Development and evaluation of egg-based stock assessment methods for blue mackerel *Scomber australasicus* in southern Australia

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Final report to the Fisheries Research and Development Corporation

Project 2002/061

Australian Government
Fisheries Research and Development Corporation

SARDI RESEARCH AND

NSW DEPARTMENT OF

Tasmanian Aquaculture & Fisheries Institute
University of Tasmania

Government of South Australia
Primary Industries and Resources SA

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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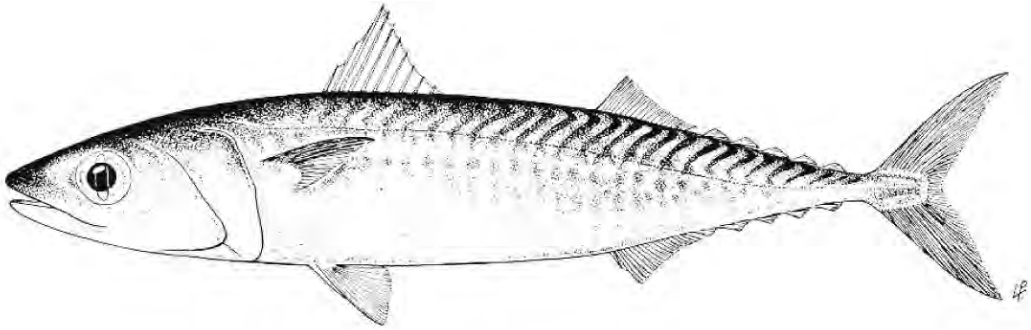
Printed on
Reviewers: Dr Qifeng Ye, Dr A Linnane and Dr Stephen Mayfield
Approved by: Dr Qifeng Ye

Signed: 

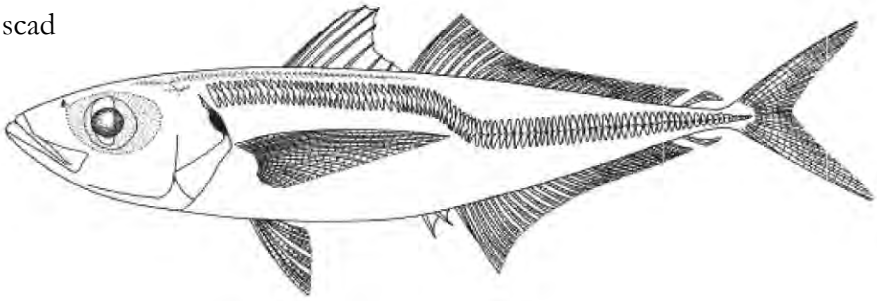
Date: 29/06/2007
Distribution: Fisheries Research and Development Corporation and SARDI Aquatic Sciences Library
Circulation Public Domain
ISBN 0 7308 5367 5

Small pelagic fish species described in this report. (Drawings courtesy of Fishbase www.fishbase.org, 30th June 2007)

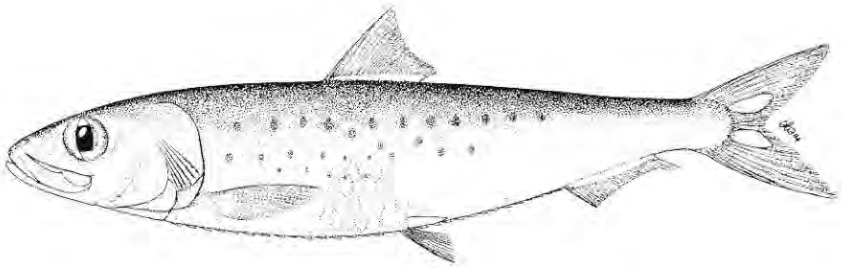
Blue mackerel
Scomber australasicus



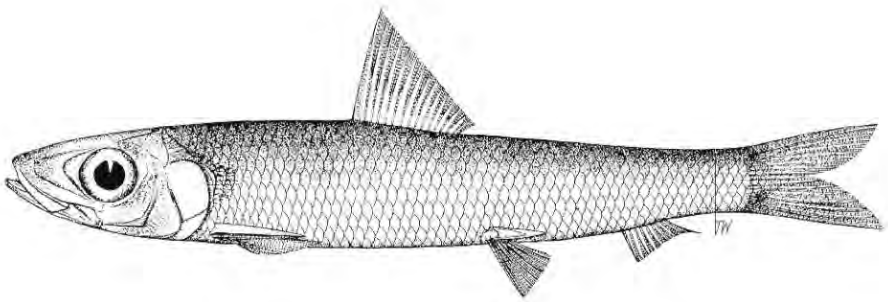
Jack mackerel/yellowtail scad
Trachurus spp.



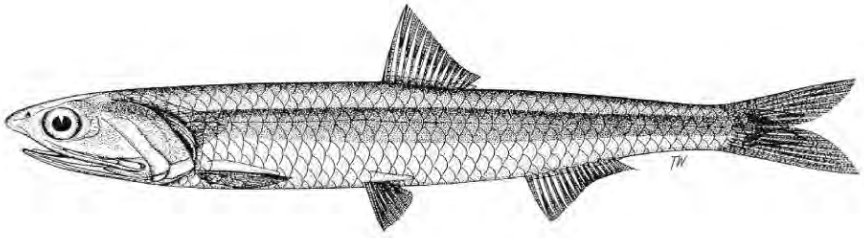
Sardine
Sardinops sagax



Maray/Round herring
Etrumeus teres



Australian anchovy
Engraulis australis



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Non-technical Summary

Project Title: Development and evaluation of egg-based stock assessment methods for blue mackerel *Scomber australasicus* in southern Australia.

FRDC Project Number: 2002/061

Principal Investigator: Dr Tim Ward

Objectives:

1. To synthesize existing information on the fisheries, surveys and potential stock assessment methods for *S. australasicus* in southern Australia;
2. To provide a preliminary description of the stock structure of *S. australasicus* in south-eastern Australia (additional objective);
3. To estimate the number, size frequency and total weight of *S. australasicus* taken by recreational (charter, gamefish and trailer boat) fishers off the New South Wales coast;
4. To describe the spatial and temporal patterns of age and growth and compare the age structure of commercial catches and fishery independent samples of *S. australasicus* from southern and eastern Australia;
5. To compare the spatial and temporal patterns of age of commercial and recreational catches of *S. australasicus* taken from NSW;
6. To describe the reproductive biology, especially spawning fractions and batch fecundity, of *S. australasicus* off southern and eastern Australia;
7. To establish methods and criteria for identifying and staging the eggs and larvae of *S. australasicus*
8. To describe the distribution and abundance of eggs and larvae of *S. australasicus* off southern and eastern Australia;
9. To describe the distribution and abundance of eggs and larvae of *Trachurus* spp., *Sardinops sagax*, *Engraulis australis* and *Etrumeus teres* in southern and eastern Australia (additional objective);
10. To develop and evaluate methods for estimating the spawning biomass of *S. australasicus* in southern Australia;
11. To evaluate potential harvest strategies for *S. australasicus* in southern Australia and provide preliminary estimates of the potential yields for each zone of the Commonwealth Small Pelagic Fishery.

The total annual Australian catch of *S. australasicus* is usually less than 1,000 t, most of which is taken in the NSW Ocean Haul Fishery (335 to 462 t in 1997/98-2004/05) and Commonwealth Small Pelagic Fishery. The maximum total catch for all Commonwealth managed fisheries was 1089 t in 1998. Combined annual catches from the SA, WA, Vic. and Qld fisheries are generally <400 t/year. Recreational fishers caught 720,814 *S. australasicus* in 2000, with ~21% released alive. Most (75%) of the recreational harvest is taken in NSW, WA and SA. Previous surveys of pelagic fishes have not provided quantitative information on abundance. For example, Russian surveys of the GAB during the 1960s reported the occurrence of large schools of mackerel at the surface and suggested that accumulations were "considerable" in some years. A literature review confirmed that egg production techniques, potentially in conjunction with age-structured models, are the most suitable tool for stock assessment of *S. australasicus* in Australian waters.

Genetic methods, parasitology and otolith microchemistry are collectively suitable approaches for determining the stock structure of *S. australasicus*. We established protocols for determining variability within and among putative stocks. Seventy-five fish from three Australian locations (Qld, SA and WA) and one NZ location were examined. Genetics and parasite assemblage were analysed for all fish; otolith microchemistry of Australian fish was also examined. Techniques were developed to extract and amplify a segment of the mtDNA control region; results showed significant genetic heterogeneity among fish from WA, Qld and NZ. Parasite analysis identified several taxa that are suitable biological tags and enabled discrimination of fish from the four locations. Studies of otolith microchemistry using LA-ICP-MS had sufficient power to distinguish fish from the three Australian locations. Results suggest that there are several stocks of *S. australasicus* in Australian waters. We establish protocols for finer scale studies of stock structure, and discuss the efficacy of our approaches for stock discrimination.

The NSW recreational trailer-boat fishery harvested 90.9 t and 53.9 t of *S. australasicus* in the two years sampled. Annual catches in gamefishing tournaments off NSW ranged between 2.7 t and 3.7 t. The annual catch of *S. australasicus* by charter operators increased from 6.3 t in 2002 to 13 t in 2004. Catch and effort data for this sector may be biased and improvements are needed to the Charter Boat Logbook system. The range of annual harvest estimates for all recreational boating sectors combined off NSW was 60.5 to 107 tonnes. During 2002-2005 the recreational harvest of *S. australasicus* was approximately 12–20% of the mean annual commercial harvest off NSW. There is considerable spatial and seasonal overlap in the activities of commercial and recreational fishers

targeting *S. australasicus* off NSW. Spatial and/or seasonal management arrangements may be needed to alleviate conflict between these sectors.

S. australasicus is a serial spawner with asynchronous oocyte development and indeterminate fecundity, and is a suitable species for stock assessment using the DEPM. Samples collected from southern Australia included large mature fish (up to 422 mm fork-length, FL), whereas samples from eastern Australia were mainly <350 mm FL. Gonosomatic indices and macroscopic stage data suggest that *S. australasicus* spawn between November and April off southern Australia and between July and October off eastern Australia. In South Australia, ~50% of males and females were sexually mature at 236.5 and 286.8 mm FL, respectively. Size at ~50% maturity could not be estimated reliably for eastern Australia due to the small proportion of large mature fish in samples. Mean spawning frequencies ranged from 2 to 11 days in southern Australia. Mean batch fecundity was 69,894 ±4,361 oocytes per batch and 134 oocytes per g of weight. Methods/locations for sampling large mature fish need to be established to support future application of the DEPM to *S. australasicus* off eastern Australia. There is also a need to determine the rate of degeneration of post-ovulatory follicles to ensure that estimates of spawning fraction/frequency are reliable.

Eggs of *S. australasicus* are transparent, spherical and 1.05-1.30 mm in diameter, and characterised by a smooth chorion, and a prominent, unsegmented yolk with a single, 0.26-0.31 mm diameter oil globule. The oil globule is located off-centre from the animal axis early in development and posteriorly in the yolk of middle- to late-stage eggs, and becomes pigmented after the blastopore closure. Eggs of *S. australasicus* are morphologically similar to those of *S. japonicus*, and the 7-stage development series we established for *S. australasicus* eggs is similar to the 15-stage series described for *S. japonicus*. Molecular analyses show that middle and late stage eggs of *S. australasicus* can be identified with a high degree of confidence using standard morphological techniques. However, significant uncertainty exists regarding the morphological identification of early stage eggs. Only early stage eggs with a high probability of being *S. australasicus* were included in the datasets used in other chapters of this report. Hence, the egg counts used in these chapters may be negatively biased (conservative). There is a clear need to develop reliable, cost-effective molecular techniques for identifying the early-stage eggs of *S. australasicus*. These methods must overcome technical difficulties associated with the small amount genetic material present in early-stage eggs. An egg development-temperature model is also needed to support the application of the DEPM to this species. Future surveys to support application of the DEPM to *S. australasicus* should involve the preservation of one (bongo net) sample from each haul in a formaldehyde solution and the other in an ethanol solution.

A total of 4,025 eggs and 938 larvae of *S. australasicus* were collected from 2,386 plankton samples collected during 12 research surveys between southern Queensland and the western Great Australian Bight during 2001-2006. Day-2 eggs were more abundant in samples than Day-1 eggs and it unlikely that total egg abundance eggs was significantly over-estimated through the misidentification of early stage eggs. The main spawning season of *S. australasicus* occurs during summer and early autumn off southern Australia, and during late winter and early spring off eastern Australia. Most eggs collected were obtained from stations located over the mid-shelf. The location of spawning off southern Australia appears to vary between years. The western GAB may be an important spawning area, but was not sampled intensively during this study. The main spawning ground of *S. australasicus* off eastern Australia was located in shelf waters of southern Qld and northern NSW. Future DEPM surveys off southern Australia will be logistically challenging due to the large and variable area over which *S. australasicus* spawns in this region. In contrast, applications of the DEPM off eastern Australia may be more tractable due to the comparatively smaller size of the spawning area.

