not infrequently causing a glut in the market. At such times the writer has seen fine fresh fishes from twenty to thirty inches long, and weighing from six to eight pounds each, sold at the rate of two shillings per dozen, while many are given away to the poorer classes, no other possible means of getting rid of them being available." … "The Salmon has a wide range throughout the southern portion of the Australian Region, occurring along the entire southern seaboard of Australia, and along the New South Wales coast at far north at least as the Clarence River District, beyond which I failed to trace it, nor has it even mentioned by Saville Kent in his Preliminary Report on the Food Fishes of Queensland."

"Fishes of Australia: A popular and systematic guide to the study of the wealth within our waters" **(1906) by David G Stead.**

Stead was Naturalist to the Board of Fisheries for New South Wales and this book primarily covers NSW species.
"The Salmon occurs in abundance along the whole of the New South Wales coastline.

"Edible Fishes of New South Wales: Their present importance and their potentialities" **(1908) by David G Stead.**

This book is somewhat more detailed than his earlier work.
"If this species is not one of the most important, it is certainly one of the most abundant. Attaining a length of 2 to 2 1/2 feet, it often reaches a weight of 8 or 9 pounds. … Like the true Salmon, this species has the habit of congregating at times in shoals of vast extent. … But whatever value is at present placed upon this species, there can be little doubt that it is destined to be of considerable importance in the future fisheries of New South Wales." (Stead also mentions the importance of salmon to recreational anglers "off the many fine sea beaches along the New South Wales coastline." although it is unclear the extent of the coastline to which he is referring.

Roughley, T.C. (1916). ***Fishes of Australia and their Technology*****.**

"As a food fish, the adult Salmon is of rather inferior quality, being somewhat dry, coarse and tasteless. Young examples, however, of a length up to about 18 inches are not to be despised. It does not take the smoke successfully". … "Salmon have not a ready sale in the Sydney markets, for which reason fishermen will not trouble to net them; frequently when a haul is obtained the fish are thrown back into the water … They are sold by the dozen, and bring from 1s. 6d. to 3s. The size ranges from 12 to 20 inches. Minimum lawful size 9 inches."

Roughley, T.C. (1951). ***Fish and Fisheries of Australia.***

"The Australian salmon is one of the most abundant fish round the southern half of the Australian coast. Although it has been recorded from the waters of southern Queensland, only a few stragglers are met with there; nor is it common on the north coast of New South Wales, but from Port Jackson southwards it becomes more and more prevalent "..

Regarding the trapping of salmon in Wagonga Inlet, Narooma, which would annually enter the inlet and 'lay up' in large shoals. A cannery for salmon was established at Forster's Bay, on the shores of the Wagonga River in 1937. Roughley writes: "For a couple of years [after installing traps, or pens to hold salmon for canning] large catches of salmon were obtained in the Wagonga River, but since then, few fish have been seen there. Until that time the salmon would periodically lie in the river in such shoals that the fish must have been almost touching. The local Inspector of Fisheries informed me that for half an hour he saw salmon entering the river so thick that he felt he could walk across their backs to the opposite shore. And did not Mr Fowler [a biologist who conducted aerial surveys for pelagic fish between 1936 and 1948] spot from a plane a shoal inside the river that he estimated to comprise a thousand tons?" In the 1966 edition of this book, this comment was expanded upon significantly, viz: "On 31st October 1936 large shoals of Australian salmon were seen in and about the entrance of Wagonga Inlet, on the south coast of New South Wales; one of these was estimated to contain 1,000 tons. In July 1937 in the same area a shoal of salmon was seen that was computed (from aerial photograph) to comprise about 12,000 tons."

D'Ombrain, Athel (1957). ***Game Fishing off the Australian Coast.***

D'Ombrain was a resident of Port Stephens and knew the fishing in this region very well. Regarding Australian salmon, he wrote: "salmon … is often taken on the troll from Sydney boats. In years gone by it was relatively common off Newcastle and Port Stephens, but it has disappeared over the last ten years and is hardly ever taken on the troll at those places". And in another section of the book: "It is plentiful at times in the southern part of New South Wales, but in recent years a marked falling-off has been noticed along the northern fishing centres of this State.

Parrot, Arthur W. (1959). ***Sea anglers' fishes of Australia.***

"On the east coast, it [the Australian salmon] is rare north of the Clarence River district, but has been recorded as far north as Brisbane. It is found in huge shoals, in coastal waters and estuaries, inlets, harbours and bays, and at certain times of the year, large shoals are seen migrating in offshore waters. .. Although they appear to be present in New South Wales waters throughout the year, enormous shoals have been observed during November and December, apparently migrating in a northerly direction.

Finally, regarding the northernmost distribution of salmon, Ern Grant wrote the following:

Grant, E. (1992). ***Guide to Fishes.***

"Occasionally fish are taken off the far southern Queensland coast in midwinter".

It seems clear from the reports of early and later fisheries writers that, from the late 1800s to the mid 1950s, Australian salmon were regarded as an extremely abundant fish along the NSW coast, at least as far north as Sydney. Its abundance was described in terms of superlatives and some professionally estimated tonnages of schools were very large compared with what we generally understand as large biomasses on the NSW coast (12,000 tons in one case). It would appear that their numbers declined north of Sydney in the 1950s, although this is only based on one writer's observations (Athel D'Ombrain).

15.4. Appendix 4 – An examination of the population structure of the eastern Australian salmon (*Arripis trutta*) stock in south-eastern Australia.

The following manuscript has been accepted for publication in the journal *Transactions of the American Fisheries Society*.

An examination of the population structure of the eastern Australian salmon (*Arripis trutta*) stock in south-eastern Australia

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Running head: Population structure of Australian salmon

Additional keywords: *Arripis trutta*, tag-recapture, otolith chemistry, LA-ICPMS, elemental signature, population structure, south-eastern Australia.

Abstract

The population structure of the eastern Australian salmon (*Arripis trutta*) stock in the waters of south-eastern (S.E.) Australia was examined using information provided by historical as well as current data sources. An extensive tag-recapture program and ageing study undertaken during the 1960s demonstrated widespread mixing of the *A. trutta* population in S.E. Australian waters and established a robust model of general movement of fish from Tasmania north to Victoria and NSW with the approach of sexual maturity at ~four years of age. However, this work also hypothesized that the portion of the stock at Flinders Island in Tasmanian waters was resident and did not undergo this northward migration. Otolith chemistry analyses were therefore used as a tool in a 'weight of evidence' approach to further examine the population structure of the *A. trutta* stock in S.E. Australia. Samples of five year old *A. trutta* for analysis of otolith chemistry were collected over seven weeks from two sites (10 per site) within each of four locations: northern NSW, southern NSW, Victoria and Tasmania. The cores and edges of otoliths were analysed using laser ablation inductively coupled plasma mass spectrometry. Univariate analyses did not find spatial differences for any of the elements Li, Na, Mg, Mn, Ba or Sr between locations. Multivariate analyses however, did find differences between the multi-element 'fingerprints' of fish from Tasmania compared to each of the other locations (which were similar). This difference was driven by a group of fish collected from Flinders Island in north-eastern Tasmanian waters. The fish collected at this site were also significantly smaller at five years of age than fish from all other sites, indicating reduced growth rates. The lack of consequential and definitive differences in otolith chemistry data combined with the highly migratory nature of *A. trutta* in this region demonstrated by tagging studies confirm that the most likely stock structure model for *A. trutta* in S.E. Australia is of a single well mixed biological stock spanning Tasmania, Victoria and NSW with fish moving north from Tasmania to mainland Australia with the approach of sexual maturity. However, the reduced growth rates and distinct elemental signature for *A. trutta* from Flinders Island highlights the need for further work to examine the pre-existing hypothesis of a potential resident sub-population there.

Introduction

The eastern Australian salmon *Arripis trutta* (Forster, 1801) is an abundant, pelagic species of fish distributed in coastal marine waters from southern Queensland to western Victoria and Tasmania (Paulin 1993). *Arripis trutta* is a member of the teleost family Arripidae; a single genus family containing four species, which are all found in the temperate waters of southern Australia and New Zealand (Paulin 1993). Arripids are a highly mobile family of fishes all of which undertake extensive migrations of up to thousands of kilometres in length motivated by life-history, reproductive or seasonal cues (Malcolm 1959, Stanley 1978, Cappo *et al.* 2000, Ayvazian *et al.* 2004).

Arripis trutta has a strong schooling habit and at times may form vast shoals of up to thousands of tonnes per school around ocean beaches and areas of exposed coast (Malcolm 1966a). It sustains high volume commercial fisheries in New South Wales (NSW), Victoria and Tasmania (2287 t landed in 2005-06; Australian Bureau of Agricultural and Resource Economics 2007), as well as being an enormously popular recreational sportfish due to its excellent fighting qualities. Owing to its substantial commercial fishery *A. trutta* has been the subject of considerable past scientific investigation in south-eastern (S.E.) Australia (Malcolm 1959, 1966a, 1966b, 1966c, Nicholls 1973, Stanley & Malcolm 1977, Stanley 1978).