Due to the relatively low densities of *S. australasicus* eggs compared to *Sardinops sagax* eggs, bongo nets (0.6m diameter; 300 μm mesh) are more suitable for collecting eggs and in estimating egg production and spawning area than Californian Vertical Egg Tow (CalVET) nets. Estimates of mean daily egg production for southern Australia (9.94 to 14.25 eggs per m^2 per day) and eastern Australia (6.82 to 9.78 eggs per m^2 per day) may be conservative as they were obtained from outside the main spawning period or location, and calculated using the method of McGarvey and Kinloch (2001) and low mortality values. Voronoi natural neighbour (VNN) methods are suitable for estimating spawning area and provided estimates of 36,370 km^2 for southern Australia in 2005 and 21,019 km^2 for eastern Australia during July 2004. Robust estimates of all adult reproductive parameters, i.e. female weight (452 g), sex ratio (0.46), batch fecundity (52,182 eggs), and spawning fraction (0.14), were obtained for southern Australia. Most estimates of spawning biomass in the areas surveyed off southern and eastern Australia were within the ranges of 45,000-70,000 t and 20,000-60,000 t. respectively. These estimates are likely to be conservative as they are based on negatively biased estimates of several parameters. Our results suggest that the DEPM is a suitable tool for assessment of Australia's *S. australasicus* populations. However, before the method is used for ongoing stock assessment of this species several technical developments need to be completed, including: 1) developing cost-effective and reliable techniques for genetic identification of early stage eggs; 2) developing species-specific egg development-temperature keys for calculating egg production; and 3) identifying locations/methods for collecting adults samples from which to estimate reproductive

parameters for eastern Australia; and 4) calculating degeneration rates of post-ovulatory follicles to provide reliable estimates of spawning fraction.

At meetings of the Small Pelagic Fishery Resource Assessment Group (SPFRAG) in late 2007 and early 2008, a Draft Harvest Strategy was developed for submission to the AFMA Board in April 2008. The strategy applies to quota species prescribed under the draft SPF Plan, namely jack mackerels (*Trachurus declivis*, *T.murphyi*, *T.symmetricus*), blue mackerel (*Scomber australasicus*), redbait (*Emmelichthys nitidus*) throughout the entire SPF and to Australian sardine (*Sardinops sagax*) in Commonwealth waters adjacent to NSW. The SPF Harvest Strategy has adopted many of the features of the harvest strategy for the South Australian Sardine Fishery and drew heavily on the findings of the present study and the concurrent evaluation of the application of the DEPM to redbait off Tasmania (FRDC Project 2004/039). The Draft Harvest Strategy is tiered to accommodate growth of the fishery and the collection of additional information to support stock assessment. The tiered approach is underpinned by the need to balance risk with knowledge by establishing exploitation rates that are initially very conservative and which increase (but remain conservative) as additional information becomes available. The framework explicitly allows the level of investment research and assessment to be varied to match commercial interest in exploiting the resource. At Tier 3, Recommended Biological catches (RBCs) within a zone may not exceed 500 t and stock assessment is done biannually based only on catch and effort data from logbooks and/or observers. At Tier 2, RBCs are specified for each species within a zone based on all available information and stock assessments are done annually based on catch and effort data and age structure information. At Tier 1, RBCs are set as a proportion of the best estimate of spawning biomass obtained using the DEPM, with the maximum harvest rate increasing from 10 to 20% based on the frequency that the DEPM is applied (once every five years up to twice in three years). The Draft Harvest Strategy for the SPF complies with the requirements prescribed under the Commonwealth Harvest Strategy Policy and Guidelines. The reliance of the Draft Harvest Strategy for the SPF on the DEPM provides clear evidence of the success of the current project in achieving it ambitious objectives. The version of the Draft Harvest Strategy that was completed by the SPFRAG in February 2008 is not reproduced in this report (under the direction of AFMA) as it is being further refined by AFMA prior to this report going to press. The Tier 2 RBCs for each species in zone will be determined at the meeting of SPFRAG and SPF MAC on 31 March and 1 April 2008, respectively.

Acknowledgements

This study was funded by the Fisheries Research and Development Corporation (FRDC), Australian Fisheries Management Authority (AFMA) and the NSW Recreational Saltwater Fishing Trust. The South Australian Research and Development Institute (SARDI) Aquatic Sciences, New South Wales Department of Primary Industries (NSW DPI), Tasmanian Aquaculture and Fisheries Institute (TAFI) and the Australian Maritime College (AMC) provided significant in-kind support. The contribution of individuals and agencies to components of the study are specifically acknowledged at the end of each chapter. Mr Wetjens Dimmlich designed and built the database in which all data from this project are stored. Drs Stephen Mayfield and Adrian Linnane (SARDI Aquatic Sciences) reviewed substantial components of the report. Dr Qifeng Ye (SARDI Aquatic Sciences) managed the review of the report and approved its release.

1. General Introduction

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1.1 Background

Blue mackerel *Scomber australasicus* (Cuvier 1832) is an important element of the pelagic ecosystems off southern Australia and is a key prey species for a large range of predatory fishes, including premier recreational species, such as tunas and billfishes. For several decades, small-scale fisheries in New South Wales (NSW), Victoria (VIC), Tasmania (Tas), South Australia (SA) and Western Australia (WA) have supplied local markets with *S. australasicus* for bait and human consumption. Significant quantities of *S. australasicus* have also been taken as by-catch in purse-seining and mid-water trawling operations conducted in these states, e.g. up to 1,200 t per annum was taken off Tasmania in the 1980's (Ward *et al.* 2001a).

Over the last few years there has been increasing pressure to expand the commercial fisheries for *S. australasicus*, with commercial operators claiming that stocks are under-exploited and capable of supporting large and valuable industries. Currently, target fishing for *S. australasicus* is being conducted off southern NSW and is planned for eastern Tas, the Great Australian Bight (GAB) and southern WA (Ward *et al.* 2001a, Mr A. Bodsworth Australian Fisheries Management Authority (AFMA) pers. comm.). Facilities to process blue mackerel for a range of purposes, including export markets for human consumption, have been established recently in southern NSW and Tasmania at considerable cost to both commercial proponents and the Commonwealth and State Governments, e.g. as part of the Eden Regional Adjustment Package. Recreational fishers commonly use *S. australasicus* as bait, especially for the large predatory fishes that commonly feed on this species. Peak representative groups such as Recfish Australia, as well as game fishing associations (e.g. Game Fishing Association of Australia, GFAA), have strongly opposed the expansion of the commercial fisheries for blue mackerel due to the lack of scientific information on population sizes and the potential effects on the abundance, distribution and availability of sport fish species.

Serious concerns have been expressed regarding the potential effects of localised depletion on the availability of gamefish on key recreational fishing grounds, such as those off Port Stephens and the south coast of NSW, and the difficulties of establishing suitable Total Allowable Catches (TAC) for a species that is thought to undergo large interannual fluctuations in abundance (Dr Julian Pepperell, pers. comm.). As a precautionary response to current lack of knowledge on fisheries biology and population sizes of blue mackerel and other temperate mackerels, AFMA recently reduced the purse-seine Trigger Catch Limit (TCL) in several zones of the Jack Mackerel Fishery, from 5000 to 2500 t and from 2,000 to 1,000 t for the mid-water trawl sector. These reductions have heightened the concerns of commercial fishers regarding the security of their access to this resource and have impeded investment in the industry (Mr Andre Remoy, commercial fisher and processor, pers comm.).

AFMA recently commissioned the Bureau of Rural Sciences (BRS) to undertake a desktop investigation and analysis of information available on the biology and fisheries for *S. australasicus* and related species (Ward *et al.* 2001a). The BRS report concluded that biological and ecological data for blue mackerel were sparse and did not provide an appropriate basis for determining suitable commercial harvest levels or the potential effects of industrial fishing on other components of the ecosystem.

This lack of information is a significant impediment to the establishment of management arrangements that fully satisfy either the core objectives or guiding principles of Australia's National Strategy for Ecologically Sustainable Development (ESD) or the Standing Committee on Fisheries and Aquaculture's guidelines for ecologically sustainable fisheries. Lack of information is also impeding efforts by the Commonwealth and State Governments to develop and implement best-practice management plans for the mackerel fisheries of southern Australia.

On 12 July 2001, a meeting was held between representatives of AFMA, BRS, the Australian Maritime College (AMC) and the South Australian Research and Development Institute (SARDI) Aquatic Sciences, to discuss options for addressing the paucity of data available on blue mackerel and related species. Prior to the meeting, Tasmanian and South Australian researchers had conducted discussions with scientists in NSW Fisheries, the Marine and Freshwater Resources Institute (MAFRI) and Fisheries WA regarding the priorities for mackerel research in their State. Participants in the meeting unanimously supported the findings of the BRS study and confirmed

that the lack of biological information was impairing management efficiency; particularly the ability to determine harvest levels that will ensure that objectives of ESD are achieved. Participants agreed that a greater understanding of blue mackerel and its role in Australia's temperate marine ecosystems was essential for the development of effective management arrangements across jurisdictions. It was also emphasised that future work should be designed explicitly to build on and synthesise results of previous projects, including (Stewart *et al.* 1998; Stewart *et al.* 1999; Ward *et al.* 2001a).

AFMA indicated in principle, support for the provision of significant funding (in the order of $55,000 p.a.) for the period 1 July 2002 to 30 June 2005 to (i) support the State monitoring and research programs and (ii) lever additional funds from the Fisheries Research and Development Corporation (FRDC) to support national collaborative investigation of blue mackerel stocks. The proposal was developed on the understanding that AFMA would contribute ~$55,000 per annum to support the project.

A preliminary research proposal involving SARDI, the Tasmanian Aquaculture and Fisheries Institute (TAFI), NSW Fisheries, AMC, Fisheries WA and BRS was submitted to Commonwealth Fisheries Research and Advisory Board (COMFRAB), Tasmanian Fisheries Research and Advisory Board (TASFRAB) and South Australian Fisheries Research and Advisory Board (SAFRAB). The project was ranked as a high priority for funding by TASFRAB and SAFRAB and was supported strongly by COMFRAB. The proposal was evaluated by the FRDC Board in March 2002. The Principal Investigator received a letter from Dr Patrick Hone on 11 March 2002 that indicated a revised application should be submitted by 28 March and should (i) focus on one key species, such as *S. australasicus* and (ii) include an analysis of the recreational harvest of *S. australasicus* off NSW, with Dr Michael Lowry (NSW Fisheries) as the co-investigator responsible for that section of the project.

The revised proposal was modelled largely on FRDC projects 94/029 (Ward *et al.* 1998), 95/043 and 98/130 (Staunton-Smith and Ward 2000), which (i) investigated the fisheries biology (age, growth and reproduction) and (ii) established quantitative stock assessment procedures for the sardine (pilchard) *Sardinops sagax* in southern and eastern Australia. The stock assessment techniques developed in those projects are now undertaken annually in SA and funded by the participants in the SA Sardine Fishery (SASF).

Ward *et al.* (2001a) concluded that additional studies of age and growth were needed to ensure that the fishery for *S. australasicus* in southern Australia is developed in a precautionary manner. FRDC has funded several investigations of the age and growth of mackerels. For example, FRDC project 95/151 (Stewart *et al.* 1998) provided information on the age and size composition of commercial and recreational catches of blue mackerel off the NSW coast. The project proposed herein does not aim to replicate that study but will extend the results by providing (i) a comprehensive analysis of the patterns of age and growth of *S. australasicus* throughout most of its Australian range and (ii) a detailed analysis of the age-specific spatial and temporal patterns of adult/spawning fish obtained using fishery-independent methods. The information on age and growth will enable development of a fishery-dependent method for monitoring the status of the stock.

FRDC project 94/029 also included a review of stock assessment methods for small pelagic fishes. That study concluded that classical fishery models that rely on fishery-dependent data are inappropriate for new and developing fisheries and that their usual reliance on CPUE data renders them unsuitable for schooling species, such as clupeoids and *S. australasicus*. The value of hydroacoustic and visual (i.e. aerial) methods is also impeded by temporal and spatial variation in schooling behaviour, and difficulties identifying the species and size composition of schools (F.J. Neira pers. comm.). As a result, aerial surveys may provide useful qualitative information on the distribution of mackerel off southern Australia (Ward *et al.* 2001a), but will not provide the quantitative estimates of stock abundance required to establish appropriate TACs (Morrison *et al.* 2001). In contrast, egg production surveys are used routinely to provide estimates of mackerel abundance in the northern Atlantic Ocean and elsewhere (Borchers *et al.* 1997; Ward *et al.* 2001a), and provide an alternative for obtaining quantitative estimates of the spawning biomass of mackerels in southern Australia. As shown by FRDC project 94/029, and the subsequent development of the SASF, egg production methods can provide conservative estimates of spawning biomass within a few years of implementation and facilitate the precautionary development of fisheries for small pelagic species. The development and evaluation of egg-based stock assessment methods for *S. australasicus* off temperate Australia will provide a mechanism for estimating and monitoring the size of what may be one of the most valuable and under-exploited fisheries resources in Australian waters.

Accurate information on the location of spawning is essential for the application of egg-based stock assessment methods (Ward *et al.* 1998). Few data are available on the location of spawning

and/or distribution and abundance of eggs and larvae of *S. australasicus*. However, eggs tentatively identified as *S. australasicus* were obtained in egg surveys conducted during summer-autumn in shelf waters of SA prior to the commencement of this project. Data from congeners in other ecosystems (e.g. *Scomber scombrus* in the North-eastern Atlantic) suggest that *S. australasicus* may also spawn near the shelf break.