The distribution, movements and age composition of *A. trutta* have been examined via an extensive tag-recapture program and ageing study (Stanley 1978). Over 5,200 *A. trutta* were aged using scales, and then tagged and released in the waters of NSW, Victoria and Tasmania. A large proportion (36%) of these fish were later recaptured and importantly, not a single tagged fish released in NSW or Victoria, was recaptured in Tasmanian waters. These results, combined with the lack of spawning activity observed in Tasmanian waters (Stanley & Malcolm 1977), suggested that the movement of fish from Tasmanian to mainland Australian waters across Bass Strait was a one-way migration and occurred with the onset of sexual maturity at ~four years old. These results, in addition to the results of other tagging programs on *A. trutta* (Stanley 1988a, 1988b), also showed that bidirectional movement of fish between NSW and Victorian coastal waters occurred regularly and it was concluded that *A. trutta* in S.E. Australia was a single, well-mixed biological stock (Stanley 1978). However, due to the presence of unusually old fish in the Flinders Island area of north-eastern Tasmanian waters (20% > four years old), both Stanley (1978) and Malcolm (1966c) hypothesized the possible existence of a resident sub-population of fish which did not undergo the migration from Tasmanian to mainland waters with the onset of sexual maturity.

The physical and chemical characteristics of the different water bodies encountered by fish may vary at a range of spatial scales. Specific trace elements present in the environment of fish are incorporated into the growing surface of their otoliths and these can reflect the ambient environmental conditions of the water in which fish reside (Fowler *et al.* 1995a, 1995b). Since fish that spend at least part of their lives in different water masses often produce otoliths of different elemental composition, the otolith elemental composition (or `elemental fingerprint') can serve as an environmentally induced tag of groups of fish (Campana *et al.* 2000). This technique has become increasingly popular and extensively used over the past 20 years for examining movement patterns and distinguishing among populations and stocks of many fish species throughout the world (*eg.* Edmonds *et al.* 1989, Campana & Gagné 1995, Campana *et al.* 2000, Daverat *et al.* 2005, McCulloch *et al.* 2005, Tzeng *et al.* 2005). Since the existing population structure data for the S.E. Australian *A. trutta* stock were not conclusive, we chose to use otolith chemistry analysis as a tool in a 'weight of evidence' approach to further examine *A. trutta* population structure in this region. Otolith chemistry analysis was chosen because i), the physical and chemical characteristics of the different water bodies encountered by *A. trutta* throughout S.E. Australia are likely to vary, and ii), it had the potential to provide dissimilar but complementary information to that from existing data sources (*ie.* tagging and ageing studies).

The stock structure of *A. trutta* has been of considerable interest to fishery managers in the three states (NSW, Victoria, Tasmania) where it commonly occurs in S.E. Australia as a species which could benefit from cross-jurisdictional management arrangements because of i), its broad geographical distribution, ii), its long distance migrations and iii), its commercial and recreational importance. Our aim therefore, was to use a 'weight of evidence' approach which utilised information provided by historical tagging and ageing studies in addition to analyses of otolith chemistry and size-at-age to examine the potential for population structure within the *A. trutta* stock in S.E. Australia.

Materials and Methods

Sample Collection and Experimental Design

Arripis trutta for otolith chemistry analyses were collected over seven weeks in 2007 (March 30 to May 16) by commercial fishers from NSW, Victoria and Tasmania using beach haul and purse seine nets. A subsample ranging from 12 to 89 fish were taken from each catch and frozen. Ages of fish were estimated by counting opaque zones in otolith sections. Ten fish, each estimated to be five years old were then randomly chosen from the catches from each of two sites (separated by kilometres to tens of kilometres) from each of four locations on the S.E. Australian coast: northern

NSW, southern NSW, Victoria and Tasmania (Figure 1, Table 1). Selecting five year old fish was done to ensure that the fish had been alive for the same period and minimised the possibility of a confounding temporal influence on spatial comparisons (Fowler *et al.* 2005).

Sample Preparation and Analysis

All fish collected were frozen for at least 24 hours before being defrosted, measured (FL to the nearest 0.1 cm) and dissected. The sagittal otoliths were removed using Teflon-coated forceps and cleaned in ultrapure deionized water. Otoliths were air dried overnight and stored in plastic 1.5 mL microcentrifuge tubes. One otolith from each fish was embedded in indium spiked (~30 ppm) two-part epoxy resin (Struers Epofix) and a ~300 µm section was taken through the core perpendicular to the long axis of the otolith using a slow speed saw (Buehler Isomet) and two spaced diamond blades. The blades were lubricated in ultrapure water and each otolith section was then polished using 9 µm lapping film and ultrapure water. Sections were then fixed to a glass microscope slide in random order (up to 14 sections per slide) using indium spiked (~200 ppm) thermoplastic glue (Crystalbond 509) and sonicated for 5 minutes in an ultrasonic cleaner (Unisonics Australia FXP4). Slides were allowed to dry overnight in a laminar flow cabinet before being transferred into individual clean sealable plastic bags prior to analysis.

Arripis trutta otoliths were analysed using a New Wave Nd Yag 213 nm UV laser operated in Q-switch mode connected to an Agilent 7500cs inductively coupled plasma-mass spectrometer (ICP-MS). The laser was operated at a frequency of 5 Hz and 65% power. To determine background concentrations, the chamber gases were analysed without any sample present for 30 s prior to the commencement of ablation. Otolith sections were ablated in a sealed chamber and ablated otolith material was transported in an argon and helium carrier gas stream to the ICP-MS. A reference standard (NIST 612, National Institute of Standards and Technology) was analysed at the beginning and end of each session and periodically throughout the session to correct for mass bias and instrument drift. Concentrations of each element analysed (Lithium-7 (Li), Sodium-23 (Na), Magnesium-25 (Mg), Manganese-55 (Mn), Strontium-88 (Sr) and Barium-138 (Ba)) were standardised to Calcium-43 (Ca), by expressing concentrations of elements as ratios to Ca (mmol/mol). For all otolith sections, both the core region and outer edge were ablated by the laser using a 30 µm diameter spot. The core region represented juvenile otolith growth and the outer edge represented otolith growth immediately prior to collection.

Statistical Analyses

Univariate analyses of variance (ANOVA) were used to test whether elemental compositions (Li, Na, Mg, Mn, Sr, Ba) differed between the core and edge of the otolith as well as between sites and among locations. A three-factor design treated 'Core/Edge' as fixed, and 'Site' as a random factor nested within 'Location'. Heterogeneous data (Cochran's *C*-test, $p < 0.05$) were Ln(x+1) transformed. Where significant differences were detected in ANOVA, means were compared using Student-Newman-Keuls (SNK) tests to determine where the differences occurred.

The discrimination between geographic areas in south-eastern Australian waters based on multiple elements in *A. trutta* otoliths was tested using discriminant analysis. Discriminant analysis has two steps: (1) an *F* test (Wilks' lambda) is used to test if the discriminant model as a whole is significant, and (2); if the *F* test shows significance, then the individual independent variables are assessed to see which differ significantly in mean by group and these are used to classify the dependent variable. Quadratic discriminant function analysis (DFA) was then used to determine the ability of elemental signatures to correctly assign fish to their collection locations. Backward stepwise quadratic functions were determined in SYSTAT (Point Richmond, CA) and then used to classify fish to groups using a jackknifed method with prior probabilities of group membership being equal. The accuracy of classifications to these groups was determined as the percentage calculated to be correct. This analysis was done separately for both the core region and outer edge of the otoliths.

A single-factor ANOVA was also used to test whether mean lengths of fish differed between sites. Heterogeneity of variances and significant differences detected in ANOVA were examined using the methods described above.

Results

Univariate Analyses

Core-Edge Comparisons

Significant differences in elemental concentrations were detected between the core region and outer edge of the otolith for all elements analysed using ANOVA (Li:Ca, Na:Ca, Mg:Ca, Sr:Ca, Ba:Ca) except Mn:Ca (Table 2). The otolith core region consistently contained significantly more Li:Ca, Na:Ca, Mg:Ca and Ba:Ca than the otolith edge although the magnitude of this variation differed by location (Figure 2a, b, c, f; Table 2). In contrast, the otolith edge consistently contained significantly more Sr:Ca than the core region (Figure 2e, Table 2), but once again the magnitude of the variation differed by location.

Spatial Comparisons

No spatial differences were detected by ANOVA for the elements Li:Ca, Na:Ca, Mn:Ca, Sr:Ca and Ba:Ca (Table 2). The only significant difference detected was for variation in Mg:Ca between sites for two of the four locations (Table 2). Otoliths of fish collected from Bermagui had higher Mg:Ca concentrations than fish from Eden in southern NSW (Figure 2c). Similarly, the otoliths of fish collected from Pettmans Beach in Victoria had higher Mg:Ca than in fish from Lakes Entrance (Figure 2c).

Multivariate Analyses

A significant difference between locations was detected for the multi-element signatures for both the otolith core region (Wilks' lambda = 0.682, $F_{9,\,180} = 3.416$, $p < 0.001$) and outer edge (Wilks' lambda = 0.565, $F_{12,\,193} = 3.878$, $p < 0.0001$) of five year old fish (Figure 3). The difference in core regions appeared to be driven by the influence of fish from southern NSW being distinct from fish from the other three locations sampled and Victorian fish being distinct from those from Tasmania (Figure 3a). With the exception of Tasmania and Victoria the ellipses from all locations overlapped one another (Figure 3a). For the outer edge of the otolith, Tasmania separated from the other three locations (Figure 3b). This trend was driven by the influence of fish from Flinders Island (Figure 4). There was however, considerable overlap between southern NSW and Victoria, and southern NSW and northern NSW (Figure 3b). The 95% confidence ellipses around the mean values for each location suggests that there was less separation among the four locations for the otolith core region because the ellipses overlapped for all locations (Figure 3a), than for the outer edge where the ellipse around the mean value for Tasmania was separate to those of the other three locations (Figure 3b).