Positive egg identification is a pre-requisite for the reliable application of egg-based stock assessment methods (Ward *et al.* 1998). Information on egg stages/ages is also useful, although conservative estimates of egg production can be obtained by ignoring egg mortality and estimating initial egg production from the abundance of Stage I eggs only (Borchers *et al.* 1997) or from mean egg abundances (McGarvey and Kinloch 2001). Eggs of *S. australasicus* have not been formally described and prior to this project, information required to stage/age eggs and to estimate egg mortality and initial egg production was not available.

Development of methodologies for obtaining representative samples of adults and for estimating batch fecundity and spawning fraction are prerequisites for the application of egg based stock assessment methods (Ward *et al.* 1998). However, information on the reproductive biology of *S. australasicus* in southern Australia is sparse. Stevens *et al.* (1984) found *S. australasicus* in the GAB reach sexual maturity at ~28 cm, and spawn in summer-autumn. No estimates of batch fecundity or spawning fraction are available for this species.

Information on levels of usage by recreational fishers obtained by synthesising the existing data on the recreational trailer boat sector and data collected from surveys of the charter and game fishing sectors will provide a sound basis for developing equitable resource sharing arrangements for blue mackerel resources off NSW.

1.2 Need

Stock assessment methods need to be developed for *S. australasicus* for a range of economic, ecological, social and legislative/administrative reasons. Perhaps most importantly, the large and valuable international markets for members of the genus *Scomber*, in conjunction with the apparently large stocks of *S. australasicus* off southern Australia, suggest that a commercial fishery for this species could generate significant export earnings. Furthermore, as the economic potential of this industry is well known, significant amounts of private and public funds have been invested in attempts to develop fisheries and processing facilities for this species. To date,

the development of these industries has been impeded by the absence of the information required to establish appropriate TACs. In fact, TCLs in Commonwealth waters were halved as a precautionary response to scientific uncertainty regarding sustainable harvest levels. *S. australasicus* is also prized as bait by recreational anglers and reliable estimates of the quantities taken by this sector are needed to determine the total impacts of fishing and to make informed decisions about resource sharing amongst stakeholders. The need for data from the recreational sector is most pressing off the NSW coast.

There is also significant concern among recreational anglers that sustained commercial fishing for *S. australasicus* may affect the local abundance and availability of tuna and billfishes. Australia's recreational and charter fisheries for these species are economically important and provide a significant source of income for many regional communities (e.g. Port Stephens and southern NSW). If stocks of *S. australasicus* are not as large as commercial fishers claim, then the concerns of recreational fishers may be valid and further development of the commercial fisheries could potentially impact on the distribution, abundance and availability of sport fish species and the viability of the recreational and charter fisheries which they support. Similarly, the removal of large quantities of a key prey species could adversely affect populations of other marine predators, including marine mammals and seabirds. Cetaceans, Pinnipeds and many gamefish species (eg marlins), which have considerable social, ecological and cultural significance, are known to prey on mackerels (Ward *et al.* 2001). As a result, there is strong public pressure for Commonwealth and State governments to conduct research and to develop management arrangements that will ensure that commercial harvesting of *S. australasicus* is ecologically sustainable. Commonwealth and State legislation, policies and strategies also require government agencies to ensure that the harvesting of fisheries resources not only provides maximum economic and social benefits to the Australian community, but also minimise impacts on other components of the ecosystem.

In the cost recovery frameworks in which most fisheries management and research agencies currently operate, acquiring funds to conduct research in support of small and developing (albeit potentially valuable) fisheries is problematic. The augmentative funding requested in this proposal is required to ensure that the harvest strategies that are developed for *S. australasicus* off southern Australia reflect the social significance of the species as well as the size and potential economic value of the resource, and take into account the potential ecological effects of the expansion of the commercial sector.

The major impediment to the development of southern Australia's commercial mackerel fisheries is the lack of quantitative information required to establish appropriate TACs. The most cost- and time-effective option for obtaining this information is to apply egg-based stock assessment methodologies, such as the Daily Egg Production Method (DEPM) (Lasker 1985; Parker 1985; Ward *et al.* 1998; Ward *et al.* 2001c). This project will (i) develop the methods for sampling adults and identifying and staging eggs that are required to apply egg-based stock assessment methods to blue mackerel and (ii) use the DEPM to calculate conservative estimates of minimum spawning biomass of blue mackerel off south-eastern Australia.

1.3 Original Objectives

1. To synthesise information available on the fisheries for *S. australasicus* in southern Australia. (Note that information on the biology of *S. australasicus* will be reviewed as part of the objectives that deal specifically with age and growth, reproductive biology, stock assessment, etc.);
2. To describe the spatial and temporal patterns of age and growth, and compare the age structure of commercial and recreational catches and fishery-independent samples of *S. australasicus* taken from throughout southern Australia;
3. To estimate the critical adult reproductive parameters for *S. australasicus*, especially spawning fractions and batch fecundities, in southeastern Australia;
4. To establish methods and criteria for identifying and staging the eggs and larvae of *S. australasicus*;
5. To estimate the size of the spawning areas and levels of egg production of *S. australasicus* off south-eastern Australia (northern NSW to the central Great Australian Bight);
6. To develop and evaluate methods for estimating the spawning biomass of *S. australasicus*;
7. To evaluate potential harvest strategies for *S. australasicus* in southern Australia and provide preliminary estimates of the potential yields for each zone of the Commonwealth fishery;
8. To estimate the number, size frequency and total weight of *S. australasicus* taken by recreational (charter, gamefish and trailer-boat) fishers off the NSW coast;

1.4 Revised Objectives

Following a meeting of the project steering committee in September 2005, the original objectives of the project were expanded to better address stakeholder needs and to allow additional

information obtained during the study to be included in the final report. The revised objectives below were approved by FRDC in October 2005.

1. To synthesize existing information on the fisheries, surveys and potential stock assessment methods for *S. australasicus* in southern Australia;
2. To provide a preliminary description of the stock structure of *S. australasicus* in south-eastern Australia (additional objective);
3. To estimate the number, size frequency and total weight of *S. australasicus* taken by recreational (charter, gamefish and trailer boat) fishers off the New South Wales coast;
4. To describe the spatial and temporal patterns of age and growth, and compare the age structure of commercial catches and fishery independent samples of *S. australasicus* from southern and eastern Australia;
5. To compare the spatial and temporal patterns of age of commercial and recreational catch samples of *S. australasicus* taken from NSW;
6. To describe reproductive biology, especially spawning fractions and batch fecundity, of *S. australasicus* off southern and eastern Australia;
7. To establish methods and criteria for identifying and staging the eggs and larvae of *S. australasicus*;
8. To describe the distribution and abundance of eggs and larvae of *S. australasicus* off southern and eastern Australia;
9. To describe the distribution and abundance of the eggs and larvae of *Trachurus* spp., *Sardinops sagax*, *Engraulis australis* and *Etrumeus teres* in southern and eastern Australia (additional objective);
10. To develop and evaluate methods for estimating the spawning biomass of *S. australasicus* in southern Australia;
11. To evaluate potential harvest strategies for *S. australasicus* in southern Australia and provide preliminary estimates of the potential yields for each zone of the Commonwealth Small Pelagic Fishery

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2. Fisheries, surveys and stock assessment options for blue mackerel *Scomber australasicus* in southern Australia.

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Objective: To synthesize information available on the fisheries for blue mackerel *Scomber australasicus* in southern Australia.

Summary: Minimal information is available on the abundance of blue mackerel *S. australasicus* in Australian waters. The total annual Australian catch ranged between 1000 -1500 t. Most of the catch is taken by the NSW Ocean Haul Fishery and Commonwealth Small Pelagic Fishery. The annual catch in the NSW Ocean Haul Fishery ranged from 335 to 462 t between 1997/98 and 2004/05. The total catch for all Commonwealth managed fisheries combined ranged between ~1089 t in 1998 and ~714 t in 2005. Combined annual catches in the South Australian, Western Australian, Victorian and Queensland fisheries are generally <400 t/year. The National and Indigenous Recreational Fishing Survey estimated that a total of 720,814 *S. australasicus* were captured in 2000, with ~21% released alive. Most (75%) of the recreational harvest is taken in NSW, Western Australia and South Australia. Previous surveys provided no quantitative information. For example, Russian surveys of the Great Australian Bight during the 1960s reported the occurrence of large schools of mackerel at the surface and suggested that accumulations were "considerable" in some years. A range of stock assessment techniques, including virtual population assessments, egg production methods, various types of surveys and integrated models, have been used to estimate the biomass of mackerel in European and Asian waters with varying, and often limited levels of success. A literature review confirmed that egg production techniques, potentially in conjunction with integrated (age structured) models, are the most suitable tool for stock assessment of *S. australasicus* in Australian waters.

2.1 Introduction

This chapter synthesises existing information on the fisheries, surveys and stock assessment options for blue mackerel *S. australasicu*s, in southern Australia. Readers requiring detailed information on the fisheries, biology and ecology of members of the genus *Scomber* are directed to the review by Ward *et al* (2001). The appraisal of stock assessment options for small pelagic fishes in Ward *et al.* (1998) is also relevant. Existing literature with particular relevance to topics investigated in the present report (e.g. stock structure, age and growth, reproduction, daily egg production method) are cited and discussed within the relevant chapter.

2.2 Taxonomy and Distribution

Mackerels in the genus *Scomber* are widely distributed in temperate and sub-tropical waters between 50^{o} north and south of the equator (Ward *et al.* 2001). The genus has traditionally included three species: blue mackerel *S. australasicu*s, chub mackerel *S. japonicus* and Atlantic mackerel *S. scombrus*. However, Scoles *et al.* (1998) showed that *S. australasicu*s and *S. japonicus* are more closely related to each other than to *S. scombrus*, and that morphological and genetic differences in Atlantic and Indo-Pacific populations of *S. japonicus* may warrant recognition of two separate species. Analyses by Infante *et al.* (2006) support this claim and a separate species *Scomber coli* has been established to replace *S. japonicus* in the Atlantic Ocean. Under these definitions, there are two closely related species, *S. japonicus* and *S. australasicus* in the Indian and Pacific Oceans, and *S. scombrus* and *S. coli* in the Atlantic Ocean.

*S. australasicu*s occurs throughout the Pacific Ocean, including South East Asia, Australia and New Zealand and in the northern Indian Ocean and Red Sea. In Australia it is found mainly in southern temperate and subtropical waters between southern Queensland to Western Australia (Ward *et al.* 2001). Juveniles and small adults usually occur in inshore waters and larger adults form schools in depths of 40-200m across the continental shelf (Kailola *et al.* 1993).

2.3 Fisheries

2.3.1 International Fisheries

Large fisheries for *S. japonicus* (e.g. ~50,000 to 500,000 t per annum) are located off Japan, Peru, China, Korea, Russia and the Ukraine (Ward *et al.* 2001). The largest fishery for *S. australasicus* is based in New Zealand where annual catches range between approximately 9,000 and 14,000 t per annum. *S. australasicus* is taken in several fisheries in Australia with total annual catches usually less than 1,000 t (Ward *et al.* 2001).

2.3.2 Australian Fisheries

2.3.2.1 Small Pelagic Fishery

The Commonwealth Small Pelagic Fishery (SPF), managed by the Australian Fisheries Management Authority (AFMA) is a purse-seine and mid-water trawl fishery. There are currently 75 licences and 5 active vessels operating in this fishery targeting several species including jack mackerel *Trachurus declivis*, yellowtail scad *T. novaezelandiae* and Peruvian jack mackerel *T. symmetricus*, redbait *Emmelichthys nitidus* and blue mackerel *S. australasicus*.

The SPF is managed by a combination of input and output controls that include limited entry, zoning, mesh size restrictions and a combination of precautionary trigger catch levels (TCL) and total allowable catch (TAC) limits. Zone A (Fig. 2.1) is managed cooperatively with the Tasmanian Government and has a TAC of 34,000 t (AFMA 2004). Zones B, C and D have species specific TCLs (Table 2.1). Catch data for the SPF are confidential and for the purpose of this report were combined with data from other Commonwealth fisheries that take blue mackerel.

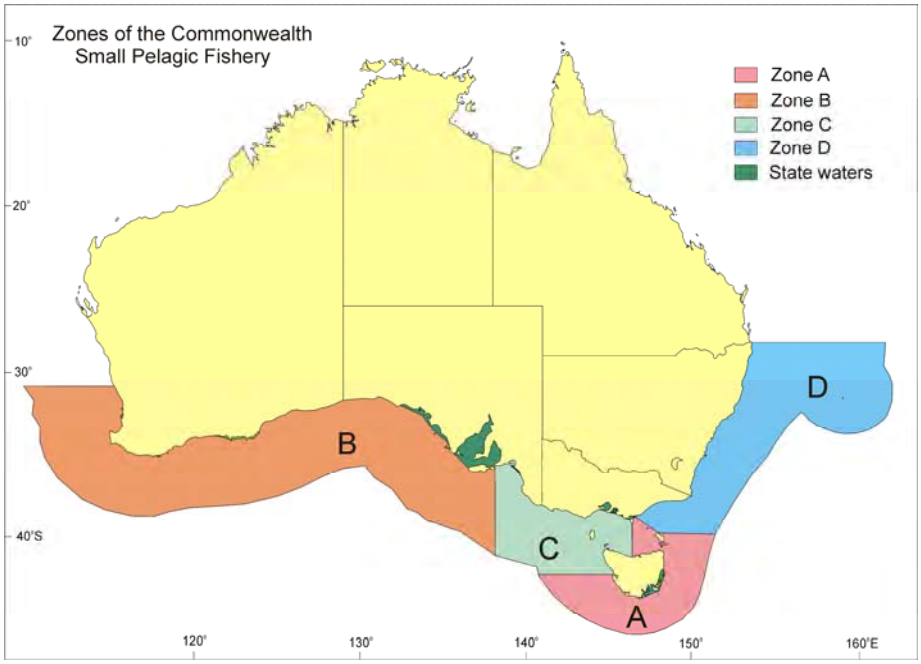

Figure 2.1. Zones of the Commonwealth Small Pelagic Fishery. (Map adapted from AFMA www.afma.gov.au).