A low percentage of five year old fish were correctly classified on the basis of multi-element signatures in the core region (44%) and outer edge (38%) of the otolith (Table 3). Correct classification of fish to their sampling locations based on elements in the core region ranged from 20% for fish from northern NSW up to 65% for fish from Victoria (Table 3a). For the outer edge of the otolith, correct classification of fish to their sampling locations ranged from 20% for fish from southern NSW up to 65% for Tasmania (Table 3b).

Length-at-age

ANOVA detected a significant difference in the mean length of fish at age five years among sites (ANOVA; $F_{7,\,72} = 13.42$, $p < 0.0001$). SNK tests showed that fish collected from Eden (southern NSW) were significantly larger than fish from all other sites and fish collected from Flinders Island

(Tasmania) were significantly smaller than fish from all other sites (Table 1). There were no differences in fish length between any of the other sites (Table 1). These results indicate that fish from Eden had grown faster, and similarly fish from Flinders Island had grown slower, than fish from all other sampled sites.

Discussion

Single Elements

Differences in elemental concentrations were detected between the core region and outer edge of *Arripis trutta* otoliths for all elements except Mg:Ca. Spot analyses of the core region represent the juvenile part of the otolith, whilst edge ablations reflected the elements present during the life of the fish immediately prior to being caught. Such differences may be a result of the changing uptake and/or incorporation of elements onto the otolith surface with the age or life-history stage of the fish as a result of ontogeny (Sadovy & Severin 1992). Ontogenetic changes such as growth variation from larval to juvenile and juvenile to adult can result in morphological and physiological modifications within fish. Ontogeny has been shown to affect otolith chemistry for several fish species (Toole *et al.* 1993, Fowler *et al.* 1995a, 1995b), but not for others (Daverat *et al.* 2005, Elsdon & Gillanders 2005).

Variation in the environment of the fish (*ie.* the waterbody the fish lives in) also has the potential to produce the variation seen between the core and edge regions of the otolith (Elsdon & Gillanders 2003, 2005, Daverat *et al.* 2005, Tzeng *et al.* 2005). The outer edge of *A. trutta* otoliths contained significantly more Sr:Ca than the core region. Conversely, the core region contained significantly more Ba:Ca that the outer edge. Correlations between ambient and otolith Sr:Ca and Ba:Ca concentrations have been investigated in several studies and a strong positive relationship exists for both elements (*eg.* Elsdon & Gillanders 2003, 2005). The concentrations of both Sr:Ca (Bath *et al.* 2004; Daverat *et al.* 2005) and Ba:Ca (Elsdon & Gillanders 2005) in otoliths have also previously been shown to be related to environmental salinity. The low Sr:Ca and high Ba:Ca concentrations found in core regions of otoliths suggest that as juveniles *A. trutta* are found in lower salinity environments than the environment they inhabit as adults. Indeed, juvenile *A. trutta* are often found in estuaries in both Australia (Stanley & Malcolm 1977) and New Zealand (Hartill & Walsh 2005).

With the exception of Mg:Ca, which has been shown to vary independent of environmental concentrations (Campana 1999), there were no significant differences in the spatial variation of individual elements in the otoliths of *A. trutta* collected from different sites. A lack of important single-element differences among locations on a similar spatial scale (tens to hundreds of kilometres) has previously been shown for several other studies on marine fish species (*eg.* Kalish et al.1996, Thorrold *et al.* 1997, Edmonds *et al.* 1999, Gillanders *et al.* 2001, Stransky *et al.* 2005). In this study, the fact that single-element analyses failed to find significant differences between locations, whereas examination of the multi-element signature did, also serves to highlight the limitations of univariate analyses of single element data in otolith chemistry analysis.

The small variation in elemental composition of otoliths of *A. trutta* collected from S.E. Australian waters may reflect the relatively homogeneous environmental conditions present in this region. The comparatively homogeneous environment of the Mediterranean in the vicinity of the south-west Iberian Peninsula was suggested as a possible cause of the lack of significant otolith chemistry differences found between locations for the sparid *Diplodus vulgaris* (Gillanders *et al.* 2001). These authors hypothesised that this environmental homogeneity was due to a lack of major rivers in proximity to study locations, the low annual rainfall and the similar influence of Atlantic currents in the region. In S.E. Australia however, there is considerable freshwater input into the nearshore marine environment via substantial rainfall and numerous large river and estuary systems. In addition, the influence of the prevailing East Australian Current (EAC) is highly seasonal (Ridgway & Dunn 2003) likely resulting in a relatively heterogeneous environment with high potential for differences in water chemistry over the ~850 km spatial scale of the study.

Alternatively, fish may move among different areas within this region. It has been conclusively shown by past tagging studies that *A. trutta* undertake extensive movements between the coastal waters of Tasmania, Victoria and NSW (Malcolm 1959, Stanley 1978, 1988a, 1988b). This highly migratory behaviour may therefore obscure any consistent differences in otolith chemistry that exist between the water bodies at each collection location. In S.E. Australia, elemental concentrations in ambient water are highly variable over small (within estuary) to large (between estuary) spatial scales (Elsdon & Gillanders 2006, Hamer & Jenkins 2007), and between estuarine and coastal marine waters (Hamer *et al.* 2006). Water chemistry in this region also has the potential to vary over a range of temporal scales from tidal cycles to years (Hatje 2003, Elsdon & Gillanders 2006, Hamer *et al.* 2006, Hamer & Jenkins 2007).

Multi-element Signatures

The multi-element signatures showed more separation among locations for analyses of the outer edge of the otolith compared to that for analyses of the otolith core. Similarly for the differences between the cores and edges for the single-element analyses discussed above, this pattern may reflect similarities in the environment of juveniles or may be a result of ontogenetic factors, or a combination of both (Gillanders & Joyce 2005). It is not possible to entirely discount the influence of ontogeny on the otolith elemental signatures seen in this study without controlled experiments in the laboratory (Elsdon & Gillanders 2005) or knowledge of environmental concentrations. The poorer separation seen in the core analyses compared with the edge may be because the fish come from a common, or a few common origins. *Arripis trutta* juveniles have been recorded from estuaries throughout S.E. Australia from Botany Bay in NSW to Port Philip Bay in Victoria (Stanley 1978) and also Tasmania (Malcolm 1966a, 1966b). The ability of otolith elemental signatures in tracking movements and/or habitat shifts throughout the life history of a fish has been an often employed tool in many previous studies on many fish species which utilise estuarine (Gillanders & Kingsford 1996, 2000, Gillanders 2002, McCulloch *et al.* 2005) or freshwater (Daverat *et al.* 2005, Tzeng *et al.* 2005) environments as juveniles. Alternatively there may be a significant amount of population mixing when the fish are young. The greater separation of locations for edge elemental fingerprints may therefore reflect the dispersal of *A. trutta* from estuarine nursery areas to offshore marine areas of the S.E. Australian coast with age. A similar increased degree of spatial segregation during the adult phase has been previously inferred from otolith chemistry for many other marine fish species (*eg.* Stransky *et al.* 2005, Fowler *et al.* 2005).

A significant difference was detected for the multi-element signature of otolith edges among locations where *A. trutta* were collected. This difference was driven by a distinct multi-element signature from the otolith edges of Tasmanian fish which separated them from fish from the other three mainland locations (*ie.* northern NSW, southern NSW and Victoria). Results from the DFA using multi-element signatures to classify fish to a location showed that attempting to classify fish using either the core (overall 44%) or edge (overall 38%) signature was extremely difficult and resulted in a low degree of accuracy, but importantly, the highest percentage of correctly classified fish using the edge signatures came from Tasmanian waters (65%). A similar overall low classification rate, but better separation by edge chemistry than core signatures has previously been reported for deepwater fish species in the Atlantic (Swan *et al.* 2003, Stransky *et al.* 2005).

Significant differences in otolith chemistry similar to that found in this research have been previously used to infer potential population or stock differentiation in many other published studies (*eg.* Edmonds *et al.* 1989, Campana & Gagné 1995, Campana *et al.* 2000). Our current understanding of the life cycle of *A. trutta* in this region is that following spawning in southern NSW and eastern Victoria between October and March there is a southward movement of early life-history stages to Tasmania (Malcolm 1966a). Evidence of spawning activity has never been recorded from Tasmanian waters and all *A. trutta* there are immature (Stanley & Malcolm 1977). On the basis of the dispersal of the larval and juvenile stages, the progeny of spawning in mainland waters are likely to be well mixed. The primary nursery areas for juveniles are the bays and estuaries of north-eastern (NE) Tasmania, although a smaller proportion is consistently found in eastern Victoria and southern NSW (Malcolm 1966c). As they reach maturity (~four years), the juveniles undertake a one-way migration from Tasmania across Bass Strait via the Flinders Island chain and return to the waters of eastern Victoria and southern NSW as adults (Stanley 1978). Following migration, extensive inter-mixing of fish and large-scale movements occur throughout mainland waters (Stanley 1978, 1988a, 1988b). The migration across Bass Strait from Tasmanian to mainland waters may represent a significant change in water chemistry and this may be reflected by the significantly different multi-element fingerprints for fish from Tasmania. In fact, it appears as though the only two groups of *A. trutta* that are spatially separate enough to be exposed to the sufficiently different water masses required to produce different otolith elemental signatures are Tasmanian fish prior to migration, and fish already present in mainland waters.

Notably, it was the group of fish collected from the Flinders Island site that were responsible for the difference between the multi-element signature of the otolith edges of Tasmanian fish which separated them from fish from the other three mainland locations. The two Tasmanian sites were separated by just ~20 km and sampling of both sites occurred within a seven week period. The distinct elemental signature from fish collected from Flinders Island is therefore unlikely related to small scale variation in the water chemistry found in NE Tasmania as there are no major rivers in close proximity to the two sites from which pulses of fresh water may be discharged, thus influencing ambient water chemistry in terms of salinity, temperature and trace elements. The influence of the EAC is also likely to affect both sites in a similar manner (Ridgway & Dunn 2003) and therefore unlikely to vary enough over such small spatial and temporal scales to produce the different elemental signatures evident for the two sites.

Alternatively, Malcolm (1966c) and Stanley (1978) proposed the hypothesis that some *A. trutta* from the waters around Flinders Island may be a contingent (*sensu* Secor 1999) non-reproductive resident population which do not undertake this northerly migration across Bass Strait. This hypothesis was based on ageing data demonstrating an unusually large number (20% > four years old) of *A. trutta* present in catches sampled from Flinders Island which were older than their reported age-at-maturity (Stanley & Malcolm 1977). If there is a non-migratory sub-population of *A. trutta* in the coastal waters of NE Tasmania, then their continuous residence in these waters could very well produce the distinct multi-element signature we see for Tasmania fish. The significantly smaller size (and resultant slower growth) of five year old *A. trutta* sampled from Flinders Island compared with all other sampling locations further supports a 'weight of evidence' approach which serves to highlight the need for further work to examine this resident sub-population hypothesis. Many species of fish have migratory and resident forms, particularly anadromous species (Northcote 1978, Elliot 1994, Morinville & Rasmussen 2006). Non-migratory individuals of such species often exhibit slower growth than migratory individuals (Jonsson 1985, Elliot 1988, Jonsson & Jonsson 1993). Slower growth may be a result of factors like adverse environmental conditions or food quality or quantity (Nordeng 1983, Elliot 1988, Olsson *et al.* 2006) that migratory forms are better able to exploit or avoid as a result of their migratory habit. It is now being increasingly shown that many marine fish species also have resident and migratory forms (*eg.* Secor 1999, Dunn & Pawson 2002, Fukumori *et al.* 2008). Of particular relevance to *A. trutta*, recent work using stable isotope ($\delta^{13}C$ & $\delta^{18}0$) analysis of otolith carbonate has suggested migratory and resident sub-populations within the stock of another member of the family Arripidae in Australia, the Australian herring (*A. georgiana*); the population of which has been shown to consist primarily of migratory animals along with a smaller proportion of resident individuals (Ayvazian *et al.* 2004). Analysis of otolith chemistry of yellowtail scad (*Trachurus novaehollandiae*) in Jervis Bay (NSW) has also recently shown that the population consists of resident and migratory sub-populations; the resident animals being significantly smaller at the same age than migratory members of the population (E. Heagney, unpublished data).

Overall however, the lack of consequential and definitive differences in otolith chemistry data presented here (*ie.* no spatial differences in single element analyses or among multi-element signatures for the otolith edges of fish collected from mainland locations) in combination with the results of historical tagging studies (Stanley 1978, 1988a, 1988b), lead us to conclude that the most likely population model for *A. trutta* in S.E. Australia is of a single biological stock spanning NSW, Victoria and Tasmania. Widespread mixing of individuals occurs both as larvae and juveniles prior to recruitment, in addition to as adults once reproductive maturity is reached and the migration of Tasmanian fish across Bass Strait occurs. In fact, *A. trutta's* extensive migratory capabilities in S.E. Australian waters demonstrated by past research have led previous researchers to conclude that *A. trutta* in S.E. Australia are indeed a single well-mixed biological stock in this region (Stanley 1978).

Conclusions

The demonstration of consistent core-edge differences in otolith chemistry using both uni- and multi-variate analyses is consistent with observations of juvenile estuarine residency of *A. trutta* in S.E. Australia. In addition, multi-element signature data suggests some differences between fish collected from Tasmanian waters compared with fish collected from other locations in S.E. Australia. We suggest that the distinct otolith chemistry of Tasmanian fish is most likely reflective of differences in water chemistry between the waters of Tasmania and mainland Australia. The highly migratory nature of *A. trutta* in this region demonstrated by tagging data combined with the lack of differences in otolith chemistry between mainland locations confirm that the most likely stock structure model for *A. trutta* in S.E. Australia is of a single well mixed biological stock spanning Tasmania, Victoria and NSW with fish moving north from Tasmania to mainland Australia with the approach of sexual maturity. However, the cause of the distinct otolith elemental signature for fish from Tasmania were those fish collected from Flinders Island, which when considered along with the reduced growth rates for this group of fish lends support more to the 'weight of evidence' approach which highlights the need for further work to examine the hypothesis of a resident sub-population in this area (Malcolm 1966c, Stanley 1978). Further work should include the use of otolith transect analysis from adult fish collected throughout S.E. Australia to provide age-specific information on migration patterns in this region. Additional analysis of the otoliths of juvenile fish from multiple locations within S.E. Australia could also assist in the identification of possible important nursery areas or habitats. These approaches have the potential to provide substantial benefits to the management of this important species via our understanding of the population structure, life history, and migratory behaviour of *A. trutta* in the waters of S.E. Australia.

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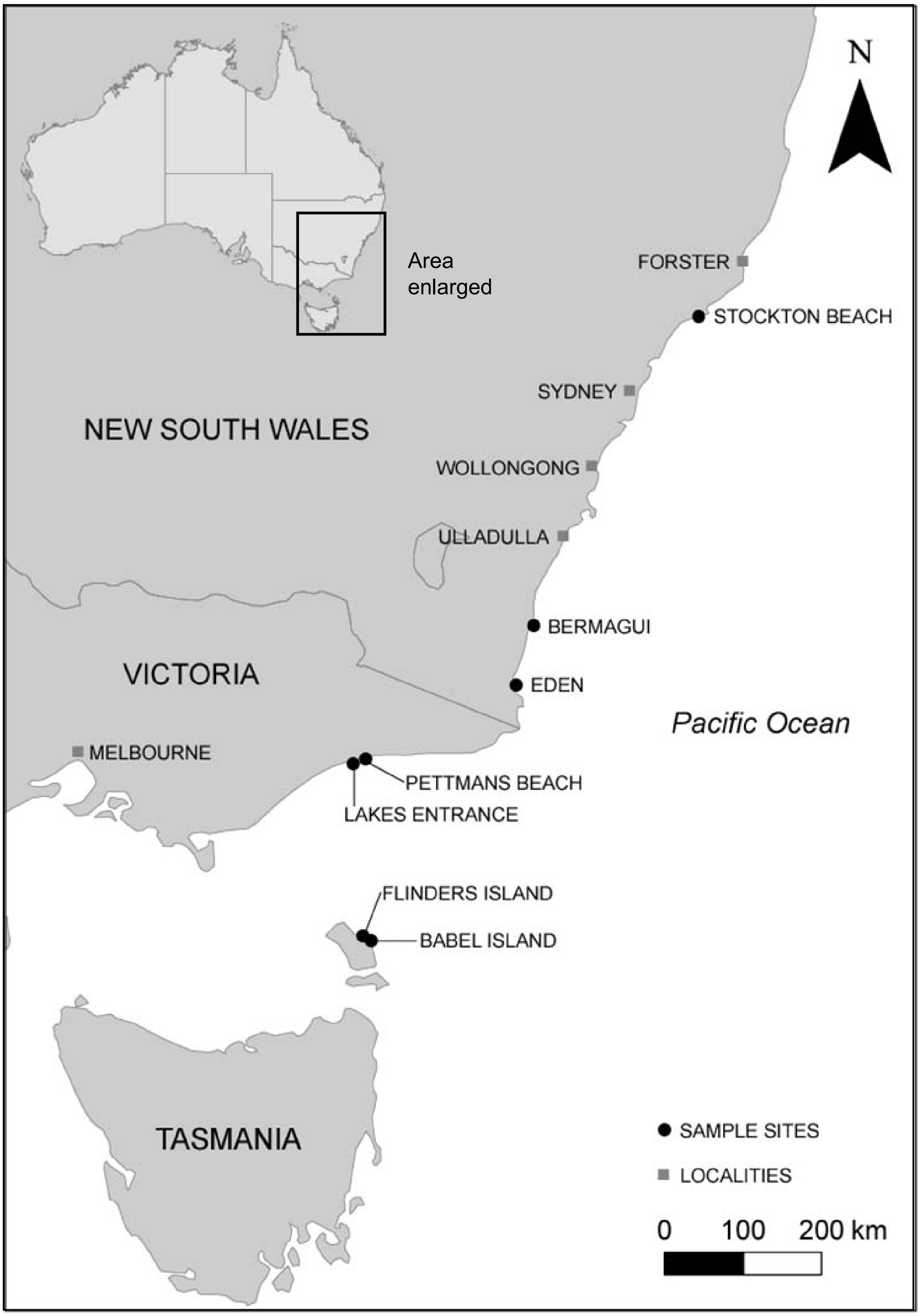

Figure 1. Map of south-eastern Australia showing collection locations of *Arripis trutta* samples taken for analysis of otolith chemistry.