Table 2.1. TCLs (tonnes) for zones of the SPF

SPECIES	ZONE		
	B	C	D
Blue mackerel (*S. australasicis*)	5000	3500	3500
Yellowtail scad (*T. novaezelandiae*)	100	100	100
Jack mackerels (*Trachurus declivus, T. symmetricus*)	4500	2500	2500
Redbait (*Emmelichthys nitidus*)	1000	1000	1000

2.3.2.2 Other Commonwealth Fisheries

S. australasicus can also be taken in the Great Australian Bight Trawl (GAB), Gillnet Hook and Trap (GHT), Southern and Western Tuna and Billfish (SWTBF and WTBF), Eastern Tuna and Billfish (ETBF) and the South Eastern Trawl (SET) fisheries. The total catch of *S. australasicus* for all Commonwealth fisheries combined (including SPF) ranged between 108.9 t and 713.8 t between 1998 and 2005 (Fig. 2.2).

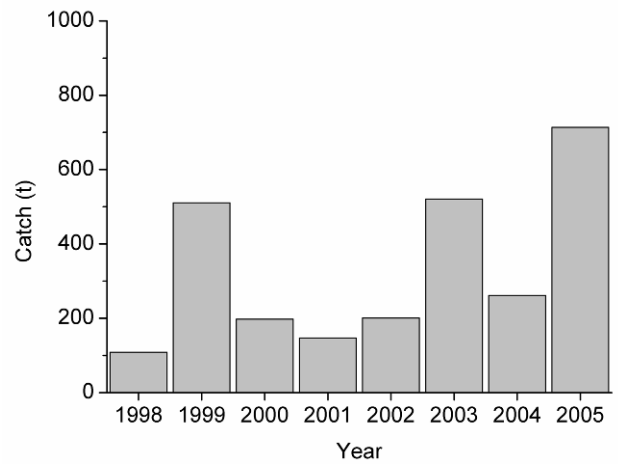

Figure 2.2. Combined catch of *S. australasicus* for all Commonwealth fisheries between 1998 and 2005.

2.3.2.3 South Australia

Catch and effort data for *S. australasicus* in South Australia are available for the financial years 1983/84 to 2004/05. Catch data were sourced from monthly research logbooks provided to SARDI Aquatic Sciences by the fishers. No reliable species-specific effort data were provided.

Relatively small quantities of *S. australasicus* are taken by Marine Scale-fish (MSF) licence holders using pole, hand-line, troll-line, long-line, gill-net, shark-net, bait-net and purse-seine nets. Due to the limited number of fishers taking the catch and associated confidentiality issues, catches taken prior to and including 1987/88 are not reported. Catches of *S. australasicus* ranged from 0.3 to 1.6 t between 1988/89 and 1992/93 (Fig. 2.3). After 1993/94, annual catches increased and ranged from 1 to 5.8 t, with the exception of 2000/01, when the catch was 0.3 t.

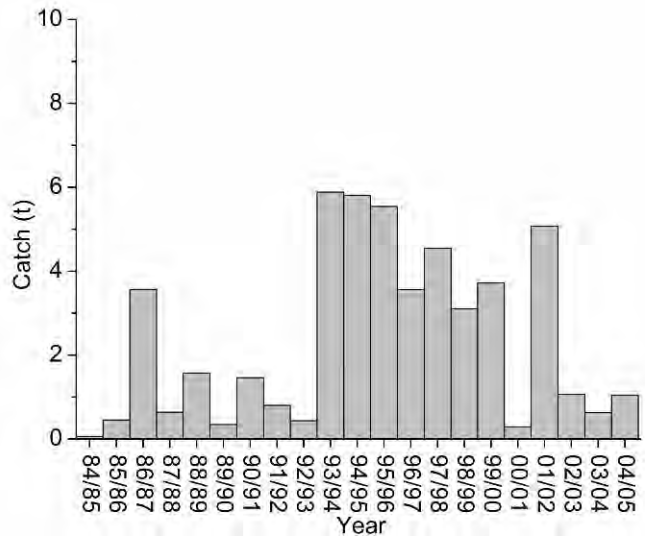

Figure 2.3. Annual catches for *S. australasicus* in South Australia by state managed fisheries between 1984/85 and 2004/05.

2.3.2.4 New South Wales

Catch data are submitted monthly by commercial fishers to the NSW Department of Primary Industries. The NSW commercial purse seine fishery has targeted yellowtail scad *T. novaezelandiae* and *S. australasicus* since the early 1980's (Stewart and Ferrell 2001). *S. australasicus* typically comprise ~38% of the catches. Other species taken include Australian anchovy *E. australis* (3%), sardine (26%), other mackerels (*Trachurus* spp., ~31%) and sandy sprat (*H. vittatus*, ~2%).

Total catches peaked at 729 t in 1987/88 and declined to 93 t in 1990/91. Since 1991/92, catches have fluctuated between ~300 and 582 t. The average annual catch in the NSW fisheries (combined) between 1984/85 and 2004/05 was 407 ± 30.7 t (Fig. 2.4). Since 1984/85 catches of *S. australasicus* have fluctuated substantially between years.

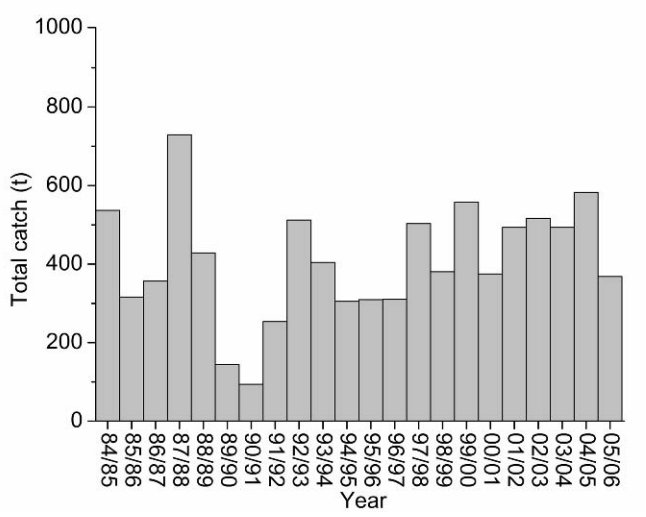

Figure 2.4. Total annual catches of *S. australasicus* in NSW by state managed fisheries between 1984/85 and 2005/06.

The purse-seine sector of the Ocean Haul Fishery takes the majority of the *S. australasicus* catch in NSW waters. This fishery mostly operates in semi-enclosed bays from Sydney to Eden. Most vessels are between 5 and 15 m. Total catches have ranged between 335 to 462 t between 1997/98 and 2004/05 (Fig. 2.5).

The remainder of the catch is taken in the Ocean Trap and Line Fishery. The total annual catches by this fishery are lower (3.3–6.1%) ranging from 19 to 31 t per year between 1997/98 and 2004/05.

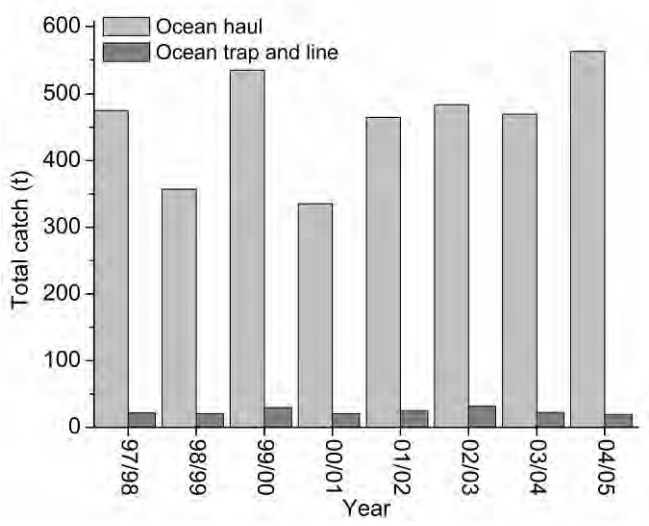

Figure 2.5. Total annual catches of *S. australasicus* in NSW for the Ocean Haul and Ocean Line and Trap Fisheries between 1997/98 and 2004/05.

2.3.2.5 Queensland

Catch data for the Queensland commercial fisheries were obtained from Commercial Fish Information System (CFIS) daily logbooks supplied to Queensland Department of Primary Industries (QDPI). No detail could be presented on annual catches, CPUE or effort due to confidentiality issues and no spatially related information is available. Data provided by calender year showed total catches of *S. australasicus* ranged between 0.26 and 8.4 t per annum between 1999 and 2003, and the average (±s.e.) annual catch was 3.58 ±1.09 t.

2.3.2.6 Tasmania

Catch and effort data for the Tasmanian Purse Seine and General Fisheries were obtained from research logbooks provided to the Tasmanian Aquaculture and Fisheries Institute (TAFI) however details of the data could not be reported here due to confidentiality issues.

The Tasmanian Purse Seine Fishery has recorded catch and effort in logbooks since its inception in 1984. Logbooks contained a shot by shot record of fishing operations and species taken. The first reported landings of *S. australasicus* occurred during the 1985/86 season, but limited species-specific information was recorded. Logbooks were replaced with a trip catch return at the beginning of the 1990/91 fishing year. Large-scale purse seining for small pelagic species ceased following the 1999/00 season.

Total catches of all small pelagic species fluctuated significantly between years. There was a gradual decline from 38,902 t in 1986/87 to 2,866 t in 1999/00 (Fig 2.6). Peak catches of 38,902, 27,469 and 15,225 t occurred in 1986/87, 1991/92 and 1997/98, respectively. *S. australasicus* only represented ~2–3.7% of catches between 1986 and 1989 and species-specific information was not available during the other years. A mid-water pair-trawl operation was then established to target jack mackerel *T. declivis* and *E. nitidus*; *E. nitidus* dominated the catch (Welsford and Lyle 2003). A joint management strategy was then established between the Commonwealth and Tasmanian Governments, to incorporate the fishery into the Commonwealth Small Pelagic Fishery.

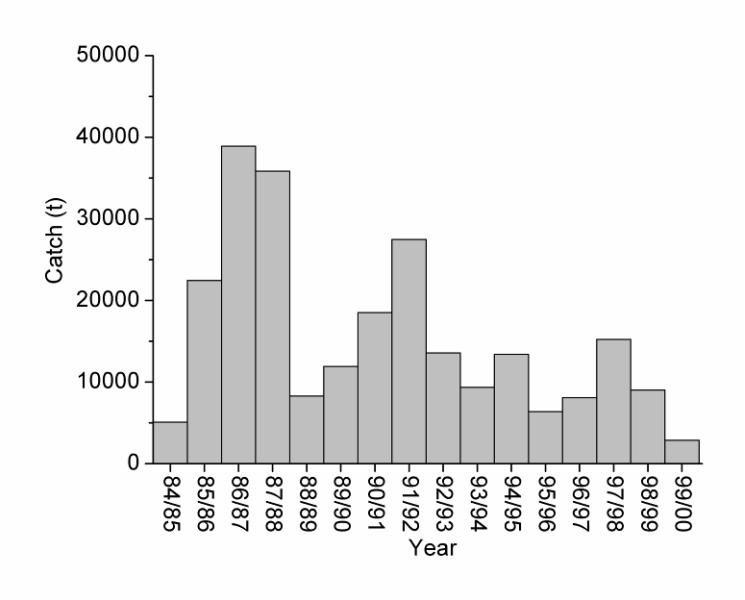

Figure 2.6. Total catches of small pelagic fish species in the Tasmanian Purse Seine Fishery between 1984 and 2000.

Catch data for the Tasmanian General Fishery was available by financial year from 1990/91 to 2005/06 (Fig. 2.7). Total catches of *S. australasicus* have ranged between 0 t in 2001/02 and 8.5 t in 1993/94.

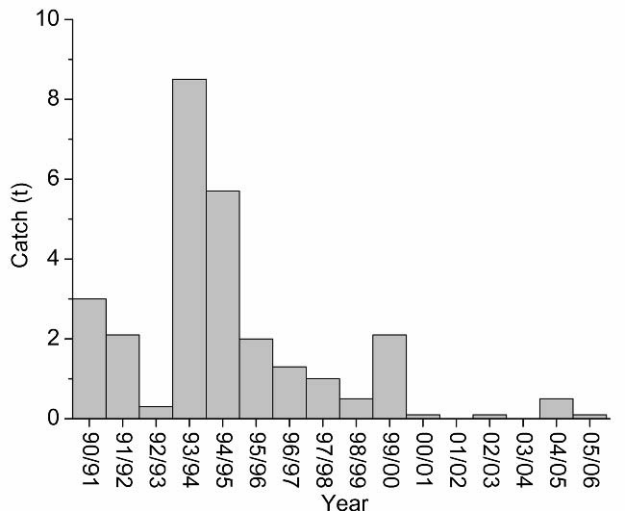

Figure 2.7. Total annual catches of *S. australasicus* in the Tasmanian General Fishery between 1990 and 2006.

2.3.2.7 Victoria

Catch information for the Victorian fisheries was provided by the Australian Fisheries Management Authority (AFMA) and Department of Primary Industries (PIRVic). Less than five licence holders took *S. australasicus* in Victorian waters and detailed catch data could not be reported due to confidentiality restrictions.

The average annual catch between 1978/9 and 2004/5 were 49 t (±22.9) and catches varied from 0.2 to 370.6 t. No effort data were available for commercial catches in Victorian waters.

2.3.2.8 Western Australia

Catch and effort data were available in Western Australia from 1988 to June 2006. Data were obtained from research logbooks provided by fishers to the WA Fisheries Department. *S. australasicus* is taken by a multi-species fishery in WA using a variety of gear types, which include purse-seine, beach seine, trawl, gill and haul nets, fishing poles and drop lines. In some logbook returns fishers grouped *S. australasicus* with other mackerel species (e.g. *T. novaezelandiae* and *T. declivis*) under the title "other mackerel". Other operators distinguished mackerel by species. The data for these two categories is presented separately as it was impossible to know the proportion of *S. australasicus* recorded in the "other mackerel" category. As in the other states where little effort data were available, these reporting issues suggest that the available effort data were unreliable for assessing fishing effort specifically targeting *S. australasicus*.

In WA waters, the annual *S. australasicus* catch ranged from 0 to 175.3 t between 1978/79 and June 2006 (Fig. 2.8). The mean annual catch was 11.3 t (±5.8). Annual catches could not be presented for *S. australasicus* in 2000 becauses less than five vessels participated in the fishery. Total annual catches for "other mackerel" ranged between 0 and 57 t and the mean annual catch was 7.4 t (±2.2). Annual catch statistics for 'other mackerels' cannot be presented for 1994 and 2003 because fewer than five vessels were responsible for taking the total landings.

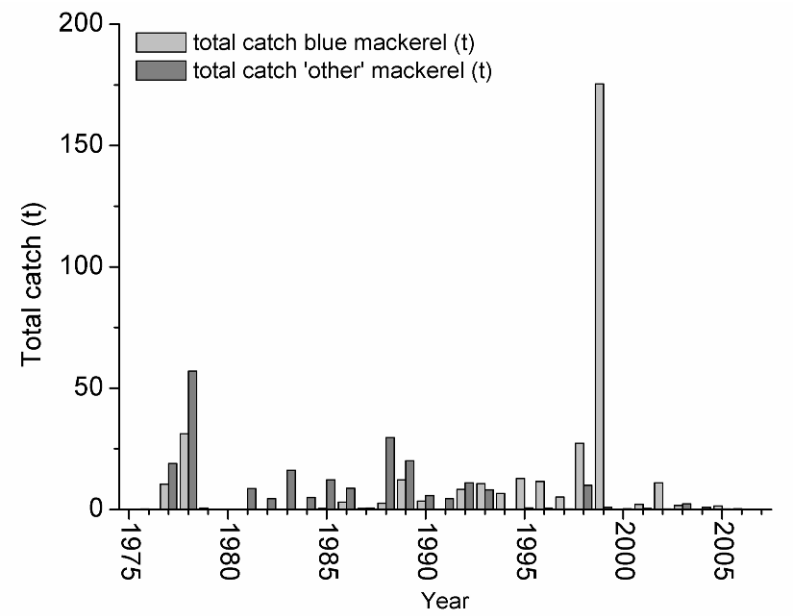

Figure 2.8. Total annual catches of *S. australasicus* and "other" mackerel in Western Australia between 1975 and June 2006.

2.3.2.9 Australian Recreational Fishery

Henry and Lyle (2003a) reported on the national recreational catch of *S. australasicus* as part of the National Recreation and Indigenous Fishing Survey (NRIFS). The numbers of *S. australasicus* retained by recreational fishers during the survey period (May 2000 and April 2001) is shown in Figure 2.9. Most (75%) of the national recreational harvest of *S. australasicus* was taken in NSW and 14 and 8% were taken in Western Australia and South Australia, respectively. Victoria, Tasmania and Queensland made up the remaining 3% of the recreational catch. The total number of *S. australasicus* captured nationwide was 720,814 and of these 21% were released.

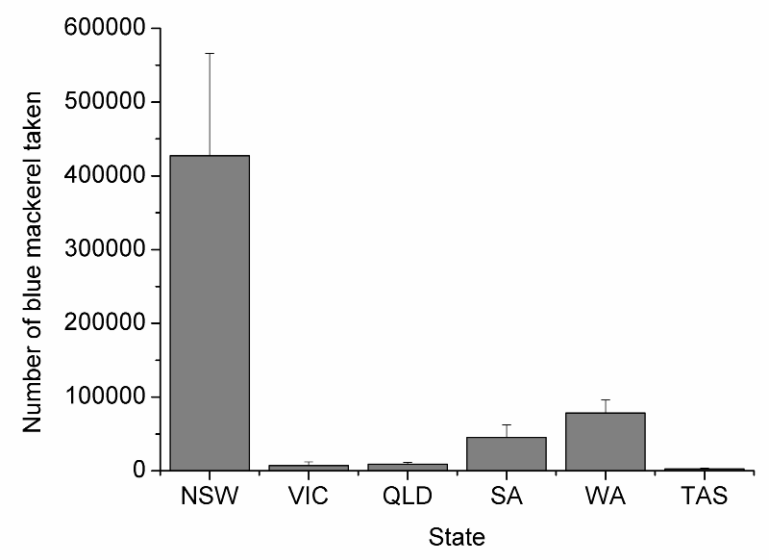

Figure 2.9. Numbers of *S. australasicus* taken in each State by recreational anglers during the National Recreational Fishing Survey. Error bars represent standard errors (Henry and Lyle 2003a).

2.4 Surveys in southern Australia

Several investigations of the potential trawl fishery resources in the GAB have been conducted over the past 50 years (Makarov and Pashkin 1968; Shuntov 1969; Stevens *et al.* 1984). These have included mid-water and demersal trawl surveys for *S. australasicus*, jack mackerels *Trachurus spp.* (reported as yellowtail scad, *Trachurus declivis*) and sardine *Sardinops sagax*. Few surveys of pelagic resources have been conducted in other parts of Australia. The exceptions are surveys off eastern Australia from the FRV Kapala and off south-western Australia from the FRV Warreen (Rapson 1953; Blackburn and Downie 1955; Wolfe 1970; Wolfe 1971; Gorman and Graham 1979; Stevens *et al.* 1984).

2.4.1 Southern Australia

2.4.1.1 Russian Surveys (1965–1968)

Between 1965 and 1968, three Russian research vessels conducted trawl surveys in the GAB with the aim of clarifying the existence of pelagic fish stocks and to gather biological data (Shuntov 1969). Information focused on the biology and schooling behaviour of small pelagic fish species, and it was reported that large schools of mackerels were present at the surface suggesting that accumulations were "considerable" in some years (Shuntov 1969). Survey results (Makarov and Pashkin 1968) reported a "yield estimate" of 9,000 t for *Trachurus* spp., although the basis for this

figure is difficult to determine. Stevens *et al.* (1984) suggested it was unreliable and based on catch rates from Tasmania.

2.4.1.2 British United Trawlers (1977–1979)

British United Trawlers (BUT) that operated in the GAB between November 1977 and May 1979 caught 1,196 t of *S. australasicus* and 873 t of *Trachurus* spp. in pelagic trawls. The average catch rate for *S. australasicus* was 840 kg/h and peaked at 5 t per hour (Stevens *et al.* 1984). The total catch of *Trachurus* spp. over this period was 873 t with an average catch rate of 600 kg/h (Stevens *et al.* 1984).

2.4.1.3 Denebola (1979–1980)

The *Denebola* was a Polish factory trawler that operated on an exploratory basis in southern Australian waters between Tasmania and the western GAB during 1979–1980. In contrast to catches of the BUT trawlers, the majority (70% by weight) of the catch consisted of *S. sagax* (15.5 t) and *S. australasicus* was the second most significant species (4.8 t). Catch rates of *S. australasicus* varied between 30.4kg/h and 34.8 kg/h. *Trachurus* spp. were caught in lower numbers with catch rates of 4.1 to 4.5 kg/h (Collins and Baron 1981).

2.4.1.4 FRV Warreen

The FRV *Warreen* documented the presence of small quantities of sardine between Albany and Esperance using acoustic surveys and purse-seine (Scottish ring net) techniques. Although purse-seine operations were not completely successful, they suggested the region was capable of supporting a viable commercial sardine fishery.

2.4.2 Eastern Australia

2.4.2.1 FRV Kapala

The FRV Kapala was a research trawler that operated in eastern Australian waters between 1973 and 1985. Surveys consisted mainly of fishing gear trials and assessing the species composition of demersal and deepwater fish resources. Acoustic measurements made on research cruises in 1973 showed large aggregations of fish and ground-truthing via midwater trawls revealed small quantities of jack mackerel, maray and sardine (Gorman and Graham 1979).

2.5 Stock assessment methods

Mackerel remain a significant component of the fisheries of the Atlantic Ocean despite large declines in catches since the 1970's (Ward *et al.* 2001). Similarly, the mackerel fisheries in the Pacific Ocean and China Sea remain large despite being widely regarded as recruitment and growth overfished (Ward *et al.* 2001). A wide variety of stock assessment techniques, including virtual population assessments (VPA), acoustic techniques, egg production methods and age-structured models, have been used to estimate the biomass of mackerel with varying, and often limited, levels of success (Ward *et al.* 2001).

Catch-per-unit-effort (CPUE) data from commercial fisheries has commonly been used as an indicator of biomass in the Atlantic and chub mackerel fisheries. Using CPUE as an index of stock abundance is inexpensive because data can be obtained directly from the fishery. However, CPUE data provide few insights into the status of pelagic fish stocks. CPUE is affected by many factors other than abundance (Maunder *et al.* 2006). For example, CPUE is not used as an index of stock abundance in the north-eastern Atlantic mackerel fishery because catch rates are known to fluctuate between locations and years and relate more to changes in fish distribution and fishing power than to variations in fish abundance (DFO 2000).

Virtual population assessments (VPAs) use age information to relate the present total biomass of a fish population to the previous biomass. These models require long-term and ideally continuous catch-at-age/length data. Sampling programs to collect catch at age information can be logistically and financially difficult to maintain. The dependence of these techniques on relatively long data series precludes the use of these models in developing fisheries. Outputs can be subject to error associated with difficulties obtaining representative samples of the age distribution (Rogers and Ward 2007) and difficulties interpreting age from otoliths (Stewart and Ferrell 2001b). Virtual population models are increasingly being replaced by integrated stock assessment models that utilise information obtained from a range of sources to estimate biomass.

Aerial surveys are used in New Zealand to provide information on the relative abundance of *S. australasicus* (Taylor 2002). Similarly, mid-water trawl and drift net surveys are used to provide information on the relative abundance of *S. japonicus* off Japan. The major problem with most surveys techniques is that data cannot readily be converted into estimates of population size. Aerial surveys have the additional constraint of accurate species identification, which can be problematic in locations where the pelagic fish community is diverse. Relative abundance from

surveys is used to tune VPAs for the Japanese mackerel fishery. One of the best uses of survey data is as an index of relative abundance in integrated stock assessment models.

Considerable information has been published on the use and application of acoustic surveys in stock assessment (Thorne 1983; Hedgepeth *et al.* 1996). Techniques for estimating biomass have improved significantly over the last 20 years. The main advantage of biomass estimates obtained from acoustic surveys is that they can be absolute. However, experience in the South African anchovy fishery suggests that estimates of population size are precise, but negatively biased (Cochrane *et al.* 1998). The main disadvantages of acoustic surveys are the relatively high initial costs, long developmental period, poor species discrimination, high data complexity and significant potential biases associated with estimation of target strength (Thorne 1983). Although stocks of Atlantic mackerel are considered to be amenable to acoustic surveys, abundance estimates obtained using acoustic methods have not yet been incorporated into fishery assessments (ICES 2002). In Australia, acoustic techniques have been used since the early 1950s to describe the distribution and abundance of pelagic fishes, however no quantitative data are available for *S. australasicus* (Rapson 1953; Blackburn and Downie 1955; Wolfe 1970; Wolfe 1971; Stevens *et al.* 1984).

Over the last two decades research agencies in Europe, Japan and Canada have used egg-based stock assessment methods for mackerels (Ward *et al.* 2001). Egg based assessments are considered to be accurate but relatively imprecise and provide absolute estimates of abundance that can be used to make decisions regarding the potential exploitation rates of unexploited stocks (Parker 1980; Lasker 1985). The main advantages of egg-based methods are that biomass estimates can be provided from a single cruise. Surveys can also be conducted in conjunction with other application methods (eg acoustics) to enhance the precision. The main disadvantages of egg-based methods are associated with the logistical difficulties of conducting ichthyoplankton and adult surveys, and the high levels of imprecision associated with estimates of individual parameters and spawning biomass (Stratoudakis *et al.* 2006).