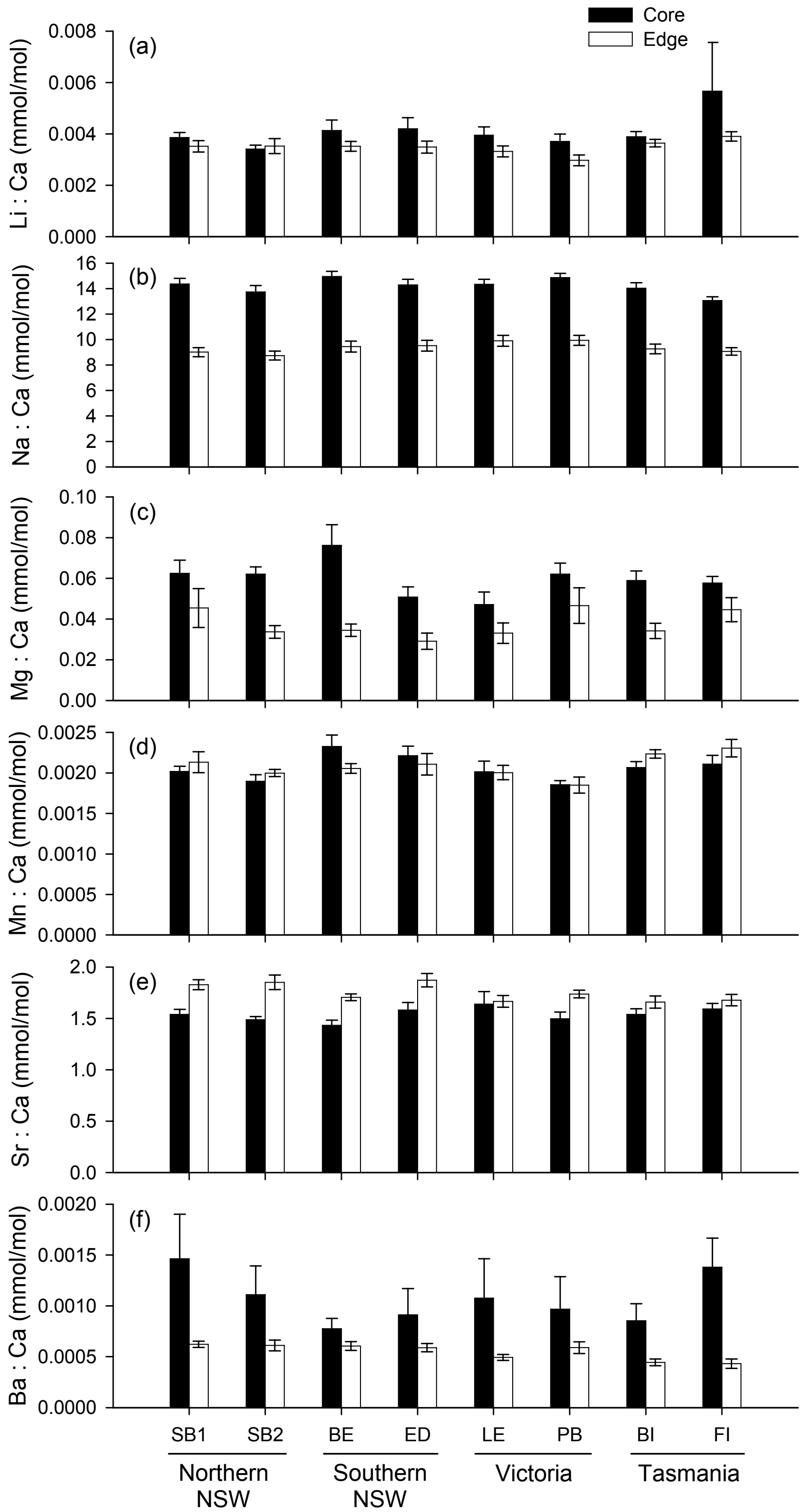

Figure 2. Mean (± standard error) concentration ratios (mmol/mol) of a) Li:Ca, b) Na:Ca, c) Mg:Ca, d) Mn:Ca, e) Sr:Ca and f) Ba:Ca from the core region (■) and outer edge (□) of 5 year old *Arripis trutta* otoliths collected from northern NSW (SB1=Stockton Beach 1, SB2=Stockton Beach 2), southern NSW (BE=Bermagui, ED=Eden), Victoria (LE=Lakes Entrance, PB=Pettmans Beach) and Tasmania (FI=Flinders Island, BI=Babel Island). *n*=10 for each site.

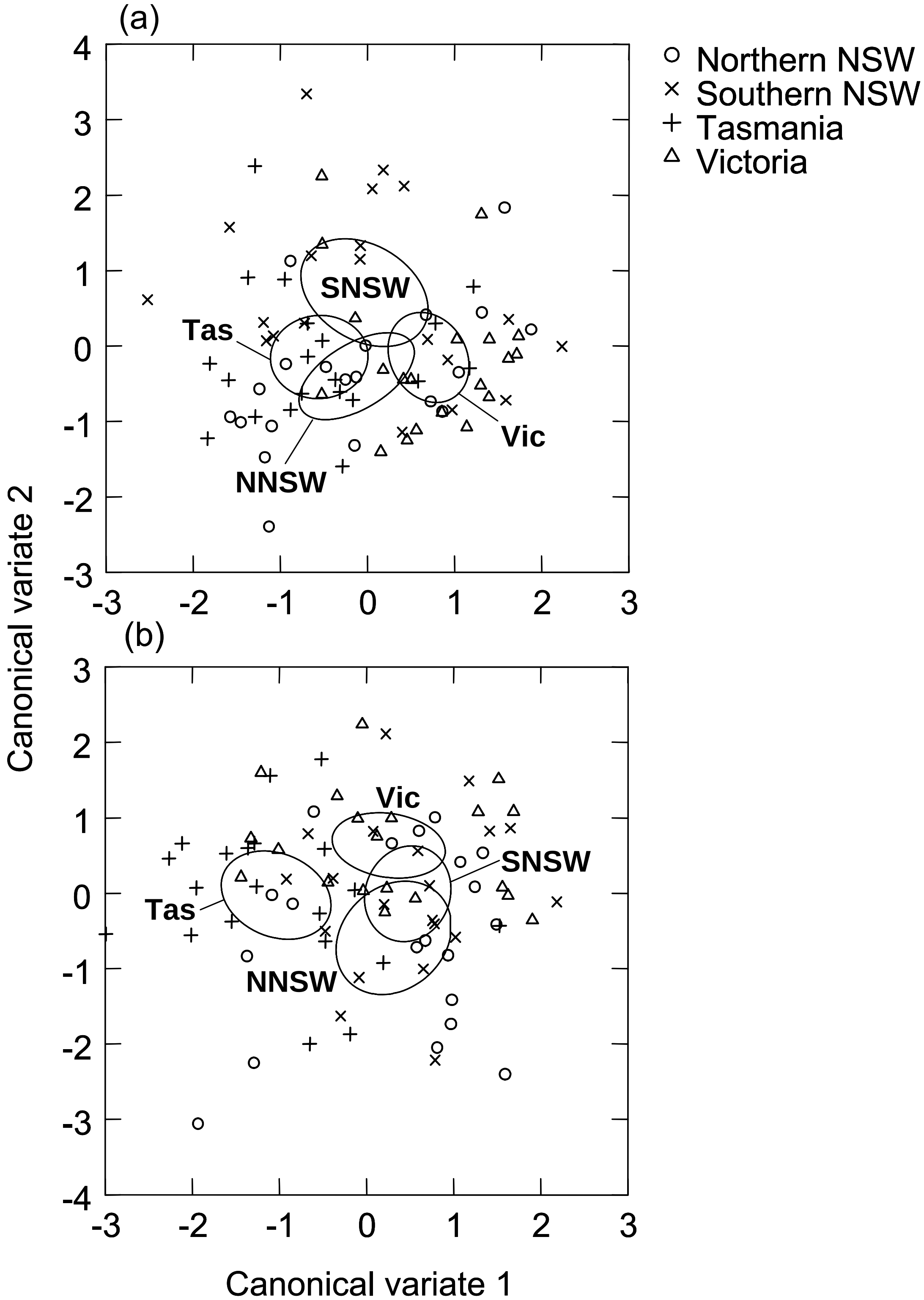

Figure 3. Canonical variate plot summarising variation in otolith elemental signatures for 5 year old *Arripis trutta* from northern NSW (NNSW- ○), southern NSW (SNSW- ×), Victoria (Vic- Δ) and Tasmania (Tas- +) for a) the core region, and b) the outer edge. Ellipses represent 95% confidence intervals around the means for each location. n=20 for each location.