Modern age structured stock assessment models are useful for pelagic fisheries as they can integrate data from a variety of sources, including catch and fishery independent surveys. The major limitation to their application for pelagic fishes is linked to difficulties obtaining representative samples of the age distribution (Rogers and Ward 2007) and interpreting age from otoliths (Stewart and Ferrell 2001b).

2.6 Discussion

Existing survey data on the pelagic fish resources of southern Australia provide minimal information about population size. The review by Maxwell (1981) concluded that occasional sightings of large aggregations of mackerels in the GAB, and elsewhere, should be treated with caution, as these species are characterized by large spatial and seasonal fluctuations in abundance.

The small size of the existing fisheries for *S. australasicus* in southern Australia also provides minimal information about the biological potential of these stocks. Currently, the development of these fisheries is limited by lack of demand for mackerel products and uncertainty about stock size and fishery potential. The absence of fisheries data also limits the types of methods that can be used to determine the size of the Australian populations of *S. australasicus*. Information on relative abundance from trawl surveys or aerial surveys would only be useful if an extended time series of data could be established, which is unlikely to occur in the absence of significant fisheries.

The only viable options for obtaining estimates of the absolute abundance of *S. australasicus* in Australia are to conduct acoustic or egg-based surveys. Acoustic surveys are not currently used by any Australian research agency for the assessment of pelagic fishes, whereas egg based techniques have been used successfully in the assessment of sardine off Western Australia, South Australia and southern Queensland. Data from the egg-based surveys for sardine in these jurisdictions have on some occasions been incorporated into integrated stock assessment models. Additional age and growth information would allow the use of this integrated approach to be assessed for *S. australasicus*.

2.7 Acknowledgements

We thank Dr Patrick Coutin (PIRVic), Dr Daniel Gaughan and Mr Timothy Leary (WA Fisheries), Ms Daniel Williams (NSW Fisheries), Dr Jeremy Lyle (TAFI), Mr John Garvey (AFMA), Ms Selina Stoute (AFMA) and Leonard Olyott (QDPI) for providing catch and effort datasets for fisheries in their jurisdictions, and for advice pertaining to data publication. Thanks to Cameron Dixon (SARDI) and Dr Adrian Linnane (SARDI) for comments on drafts of the chapter.

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3. Techniques for discriminating stocks of blue mackerel *Scomber australasicus*

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Objectives: To describe the stock structure of *S. australasicus* in south-eastern Australia.

Summary: This chapter assesses the suitability of genetic approaches, parasitology and otolith microchemistry for determining the stock structure of *S. australasicus* across the range of its distribution in Australian and New Zealand waters and establishes protocols for using these techniques to determine variability within and among putative stocks. Seventy-five fish from three locations in Australian waters (SE Queensland, South Australia and SE Western Australia) and one location in New Zealand were examined. Genetics and parasite assemblage were analysed for all fish; otolith microchemistry of Australian fish was also examined. Techniques were successfully developed to extract and amplify a segment of the mtDNA control region, and results showed significant genetic heterogeneity among fish from Western Australia, Queensland and New Zealand. Parasite analysis identified several taxa that are suitable for use as biological tags and enabled discrimination of fish collected from the four locations. Studies of otolith microchemistry using LA-ICP-MS had sufficient power to distinguish fish from the three Australian locations. This study suggests that there are multiple stocks of *S. australasicus* within Australian waters, proposes protocols for future studies of finer scale stock structure, and discusses the efficacy of each technique for stock discrimination.

3.1 Introduction

Knowledge of stock structure is critical for the management of pelagic fisheries (Ihssen *et al.* 1981). Different stocks of pelagic fishes, such as sardine (Gaughan *et al.* 2002), horse mackerel (Abaunza *et al.* 2003) Atlantic herring (Ruzzante *et al.* 2006) and Atlantic mackerel (Villamor *et al.* 2004), often have distinct biological characteristics (e.g. abundance, fecundity, recruitment, growth rate, mortality) that affect their responses to fishing pressure. Managing multiple stocks on the basis of stock assessments that do not consider stock structure can lead to localised depletion. For example, the Californian sardine fishery in the middle of last century did not account for four separate stocks, resulting in the sequential collapse of stocks from north to south, and eventual collapse of the entire fishery (Radovich 1982). The North Sea herring fishery comprises several seasonally mixing spawning stocks that are managed as one unit. Overfishing in the 1970s led to the collapse of the fishery and in the subsequent recovery, some stocks failed to return to their spawning grounds (Corten 2001).

A range of techniques have been used, with varying success, for stock discrimination of pelagic fishes (Ihssen *et al.* 1981; Pawson and Jennings 1996; Begg and Waldman 1999; Cadrin *et al.* 2004). The combination of two or more stock discrimination techniques, preferably for the same samples, has been termed a "holistic approach" (Begg and Waldman 1999) and can increase the likelihood of discerning stock structure. Although the value of using several stock discrimination techniques has been emphasised repeatedly, this approach has been applied to only a few species, including Spanish mackerel, *Scomberomorus commerson* (Moore *et al.* 2003; Newman *et al.* 2006; Ovenden and Street 2006) and horse mackerel, *Trachurus trachurus* (Abaunza *et al.* 2003; Karaiskou *et al.* 2004; MacKenzie *et al.* 2004).

In both the *S. commerson* and *T. trachurus* studies, parasite assemblages, genetics and otolith microchemistry were used for stock discrimination. These techniques provide information at varying temporal scales. In doing so, these techniques can be used to discriminate stocks based on the definition of a stock proposed by Ihssen *et al.* (1981): an intraspecific group of randomly mating individuals with temporal or spatial integrity.

Genetics provides stock structure information at an evolutionary timescale. Genetic spatial heterogeneity indicates group integrity over large time scales, but due to the inherited nature of genetic markers, only a small level of mixing is required to prevent population heterogeneity. Analysis of mtDNA provides stock resolution at higher levels of geneflow than other genetic

methods. This has enabled genetic approaches for investigating the population structure of many marine fish species (Ovenden 1990) including highly mobile species such as *Scomber* (Nesbo *et al.* 2000). Changes in the nucleotide sequence of mtDNA accumulate at the population or stock level and are regulated by evolutionary forces, such as genetic drift, migration, mutation and selection (Stepien 1995). The mtDNA 'control' or 'D-loop' region promises to be one of the most useful genetic markers. Properties that make it useful for stock structure studies include high sequence variability, protein non-coding, selective neutrality and random accumulation of mutations (Stepien 1995). Failure to detect genetic stock structure may be explained by other hypotheses such as recent stock separation or contemporary geneflow. In this instance, alternative stock discrimination techniques may be more effective according to the required outcomes of the stock analysis.

Parasite assemblages can provide information about the past location and movement of the host fish over a timescale ranging from days to years, depending upon the biology and distribution of the parasite species studied. The principle underpinning the use of parasites for stock discrimination is that fish from different regions may harbour different parasite assemblages and analysis of these assemblages can be used to define different stocks (Lester 1990; MacKenzie and Abaunza 1998; MacKenzie 2002). The utility of parasite species for stock discrimination is directed by several general criteria, the most desirable of which are: 1) parasites should have significantly different levels of infection in the different locations sampled; 2) parasites should persist in the host for a sufficient period of time; 3) parasites with single-host life-cycles should be preferred over complex life-cycles; 4) infection levels should be constant over time; 5) parasites should be easily detected, removed and identified; and 6) parasites that affect the behaviour of the fish should be avoided, especially if that behaviour increases the catchability of the fish (MacKenzie and Abaunza 1998).

Otoliths provide a permanent record of individual growth and aspects of the physical and chemical environment encountered by a fish over its entire life. Variation in water chemistry among locations results in different otolith composition which can be used to distinguish stocks (Campana 1999; Campana and Thorrold 2001). Spatial heterogeneity in otolith microchemistry data can be investigated in relation to life-history providing information about the temporal integrity of a stock over the lifetime of the fish. The analysis of chemical composition of otoliths, or otolith microchemistry, is based on three general assumptions about the nature of otoliths: 1) Otolith material is not subject to dissolution or resorption once it has been laid down on the

otolith surface; 2), the trace element uptake of otoliths reflects the chemical and physical environment (Campana *et al.* 2000); and 3), otolith composition is stable on removal and storage, and is not contaminated during storage or analysis (Thresher 1999).

S. australasicus is distributed anti-tropically in the Pacific Ocean, the south-eastern Indian Ocean and the Red Sea (Collette 1999). *S. australasicus* is an epi-pelagic, neritic species that schools by size (Collette and Nauen 1983) and is an important component of pelagic ecosystems off southern and eastern Australia. Recent moves to expand the commercial fishery in Australia have been constrained by a justifiably precautionary approach to management of the resource in the absence of information about stock size, distribution and structure.

The stock structure of *S. australasicus* in Australasian waters is uncertain. One study found significant differences between Australia and New Zealand in the morphology of monogenean parasites (Rohde 1987). However, Scoles *et al.* (1998) found no genetic differences between *S. australasicus* from Australia and New Zealand using mtDNA RFLP analysis and cytochrome b sequencing, despite identifying distinct North and South Pacific populations and a discrete Red Sea population. However, the methods used and sample sizes of Scoles *et al.* (1998) may not have been suitable for distinguishing between these populations.

There is no information on the stock structure of *S. australasicus* in Australian waters. As several oceanographic factors, such as Bass Strait, the East Australia Current, the Flinders Current and the Leeuwin Current, may influence the distribution and movement patterns of *S. australasicus* (Godfrey *et al.* 1980; Middleton and Cirano 2002; Cresswell and Griffin 2004), there is significant potential for structure within the Australian population. Such structure has significant implications for the management of *S. australasicus* in Australia, and warrants investigation.

This study had the following three aims. (1) To conduct a preliminary assessment of the potential level of stock structure of *S. australasicus* in Australasia. (2) To establish specific protocols for the use of each technique in a detailed future study of the stock structure of *S. australasicus* in Australasia. These protocols will involve recommendations regarding sample sizes based on power analysis (Peterman 1990), which are critical for ensuring that type-two errors are avoided in stock discrimination studies (Mapstone 1995). (3) To assess the efficacy of genetic approaches, parasitology and otolith microchemistry for investigating *S. australasicus* stock structure in Australasia.

3.2 Materials and Methods

Samples were collected between June and November 2003 at three locations within Australia, which were selected to comprise the widest distribution of *S. australasicus* as possible (Fig. 3.1). Twenty fish from Cape Moreton in SE Queensland (Qld) and 19 fish from Gulf St. Vincent in South Australia (SA) were line caught, while 23 fish from Fremantle in Western Australia (WA) and 13 fish from the north of New Zealand (NZ) were captured by purse seine. All fish were frozen as soon as possible after capture, then transported to Adelaide, Australia, for processing. In the laboratory, each fish was defrosted, then the length, weight, sex, gonad development and mature gonad weight of each fish was recorded. The gills and viscera were removed for further examination for parasites. Unless otherwise stated, all statistical analyses were performed using SPSS v.13.0.

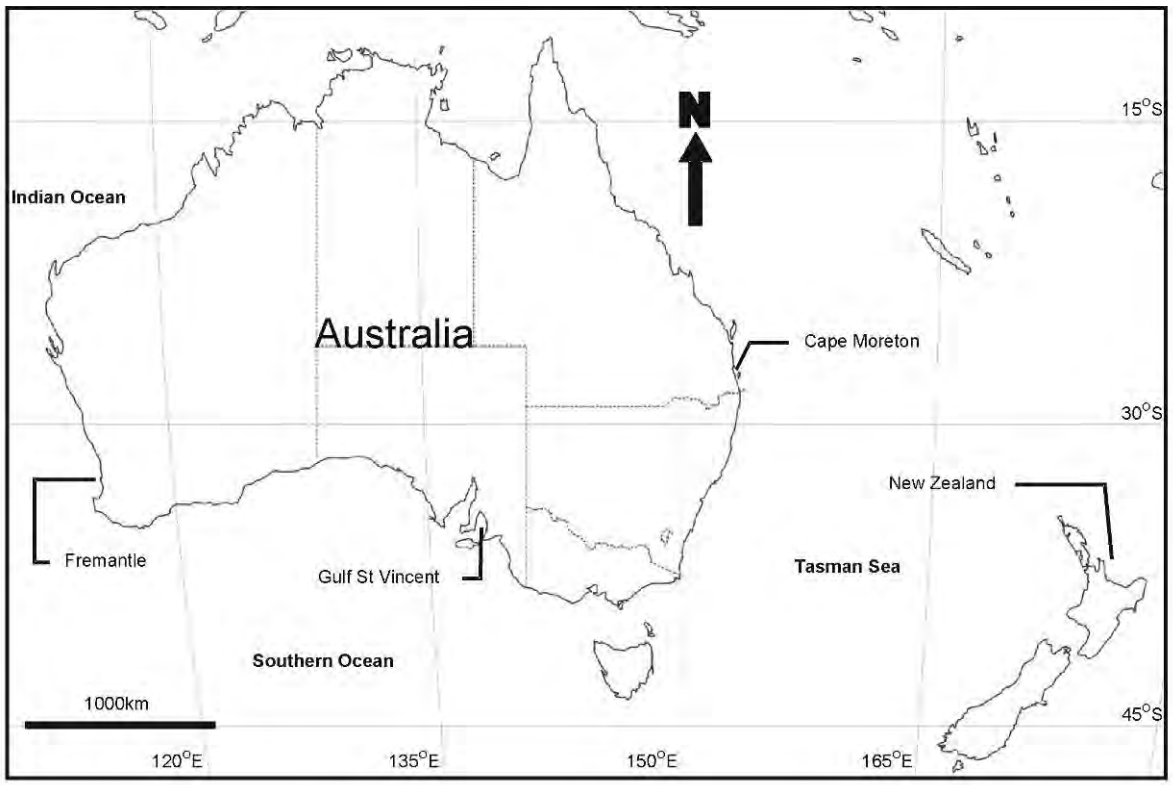


Figure 3.1. Collection locations of *S. australasicus* samples in Australia and New Zealand.

3.2.1 Genetic analysis

Raw DNA was extracted from muscle tissue samples stored in 10% DMSO. Several methods of extraction were used, but the most practical was a modified salting out method (Miller *et al.* 1988). For Australian fish, a segment of mtDNA was amplified using a PCR protocol (Ovenden *et al.* 2002) and primers Pro889U20 (CCW CTA ACT CCC AAA GCT AG) and TDKD1291L21 (CCT GAA ATA GGA ACC AAA TGC) designed to amplify approximately 375 bp of the left domain of *Scomberomorus commerson* mtDNA control region (Ovenden and Street 2006). The PCR products were purified then sequenced using forward and reverse primers. Sequences were obtained with an ABI automated sequencer using the chain-termination method with BigDye® terminators. New Zealand fish were extracted using a Gentra™ Puregene™ DNA purification protocol. The PCR conditions were: 50–100 ng of DNA, 0.1 μM of each primer, 200 μM of each dNTP, Finnzymes Dynazyme™ buffer equivalent to 1.5 μM $MgCl_2$, and 0.5U of DyNAzyme™ EXT DNA Polymerase in a reaction volume of 25 μl. PCR cycling conditions on an Eppendorf Thermal Cycler were: 94°C for 2 min followed by 35 cycles of 45 s at 94°C, 45 s at 48° and 1 min at 72°C with a final extension of 72°C for 6 min. PCR products were purified then sequenced using the forward primer.

Sequences were edited using Bioedit v5.0.9 (Hall 1999), aligned using Clustal X v1.83 (Thompson *et al.* 1997) and compared by analysis of molecular variance (AMOVA) using Arlequin v2.0 (Schneider *et al.* 2000). To determine the sample size required for a future stock discrimination study, the binomial sampling equation was calculated with 95% confidence using the minimum observed haplotype frequency (Bartley *et al.* 1995).

3.2.2 Parasite analysis

Each fish was examined thoroughly for parasites. The skin, gills and oral surfaces were examined for ectoparasites under a dissecting microscope. The stomach, pyloric caeca and intestine were opened longitudinally and washed with saline solution. Parasites were removed, sorted under a dissecting microscope to the lowest taxonomic group possible and by their location on the fish, and preserved according to the conventions of Pritchard and Kruse (1982). Parasite material collected in this study is deposited in the Australian Helminth Collection (AHC) and the Marine Invertebrate Collection (C) at the South Australian Museum. The measures of parasite infection used in this study were prevalence (the number of fish in each sample infected by each parasite species) and abundance (the average number of parasites per fish in each sample) as defined by Bush *et al.* (1997). Conventional multivariate analyses usually require normally distributed data,

but the distribution of abundance data was non-normal in this study. Typically, there were two common features of parasite distribution: a large component in the zero category and a negative binomial distribution. To bring the distribution of parasite abundance closer to normality, it was transformed by the natural logarithm plus one. Due to instances of parasites being absent from all fish in some areas, an insignificant random number (between –0.005 and 0.005) was added to each count enabling matrix inversion in discriminant function analyses (DFA) (Lester *et al.* 1985). The results of the DFA were displayed graphically as plots of the first versus second canonical discriminant functions. Confidence limits (95%) were represented by circles around the group centroids with radius $\sqrt{5.99/\underline{n}}$, where 5.99 is the critical value in a χ^2 test where $\alpha = 0.05$, d.f. = 2 and n = sample size (Mardia *et al.* 1979). Classification rates of the discriminant functions were calculated based on group classification. Multivariate analyses of prevalence data were performed using hierarchical cluster analyses displayed graphically as dendrograms. Estimates of power were calculated for univariate and multivariate data using multivariate analysis of variance (MANOVA).

3.2.3 Otolith microchemistry

The sagittal otoliths were dissected with adhering tissue removed. They were rinsed in Milli-Q™ water and placed in a sterile plastic multi-well plate. Otoliths were embedded in Struers Epofix™ resin and transversely sectioned through the nucleus of the otolith to a thickness of 1-1.5 mm using a Buehler Isomet™ low-speed diamond saw. Otolith sections were hand-polished with 10 and 3 μm lapping film lubricated with Milli-Q water. Polished otolith sections were mounted on glass slides with Crystalbond™ Thermoplastic adhesive (28 per slide in two rows of 14 sections). Slide-mounted otoliths were ultrasonicated in Milli-Q water for 5 minutes. These slides were air-dried and stored in clean individual zip-lock bags.

The laser ablation ICP-MS (LA-ICP-MS) system was used as described by McCulloch *et al.* (2005). To remove potential surface contaminants, a transect along each otolith was pre-ablated by laser using a 180 μm diameter spot. Several otoliths were spot-analysed to screen for detectable elements. These elements were manganese (Mn), calcium (Ca), magnesium (Mg), rubidium (Rb), strontium (Sr), barium (Ba) and lead (Pb).

Otoliths were analysed in series of seven at a time. Two reference standards (a powdered coral standard and NIST 614 (National Institute of Standards and Technology; Gaithersburg, MD, USA)) were measured before and after every seven otoliths to correct for instrument drift. Each

otolith was ablated along a continuous transect from ventral to dorsal edge using a 22 μm diameter laser spot pulsing at 50 Hz and a scan rate of 0.6 $mm.min^{-1}$. Between each otolith ablation, the system was allowed to return to background levels. Each otolith transect was standardised by subtracting background readings and correcting against the NIST 614 reference standard. The readings were then transformed into a ratio to calcium, and smoothed using a 10 point running median and an 11 point running mean to remove spiked outputs. Readings for each of the elements analysed were averaged from a transect length of 100 μm at the edge of the otolith and from another transect length of 100 μm located across the core of the otolith. These two measures were used to compare fish from different regions. Sample statistics were analysed using univariate and multivariate data, from which power was calculated. Multivariate data was analysed using the same statistical methods as the parasite abundance data. Discriminant functions were plotted with 95% confidence intervals and classification rates were calculated. In order to determine whether juvenile fish had developed in different water bodies, elemental composition at the core of the otolith was analysed by hierarchical cluster analysis and presented as a dendrogram.

3.3 Results

3.3.1 Genetic analysis

A 345 bp region at the 5' end of the mtDNA D-loop was examined. Complete high quality sequences were obtained from 14 Qld fish, 23 WA fish and 13 NZ fish. DNA from the SA sample was degraded and unsuitable for further analyses. Queensland fish had 11 different haplotypes with 27 polymorphic sites, a haplotype diversity of 0.956 ± 0.045 and nucleotide diversity of 0.029 ± 0.016. Western Australian fish had 21 different haplotypes with 42 polymorphic sites, haplotype diversity of 0.992 ± 0.015 and nucleotide diversity of 0.028 ± 0.015. New Zealand fish had 10 different haplotypes with 34 polymorphic sites, haplotype diversity of 0.961 ± 0.041 and nucleotide diversity of 0.027 ± 0.015. A comparison of sequence data using AMOVA showed a significant difference between these populations (F_{ST} = 0.0898, p = 0.00684). Pairwise differences showed that the WA population was significantly different from both the Qld and NZ populations (F_{ST} = 0.0915, p = 0.0198 and F_{ST} = 0.1389, p = 0.003), but the Qld population was not significantly different from the NZ population (F_{ST} = -0.0063, p = 0.3722). The least common haplotypes had a frequency of 2.7%. Binomial sampling theory (Bartley *et al.* 1995) was used to estimate the sample size required to draw each unique haplotype from the entire population with 95% confidence. This was calculated as a total sample size of at least 55 specimens.

3.3.2 Parasite analysis

Thirty-one parasite species were identified: 15 digenean, 2 nematode, 2 acanthocephalan, 4 cestode, 4 monogenean, 2 isopod and 2 copepod species (Table 3.1). The prevalence of parasites ranged from 1 to 96%. Of these parasites, 16 species were prevalent enough (>10%) for comparison of populations (Bush *et al.* 1990). The first two transformed parasite abundance canonical discriminant functions allowed 97.5% of the samples to be assigned to their capture location (Table 3.2). The overall correct assignment rate was 95.3%, with 100, 90, 84.2 and 100% of fish from NZ, Qld, SA and WA correctly classified, respectively. The plot of the first two canonical discriminant functions shows the high level of differentiation between locations (Fig. 3.2). Fish from NZ were strongly differentiated from Australian fish by the first discriminant function. Australian fish were differentiated along the second discriminant function.

Table 3.1. Prevalence (P) and abundance (A) of parasites from *S. australasicus* sampled at four locations in 2003.

Parasite group	Parasite species	Total (n=75) P (%)	A (± S.E.)
Isopoda	*Ceratothoa imbricata*	12	0.37 ± 0.13
	Nerocila macleayi	1	0.01 ± 0.01
Trematoda	*Lecithocladium sp.*	77	21.16 ± 3.56
	Hemiurid sp.	13	0.63 ± 0.28
	Dinuris sp.	1	0.57 ± 0.57
	Opechona sp.1	32	18.52 ± 6.39
	Opechona sp.2	3	0.49 ± 0.48
	Allocreadid sp.1	59	14.27 ± 3.74
	Allocreadid sp.2	16	0.33 ± 0.11
	Allocreadid sp.3	1	0.08 ± 0.08
	Nematobothrid type 1	8	0.61 ± 0.46
	Nematobothrid type 2	17	1.31 ± 0.48
	Nematobothrid type 3	29	2.75 ± 1.13
	Nematobothrid type 4	29	2.91 ± 0.73
	Didymocystis sp.1	5	0.16 ± 0.08
	Didymocystis sp.2	1	0.03 ± 0.03
	Neodiplotrema sp.	15	0.25 ± 0.08
Copepoda	*Clavellisa scombri*	19	0.27 ± 0.09
	Caligus sp.1	4	0.04 ± 0.02
Monogenea	*Kuhnia scombri*	31	1.97 ± 0.64
	Kuhnia scombercolias	9	0.15 ± 0.06
	Pseudokuhnia minor	15	0.77 ± 0.33
	Grubea australis	4	0.05 ± 0.03
Cestoda	Trypanorynch metacestode type 1	5	0.09 ± 0.05
	Trypanorynch metacestode type 2	1	0.03 ± 0.03
	Tetraphyllid metacestode type 1	1	0.01 ± 0.01
	Cestode scolex polymorphous type 1	3	0.49 ± 0.41
Acanthocephala	*Rhadinorhynchus sp.1*	15	0.25 ± 0.10
	Rhadinorhynchus sp.2	16	0.69 ± 0.21
Nematoda	Ascarid nematodes[1]	96	20.60 ± 3.36

[1] *Hysterothylacium* sp. and *Contracaecum* sp.

Table 3.2. Results of discriminant function analysis of *S. australasicus* samples from Australia and New Zealand with standardised coefficients of the first and second canonical discriminant functions for transformed parasite abundances. Parasite species with prevalence below 10% were excluded from these analyses.