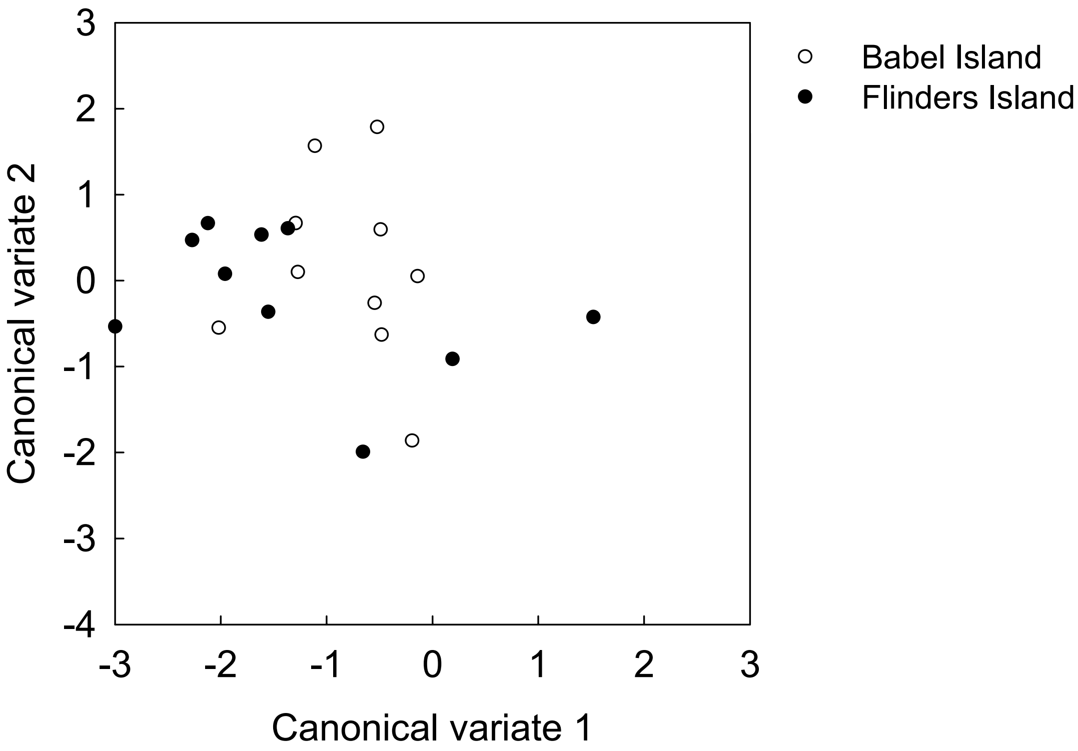

Figure 4. Canonical variate plot summarising variation in otolith elemental signatures for 5 year old *Arripis trutta* from sites in Tasmanian waters (Babel Island- ○, Flinders Island- ●). *n*=10 for each location.

Table 1. Details of capture sites and dates, fishing gears used and lengths (mean ± S.E.) for 5 year old Australian salmon. *n* is sample size, FL is fork length, * denotes significantly different at $p < 0.05$.

Location	Site	Latitude, Longitude	Date caught	Gear	*n*	FL (cm)
Northern NSW	Stockton Beach 1	32º 49' S, 151º 54' E	May	Beach haul	10	44.84 ± 0.62
	Stockton Beach 2	32º 49' S, 151º 54' E	May	Beach haul	10	46.90 ± 0.32
Southern NSW	Bermagui	36º 25' S, 150º 05' E	April	Purse seine	10	46.65 ± 0.75
	Eden	37º 04' S, 149º 54' E	April	Purse seine	10	49.09 ± 0.71*
Victoria	Lakes Entrance	37º 52' S, 147º 59' E	May	Purse seine	10	45.24 ± 0.58
	Pettmans Beach	37º 49' S, 148º 11' E	April	Purse seine	10	45.69 ± 0.66
Tasmania	Babel Island	39º 56' S, 148º 19' E	May	Purse seine	10	45.06 ± 0.42
	Flinders Island	39º 56' S, 148º 12' E	April	Purse seine	10	40.65 ± 0.97*

Table 2. ANOVA results comparing elemental concentrations (Li:Ca, Na:Ca, Mg:Ca, Mn:Ca, Sr:Ca, Ba:Ca) of core regions and outer edges of otoliths from 5 year old fish collected from Stockton Beach 1 and 2 (northern NSW), Bermagui and Eden (southern NSW), Lakes Entrance and Pettmans Beach (Victoria), and Babel and Flinders Islands (Tasmania). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, *df* is degrees of freedom.

Source	*df*	*F*
Li:Ca		
Core-Edge	1	9.65*
Location	3	1.70
Site (Location)	4	1.02
Core-Edge x Location	3	0.87
Core-Edge x Site(Location)	4	0.55
Residual	144	
Na:Ca		
Core-Edge	1	1003.59***
Location	3	4.38
Site(Location)	4	1.13
Core-Edge x Location	3	1.58
Core-Edge x Site(Location)	4	0.60
Residual	144	
Mg:Ca		
Core-Edge	1	46.55**
Location	3	0.09
Site(Location)	4	3.58**
Core-Edge x Location	3	1.24
Core-Edge x Site(Location)	4	1.19
Residual	144	
Mn:Ca		
Core-Edge	1	1.18
Location	3	5.34
Site(Location)	4	1.20
Core-Edge x Location	3	14.44
Core-Edge x Site(Location)	4	0.19
Residual	144	
Sr:Ca		
Core-Edge	1	53.61**
Location	3	0.36
Site(Location)	4	1.85
Core-Edge x Location	3	3.62
Core-Edge x Site(Location)	4	0.88
Residual	144	
Ba:Ca		
Core-Edge	1	36.47**
Location	3	1.55
Site(Location)	4	0.57
Core-Edge x Location	3	1.40
Core-Edge x Site(Location)	4	0.65
Residual	144	

Table 3. Results of quadratic discriminant function analysis (DFA) where 5 year old fish from each location were classified to each group based on otolith elemental signatures (Li:Ca, Na:Ca, Mg:Ca, Mn:Ca, Sr:Ca, Ba:Ca). The percentage of fish classified to each group is shown for **a)** the core region, and **b)** the outer edge of the otolith. Overall, 44% (core) and 38% (edge) were correctly classified. Values in **bold** indicate fish which were correctly classified. *n*=20 for each location.

		Northern NSW	Southern NSW	Victoria	Tasmania
a)	Northern NSW	**20**	15	25	40
	Southern NSW	10	**40**	30	20
	Victoria	15	20	**65**	0
	Tasmania	20	10	20	**50**
b)	Northern NSW	**35**	15	25	25
	Southern NSW	30	**20**	35	15
	Victoria	25	20	**30**	25
	Tasmania	15	10	10	**65**

15.5. Appendix 5 – Indigenous cultural uses and values of eastern Australian salmon in southern NSW.

INDIGENOUS CULTURAL USES AND VALUES OF EASTERN AUSTRALIAN SALMON IN SOUTHERN NSW

Report prepared by Jesse Waddell
as part of an Honours project for SCU supervised by Dr David Lloyd, Dr John Stewart and Assoc. Prof. Stephan Schnierer

For

INDUSTRY AND INVESTMENT NSW
Cronulla Fisheries Research Centre of Excellence

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EXECUTIVE SUMMARY

This report documents research findings of a recent cultural study undertaken within Indigenous communities on the south coast of NSW. Focussing on eastern Australian salmon, the study initially explored the customary values and uses surrounding marine resources for Indigenous people by way of a literature review. Historical accounts and archaeological findings on midden analysis found that salmon have long represented customary importance, primarily as a staple food, to the local Yuin people of southern NSW. In the absence of any specific information on salmon use within contemporary Indigenous culture, qualitative research methods such as key informant interviewing provided a means to locating knowledge specific to local fishing practice and cultural uses of salmon.

During consultation with Indigenous communities along the south coast of NSW, a number of issues surrounding marine use and access to cultural resources were uncovered, however are outside the scope of this report1. Specific to salmon, contemporary values and use of this species were found to include commercial value, communal values (staple cultural food), and totemic significance. Traditional ecological knowledge was also found to be important to modern Indigenous fishing practices for salmon, with environmental cues such as the flowering of a tree used as an indicator to resource availability. An example of the ongoing importance of salmon to Indigenous fishers is given in the small but well managed beach haul fishery that has provided local Indigenous fishers with income and livelihood for many decades (see p. 9).

In light of these findings, a number of considerations to future management of the species are discussed. Primarily:

- Salmon continue to bring commercial value as an important economic resource for Indigenous beach-haul fishers;
- Many indigenous fishers practice a subsistence harvest and resource sharing regime which, if limited can severely impact on standard of living and quality of life;
- Further commercialisation of this resource will negatively affect Indigenous use and values;
- Resources allocation and fisheries use planning of salmon and other marine resources must take account of a range of needs, uses and values within Indigenous communities;
- Spiritual and belief values, such as totem significance of the fish are a significant value to be considered by managers; and
- Traditional ecological knowledge should be employed in achieving ecologically sustainable use of marine resources.

1 For more information on Indigenous marine use in southern NSW, refer to: Waddell (2010), Indigenous Customary and Contemporary Uses and Values of Marine Resources in Batemans Marine Park, Southern NSW (Honours Thesis).

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PROJECT BACKGROUND

Eastern Australian salmon (see Figure 1) occur along the east coast from the central coast of NSW to Tasmania, and have been recorded around Norfolk Island and Lord Howe Island (Commonwealth of Australia, 1993). Anecdotal evidence suggests that stocks are not currently heavily fished (NSW Department of Primary Industries, 2008). In the absence of detailed stock assessment data, NSW Fisheries have commenced research to determine population structure, reproduction, diet and composition of commercial and recreational catches in NSW. This research on salmon will eventually provide key biological information on this species, as well as identify the cultural uses and values for Indigenous groups (Dr. J. Stewart, pers. comm., 2009).

This study was funded and supported by a research grant made available by Industry and Investment NSW, Primary Industries- Fisheries. The research funding came from the Fisheries Research and Development Corporation (FRDC) funding program, which provides for research and development within NSW fisheries management. The primary aim of this work was to identify the cultural values and uses of salmon within Indigenous communities. Up until now, very little research has been undertaken specifically on cultural uses of salmon in NSW, with a limited understanding of Australian Indigenous fisheries generally.

Figure 1: Eastern Australian Salmon. Photograph: Sasha Schultz. Source: Australian Museum, 2010.

INDIGENOUS MARINE USE IN NSW

In southeast Australia, Indigenous coastal people have maintained a long tradition (a 'cultural practice') of ownership, stewardship and utilisation of terrestrial and marine resources (Bennett, 2007; Egloff, 1990; Egloff, 2000; Kersey, 2003; McKenna, 2002). The area was initially inhabited by the traditional people of the Walbangal group, part of the Yuin nation (About NSW, c.2009; Edmunds, 2008) for at least 20,000 years and probably much longer (Bennett, 2007; Cruse *et al.*, 2005). From around 5000 years before present (BP) an increasing and continued use of many coastal areas appears to have ensued (Sullivan, 1984). Coastal midden analysis suggests that Indigenous people relied heavily on fishing in riverine, estuarine, and marine environments (including coastal islands), consuming a wide range of shellfish and finfish species (Bailey, 1975; Cruse*, et al.*, 2005; Walters, 1987; Bennett 2007), with many of these sites still in use today (see Figure 2).

Figure 2: Mystery Bay near Narooma, an important cultural marine use site for Indigenous people. Photograph: J Waddell.

Nicholson and Cane (1994) noted major changes in the diet along the south coast of NSW from around 1500 BP, with a shift from reliance on shellfish toward other coastal resources including many types of finfish. It is suggested that with the development of fishing technologies, such as line with shell fish hooks, fish trapping and netting, finfish become more prevalent in the diet (Faulkner, 2000; Nicholson & Cane, 1994).

Salmon Fishing

In the Twofold Bay area, and further south into Gippsland, salmon were an abundant fish easily caught by the expert local fishers by spearing and haul netting (Sullivan, 1984). Line fishing, spearing and netting were techniques used for catching salmon (Roughley, 1951; Sullivan, 1984). Mackaness (1941) in describing the fishing habits of the Mittong people (an Indigenous clan residing near Cape Howe, close to the NSW/Victorian border) states:

> "The natives occupy a kneeling position in their Mudjerre or canoes and may be seen like floating specks off the coast spearing salmon; they are expert fishers" (in Sullivan, 1984, p. 13).

These accounts, among others, give representation of salmon being a traditional and abundant food item, taken in a number of ways. More recent historical reports from the 1940s claim that schools of salmon estimated at over 1000 tones were seen at Wagonga Inlet at Narooma (Pepperell, 2008). Whether due to abundance or preference, Indigenous people were observed consuming salmon, often baked whole over hot coals or sometimes cooked by women over a small fire in a canoe while fishing (Roughley, 1951).

Traditional Ecological Knowledge

Indigenous fishers have developed specialist knowledge about the marine environment and ways to sustainably harvest marine species. For south coast people, this knowledge includes seasonal clues for hunting and ecological information about key species (Cruse, *et al.*, 2005; Evans & Birchenough, 2001), shared among family and tribal groups and transmitted through generations via rituals, customs and belief systems (Costa-Neto, 2000; Drew, 2005; Mackay, 2009). Around the world, there is growing evidence that incorporating traditional ecological knowledge (TEK) into resource management structures, and involvement of Indigenous fishers in management and policy decision-making, can bring many benefits to biodiversity conservation (Berkes, 2003; Berkes, Colding, & Folke, 2000; Berkes, *et al.*, 1995; Berkes, Olsson, & Folke, 2004; Hanna, 2000; Stapp & Burney, 2002). The application of TEK to management is discussed in later sections (p. 12).

FIELD METHODOLOGY

The recording of Indigenous values and viewpoints required descriptive methodologies. Following a literature review, the methodology chosen for this project was semi-structured interviews (with 'key informants') with an interpretive focus to capture modern day, individual realities (Konza, 2005). The demand for descriptive research on socially complex issues involving multiple realities is growing (Firestone, 1987). Given the complexity of Indigenous marine use research, a case study approach was adopted allowing for focus on narrative detail that uncovered social practices and beliefs (Perry, 1989; Riessman, 2008); an approach often taken by researchers studying the workings of the social and physical world (Eisenhardt, 1989; Huberman & Miles, 2002; Riessman, 2008). These methods were especially suited to examining Indigenous cultural values surrounding salmon, which involved working within both human behavioural sciences and resources management fields.

Key Informant Interviews

The key informant approach is often used in seeking knowledge from persons who have specific knowledge about specific characteristics of the subject being studied (Eyler, *et al.,* 1999). In this case, key informant interviewing allowed the researcher to obtain specific knowledge relating to Indigenous fishing, through witnessing people's lives and circumstances firsthand (Australian Government, 2007; Marshall, 1996; Weinberg, 2002). Further, being 'on the scene' allowed the researcher to ask questions of community experts; it also allowed the opportunity to learn *which* questions to ask (Wolcott, 1997). Following selection through referral from Local Aboriginal Lands Council offices, 8 participants took part in interview.

Participant concerns surrounding Indigenous knowledge property rights and appropriate use of culturally sensitive information became apparent through the course of this study. This has brought implications to the publication of participant names and disclosure of Indigenous knowledge, some of which has been kept confidential.

CONTEMPORARY VALUES AND USES OF SALMON IN SOUTHERN NSW

Respondents were asked to explain the values and uses that came from salmon in the area. The research brought up information specific to methods and knowledge about catching and eating salmon, as well as totemic significance. Table 1 below outlines the four main values as identified by Indigenous fishers, with descriptive analysis of responses following.

Table 1: Contemporary Indigenous Values and Uses of Salmon.

Eastern Australian Salmon (*Arripis trutta*)	Values	Uses
Food (consumption)	Highly regarded Good eating	Smoked Fish Cakes Fried fillets Baked in coals whole
Totem	Low to moderate occurrence	Personal totem for some people, group totem unknown2
Commercial Fish	Important commercial species, netted by beach seining with 4WD assist	Market fish Sale/income
Pleasure/sport Fish	Highly regarded sport species	Fishing/Relaxing

Food (consumption) Value

Largely evidenced in midden findings and early observation from white settlers, salmon has featured in customary diets of Indigenous people in southern NSW (Pepperell, 2008; Roughley, 1951; Sullivan, 1984). In the field research, it was found that respondents regard salmon as a staple food species within modern diets, and remains of importance for Indigenous fishers. Participant 6 explains:

> "Salmon, he's a good fish, lovely fish…there's a lot of old people who go fish out off the beach here for them" (Participant 6, pers. comm., 2010).

Salmon have been traditionally found moving along the coast, appearing at different times throughout the year. A local fisherman recalls the excitement of salmon appearing in the local area:

> "Whenever the salmon used to come into the little bays, Bang!... Dalmeny, Mystery Bay, Congo… Broulee was one of the best salmon beaches ever" (Participant 8, pers. comm., 2010).

Generally, interview respondents regarded salmon to be a good eating fish if eaten fresh, or otherwise smoking the flesh was a popular method (see *Uses:* Table 1). Salmon was generally not regarded as good eating as other marine species, such as groper, abalone or bimbulla3.

> "You couldn't keep a salmon for so long…there were no fridges or freezers in those days, so that's why they used the method of smoked salmon, because it lasts for days, you know…just in a chimney smoker" (Participant 1, pers. comm., 2009).

Fish smoking continues to feature in today's methods for cooking salmon, along with baking whole in the open fire coals, pan-frying and fish cakes.

> "I'll fry a salmon fresh, or if I get it and I freeze it, I'll make fish cakes with it" (Participant 7, pers. comm., 2010).

2 Salmon could have been totemic to groups, although participants knew more about family and individual totems.

3 For a more comprehensive list of cultural species within the topic of Indigenous marine use, refer to Waddell (2010).

Totemic Value

On the surface it appears that the totemic value of salmon may be relatively low, with only three respondents recounting knowledge of totem use, while the remaining 5 made little or no comment on salmon totems. However, this may also be an example of an area that is difficult to study due to cultural sensitivities and customs surrounding rights to traditional knowledge.

Rose (1990) describes that while a person's Yuin identity is derived from both the mother and father, their totemic identity and specific relationships to country inherited via birth rights, place of birth and so on, are also significant (Dibden, 2006). On the south coast, totems also historically regulated the marriage system. For example, red bream could marry shark, curlew and stumpy lizard, while magpie could marry pheasant and echidna (Bennett, 2007).

Participant 6 described the working of totemic systems within local fishing culture, and how it applies to someone when a totem fish is caught:

> "See if you caught your totem, and you wasn't allowed to eat him, you had to swap him or something. He might have a bream, and you might have a salmon… he might be a bream fella, and so if you catch a salmon you would give it to him" (Participant 6, pers. comm., 2010).

More general recollections of salmon in the past being totemic for both family and individual purposes were also given, as participant 7 explains:

> "I think I can remember one person who used to be, see my family totem is the black duck… I go under the family totem, not like ah…a lot of people take a totem now for, ah, an individual totem, but I'm a family totem" (Participant 7, pers. comm., 2010).

It seems that salmon were regarded both as a personal and group totem for local fishers. It is not known, however, to what extent salmon may have been a family or group totem, with reports of salmon being a totem for groups and clans from outside the BMP area. Participant 2 recalls the totemic significance of salmon:

> "For some families it is, for some families it certainly is…they're not in the marine park area…yeah, there is" (Participant 2, pers. comm., 2010).

It is not unlikely that complex totemic systems involving a range of marine species may still govern Indigenous fishing practice. It may be appropriate to conduct a culturally appropriate study of totemic systems over a larger geographic area to properly inquire into totemic significance that salmon, and other marine species, may hold.

Commercial Value

A number of Indigenous commercial fishermen took part in this study. It was found that today, salmon and mullet continue to provide a main source of income. Salmon have been commercially important to south coast professional fishers for a long time in the industry, with fish canneries at Wagonga Inlet (Narooma) and Eden in times past a testament to a once thriving commercial salmon fishery. As participant 3 explains:

> "Salmon was really our main industry, because when the cannery opened, ah, that was our main thing…I mean to say if the old man said there was a patch of salmon

> coming, you gave up what you were doing and helped…salmon and mullet were our main income" (Participant 3, pers. comm., 2010).

Since the early decades of white settlement, salmon has remained central to a long history of commercial beach hauling for Indigenous fishing families in the area, notably two big families: the Nyes and the Brierlys (Edmunds, 2008). Salmon today were reported to be commonly caught at Congo, Broulee, Pedro point, Murramurrang, as well as many other places along the coast that remain in use today (Participants 3, 4 and 5, pers. comm., 2010). Broulee Lookout has long been an important site for gauging weather conditions and locating schools of salmon:

> "The lookout is used in the first instance, before the days fishing begins, as a point of information… I've used that lookout to spot fish since I was a child, working with my father" (Donaldson, 2008, p.2).

Recreational Value

A value easily overlooked when considering Indigenous fishing, as a whole, is the contemporary value of fishing as recreation and sport. In a traditional context people may have fished only in a utilitarian light, to survive and get by. As there is no way of confirming the pre-European contact values of fishing as possibly a pleasurable activity, it is impossible to know the customary aspect. Contemporary values surrounding salmon for Indigenous fishers were found to include fishing as a pleasure and sport. Local fisherman, participant 1 comments:

> "I reckon it's the best form of relaxation you could ever have, its fishing. Sometimes I'll go fishing nearly everyday, sometimes" (Participant 1, pers. comm., 2009).

Similarly, salmon are regarded as being a strong fighting fish, nowadays being caught off the beaches with big rods:

> "Good fighting fish, yeah they used rods, yeah, because they gotta get into the surf, you know they like a bit of whitewater" (Participant 2, pers. comm., 2010).

Traditional Ecological Knowledge in Salmon Fishing

As evidence of traditional ecological knowledge remaining important to local culture, seasonal variation was described as an ongoing salmon fishing practice. Seasonal cues helped local indicate to people when to hunt a particular species. As participant 6 describes, the flowering of a particular tree4 is an indicator for looking for salmon throughout the year:

> "We got a tree that tells us when the salmon are on, yeah…a couple times a year" (Participant 6, pers. comm., 2010).

Similarly, the seasonal influence on fishing was observed by participant 2 in her childhood:

> "What they used to do the old fells, they'd used to watch for certain flowers to bloom, then they'd pack their gear and off they'd go…if a certain wind was blowin' they'd know what was runnin' on the beaches" (Participant 2, pers. comm., 2010).

Certain plants were used as indicators in conjunction with lunar cycles and tidal influences fro a range of species, such as:

4 The name of this tree was not disclosed to the researcher for reasons of knowledge property rights.

> "The plants all along, and when they're flowering, that tells you when you go salmon fishing or lobstering… all depends on the flower and what time of year, that was indications for when you went hunting…and there's times of the moon when you know" (Participant 7, pers. comm., 2010).

> "My uncle knew a lot about the snapper fishing, he used the seasons with the blossoms on the trees…you know he said when the blossom's on, the snapper is on, at different times of the month" (Participant 1, pers. comm., 2009).

This and other examples of TEK being intertwined into harvesting practices may be indicative of customary resources rotation techniques, similar to those practiced by Indigenous peoples around the world (Berkes & Folke, 1998; Gadgil, Berkes, & Folke, 1993). Indigenous participants related their use of salmon and following the flowering of trees as an example of how they never overused one resource, instead relying on a range of food sources depending on time of year.

ISSUES FOR CONSIDERATION IN THE MANAGEMENT OF SALMON

Cultural Use and Future Resources Planning

As is apparent, salmon are regarded as a popular, plentiful and accessible pelagic species for many Indigenous fishers. In comparison to other marine species, salmon did not appear to be as highly valued as groper, bream or snapper in example[5]. Similarly, benthic species such as abalone, rock lobster, bimbullas (mud cockles) and mussels seemed to represent greater importance as cultural foods. Nevertheless, non-commercial take of salmon was described as a regular food gathering activity within the Indigenous community, representing the ongoing cultural significance of salmon as a readily available staple food. Additionally, salmon continue to bring commercial value as an important economic resource for Indigenous beach-haul fishers[6].

For the reasons above, there is potential for further commercialisation of this resource to negatively affect Indigenous use and values. Therefore, managers must be prepared to consider and adequately address the needs identified by Indigenous fishers in future consultation about cultural take and resources allocation agreements.

Traditional Ecological Knowledge in Fisheries Management

As with many other countries around the world, there are opportunities and benefits to incorporating TEK in current management systems, which are often input/output driven approaches (Berkes, 2004; Berkes & Folke, 1998; Berkes, *et al.*, 2005; Hughes, *et al.*, 2007). It is now realized that the resource harvesting practices developed by Indigenous peoples knowledge of the environment serve to manage species diversity, create habitat heterogeneity, and manage intensity of use, therefore enhancing the diversity of biological resources (Berkes, Folke, & Gadgil, 1995; NSW National Parks and Wildlife Service, 2002).

This study confirmed that traditional ecological knowledge still guides contemporary fishing practice. Essentially, it was found, the locals manage their use of salmon with open and closed seasons. The seasonal triggers are based on environmental conditions which, in this case, are

5 For further information, see appendix 1: Culturally Important Species (Waddell 2010).
6 For more information on the NSW beach-haul salmon fishery, see Edmunds (2008).

exemplified by the flowering of a particular tree, a few times each year7 (Participants 1, 3, 6, 7, 8, pers. comm., 2009-2010). In the management of salmon for example, it may be appropriate to adopt open and closed 'seasons' inline with Indigenous practices, based on environmental cues. Further research on traditional ecological knowledge within contemporary Indigenous communities would be required.

Totemic Values

As outlined above, totem systems in local Indigenous custom play an important role in providing meaning and social order, as exemplified by the regulation of marriage systems and use taboos on certain species (Bennett, 2007). This study has also demonstrated that Indigenous fishers continue to maintain totemic systems, and this cultural law should be recognised and respected in management consultation between Indigenous and non-Indigenous parties. Further research is needed on totemic values surrounding salmon and other marine resources within Indigenous communities before management decisions, which may affect cultural values and needs, can be safely made surrounding Indigenous fisheries use.

CONCLUSION

In summary, it was found that salmon are linked to Indigenous culture through a long history as a staple food in customary diets. Cultural practices, knowledge and values surrounding salmon are broad and interlinked. In example, the meanings associated with totems mean that various animals in Indigenous culture provide social order and systems of regulated resource use. Indigenous salmon fishing is guided by traditional ecological knowledge, which may offer much to modern resources management in dealing with the current environmental problems and management challenges.

Salmon have represented an economic value to the Indigenous community, some directly who have operated commercially since white settlement. Salmon are also a staple food for non-commercial fishers today. For these reasons, the future growth and management of fisheries such as the beach haul salmon fishery must consider all aspects of past and present Indigenous uses and values, in-line with recent legislative amendments that also promote improved Indigenous involvement in commercial fisheries management. In addressing these values and needs with regard to co-management and shared access to marine resources, the past problems related to exclusion for Indigenous people, as seen in the rock lobster and abalone fisheries, may be avoided. Appropriate consideration and consultation between Indigenous groups and management bodies must focus on ways to accommodate Indigenous values and cultural uses, and consider fisheries resource allocation models that represent Indigenous needs and interests in the management of the salmon fishery.

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7 Concerns over Indigenous knowledge property rights has meant that the name of this tree was not disclosed to the researcher, however this does not invalidate in any way the relevance or essence of this method in traditionally harvesting salmon.

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APPENDIX 1

Culturally Important Species for Indigenous Fishers in the Batemans Marine Park area. Source: Waddell (2010), *Indigenous Customary and Contemporary Uses and Values of Marine Resources in Batemans Marine Park, Southern NSW* (Honours Thesis) p. 53.

Seafood type	Species identified[8]	Uses/ Values
Shellfish	Abalone Mussel Oyster Bimbulla (mud cockle) Pipis Scollop Periwinkles	1. Food (nourishment, protein) 2. Medicine 3. Barter (for other goods) 4. Ceremonial gatherings 5. Cultural practice
Finfish	Mullet Groper Bream Salmon Snapper Whiting Garfish Tailor Kingfish Blackfish (luderick) Drummer	1. Food 2. Sharing 3. Barter (for other goods/foods) 4. Relaxation/recreation 5. Cultural practice 6. Income/employment
Crustaceans	Rock Lobster (eastern and southern) Prawns Crabs (Blue swimmer, Mud)	1. Food 2. Barter (for other goods) 3. Trade (before outlawed) 4. Ceremonial gatherings

8 Species identified by participants as the most common or highly regarded. This list is not exhaustive, and may not represent other species of importance or the values of other people within the study area.

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