	Function 1	Function 2
Eigenvalue	16.575	4.511
% of Variance	76.6	20.9
Canonical Correlation	0.971	0.905
Parasite species		
Ceratothoa imbricata	-0.149	-0.163
Lecithocladium sp.	-0.538	-0.559
Opechona sp. 1	-0.090	-0.358
Allocreadid sp. 1	-0.061	0.129
Hemiurid sp.	-0.008	0.297
Allocreadid sp. 2	0.111	0.312
Nematobothrid type 2	0.011	0.226
Nematobothrid type 3	-0.085	0.143
Nematobothrid type 4	0.014	0.693
Neodiplotrema sp.	0.582	-0.331
Clavellisa scombri	0.125	0.051
Kuhnia scombri	-0.049	-0.411
Kuhnia scombercolias	0.213	0.094
Pseudokuhnia minor	0.000	0.349
Rhadinorhynchus sp. 1	0.004	0.049
Rhadinorhynchus sp. 2	0.832	-0.293
Ascarid nematodes	-0.310	-0.172

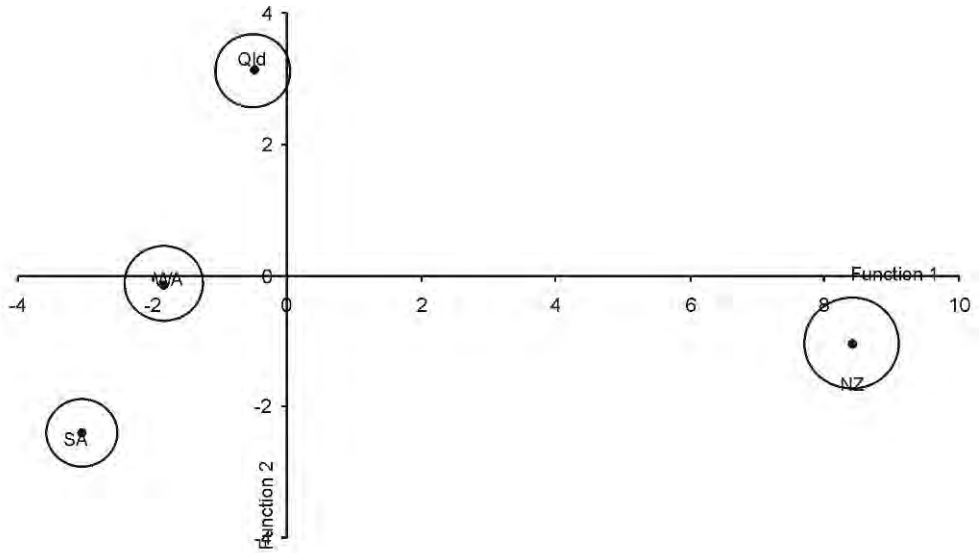
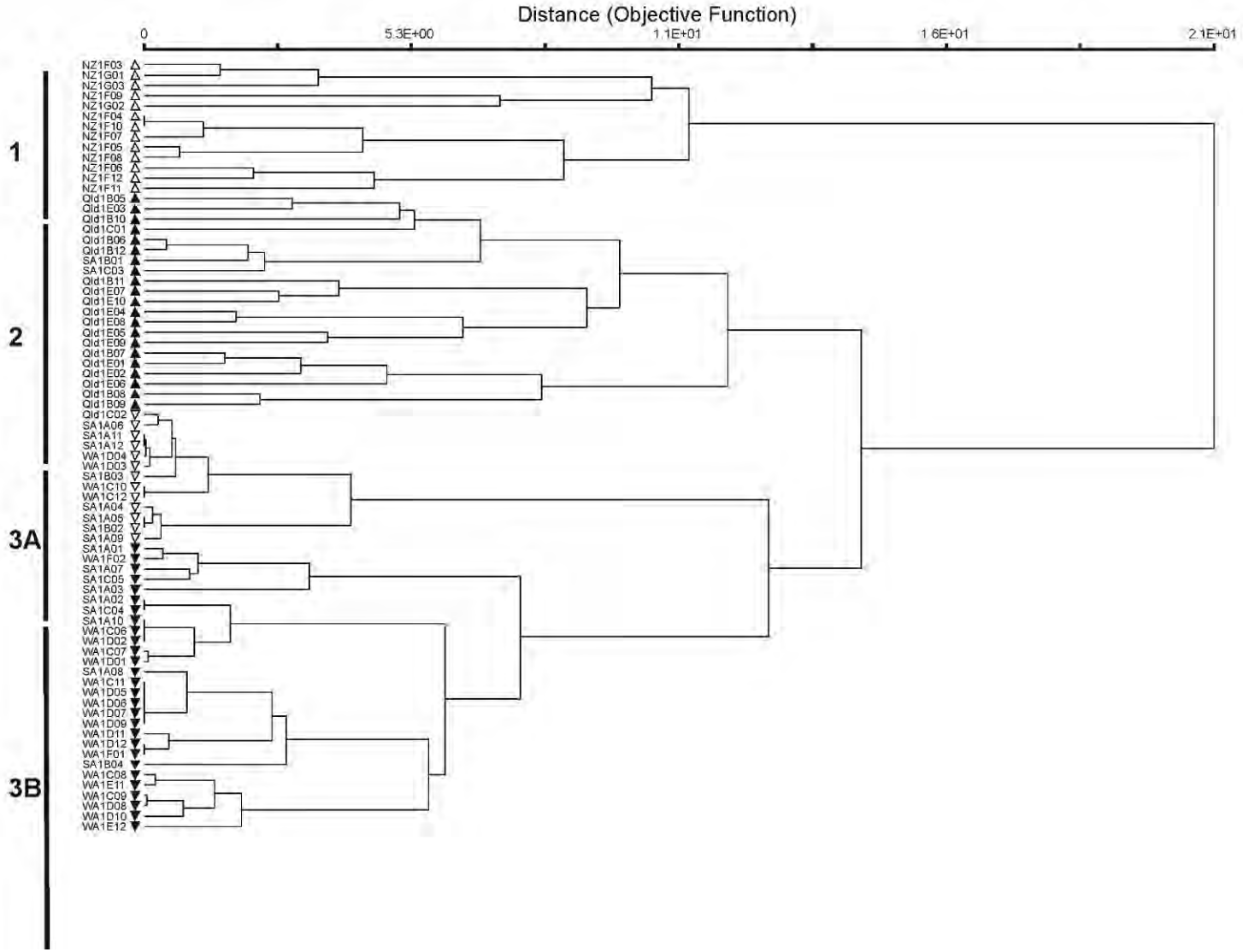


Figure 3.2. Results of DFA of parasite abundance plotting the first two functions at group centroids with 95% confidence rings.

Hierarchical cluster analyses of parasite prevalence data (Fig. 3.3) showed three distinct clusters: one containing only NZ fish (1), another containing 19 Qld fish with two SA fish (2), and the last containing one Qld, 17 SA and 23 WA fish (3A and 3B). The last cluster was broken down into two further clusters: one small cluster containing one Qld, eight SA and four WA fish (3A); and another cluster containing 19 WA fish and nine SA fish (3B). Cluster analyses used parasite prevalence data, which is based on the presence or absence of a parasite species on each fish. This approach eliminates the effect of environmental or stochastic effects that may bias abundance or infection intensity measures. Cluster analysis suggests that there may be a large amount of exchange between WA and SA populations, a small amount of exchange between Qld and SA fish and a very small exchange of fish between WA and Qld fish. It also suggests that there is no exchange of fish between Australia and NZ.

Figure 3.3. Hierarchical cluster analysis dendrogram using parasite prevalence data. Triangles indicate clusters assigned to groups. Labels indicate fish identity and location.



Results from MANOVA showed a statistically significant difference between populations of fish collected across Australasia (Wilk's $\lambda = 0.024$, $F = 7.848$, d.f.= 51, $P<0.001$), and a dataset with a high degree of power (>0.99 at $\alpha = 0.05$). Univariate data confirmed these results with a majority of the parasites having a high degree of power to discriminate populations (Table 3.3). Results of power analyses indicate that sample sizes in this study are sufficient for further stock structure study.

Table 3.3. Results of univariate analyses of parasite abundance from *S. australasicus* collected from Australian and New Zealand waters with observed statistical power at $\alpha=0.05$.

Parasite species	F	d.f.	P	Observed Power
Ceratothoa imbricata	10.347	3	<0.001	0.998
Lecithocladium sp.	66.401	3	<0.001	>0.999
Opechona sp. 1	3.038	3	0.035	0.690
Allocreadid sp. 1	.195	3	0.900	0.085
Hemiurid sp.	3.986	3	0.011	0.816
Allocreadid sp. 2	9.294	3	<0.001	0.995
Nematobothrid type 2	4.567	3	0.006	0.869
Nematobothrid type 3	3.475	3	0.020	0.754
Nematobothrid type 4	24.137	3	<0.001	>0.999
Neodiplotrema sp.	13.399	3	<0.001	>0.999
Clavellisa scombri	.751	3	0.525	0.203
Kuhnia scombri	4.202	3	0.009	0.837
Kuhnia scombercolias	8.511	3	<0.001	0.992
Pseudokuhnia minor	3.634	3	0.017	0.775
Rhadinorhynchus sp. 1	6.179	3	0.001	0.954
Rhadinorhynchus sp. 2	21.058	3	<0.001	>0.999
Ascarid nematodes	5.724	3	0.001	0.938

3.3.3 Otolith Microchemistry

Otoliths from 19 Qld fish, 18 SA fish and 23 WA fish were sampled for the elements Mn, Ca, Mg, Rb, Sr, Ba and Pb.

The first and second canonical discriminant functions of element concentrations from the core of the otolith contributed 100% to the classification of samples (Table 3.4). The overall correct classification rate was 68.3%, with 63.2, 77.8 and 65.2% of fish from Qld, SA and WA correctly classified. The plot of the two canonical discriminant functions from the otolith core shows that

each location is significantly differentiated from the other locations (Fig. 3.4). SA fish were discriminated from Qld fish along the second discriminant function, with Mg and Mn contributing most to this result (Table 3.4). The first and second canonical discriminant functions of element concentrations from the edge of the otolith contributed 100% to the classification of samples (Table 3.4). The overall correct classification rate was 76.7%, with 73.7, 77.8 and 78.3% of fish from Qld, SA and WA correctly classified. The plot of the two canonical discriminant functions from the otolith edge shows significant differentiation of WA fish from SA and Qld fish, but does show some overlap in confidence intervals for SA and Qld fish (Fig. 3.5). WA fish were discriminated from SA and Qld fish along the first discriminant function, with Ba contributing most to this result (Table 3.4).

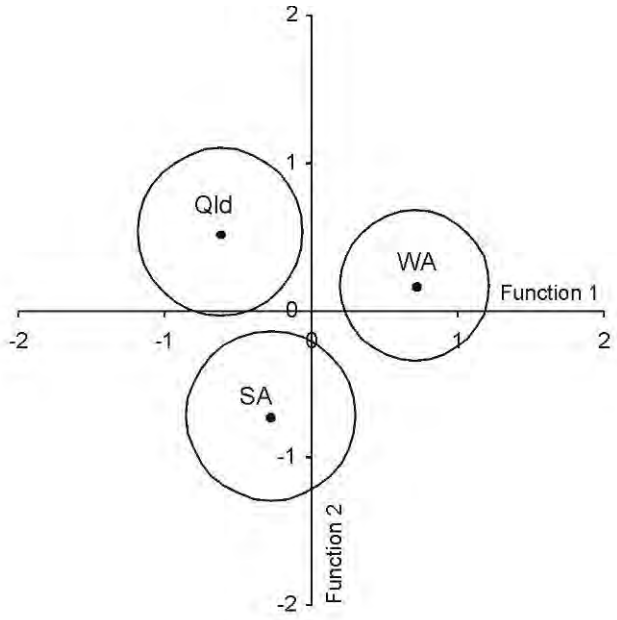


Figure 3.4. Results of DFA of elemental composition from the core of the otolith plotting the two functions at group centroids with 95% confidence rings.

Table 3.4. Results of discriminant function analysis of *S. australasicus* samples from WA, SA and Qld with standardized coefficients of the first and second canonical discriminant functions for trace element concentrations at the core and edge.

	Core		**Edge**	
	Function 1	**Function 2**	**Function 1**	**Function 2**
Eigenvalue	0.361	0.267	0.992	0.117
% of Variance	57.5	42.5	89.5	10.5
Canonical Correlation	0.515	0.459	0.705	0.324
Element				
Mg	0.368	0.700	0.375	-0.387
Mn	-0.571	0.730	-0.807	0.373
Rb	0.077	0.322	0.268	0.653
Sr	0.407	-0.342	-0.267	0.427
Ba	0.699	0.261	0.897	0.127
Pb	0.147	-0.600	0.024	-0.504

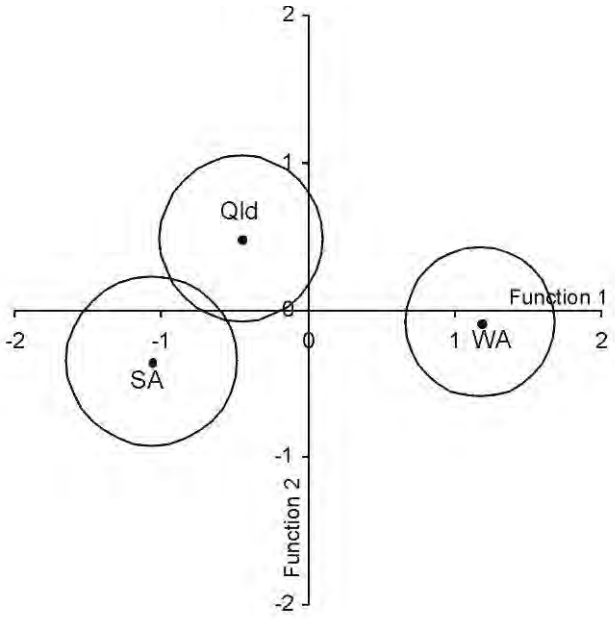


Figure 3.5. Results of DFA of elemental composition from the edge of the otolith plotting the two functions at group centroids with 95% confidence rings.

A similar pattern is illustrated by hierarchical cluster analyses (Fig. 3.6). Based on otolith-core element concentration, most fish were assigned to their capture location, a small number of fish were assigned to their closest neighbouring sample region, but none was assigned to their farthest neighbouring sample region. Cluster analysis and DFA of otolith-core element concentration indicate that most fish originated in the same location as the fish that they were captured with, but a small number possibly originated in other locations. Results from otolith-edge element concentration show that more fish were assigned to their capture location, although with slightly less confidence than otolith-core element concentration.

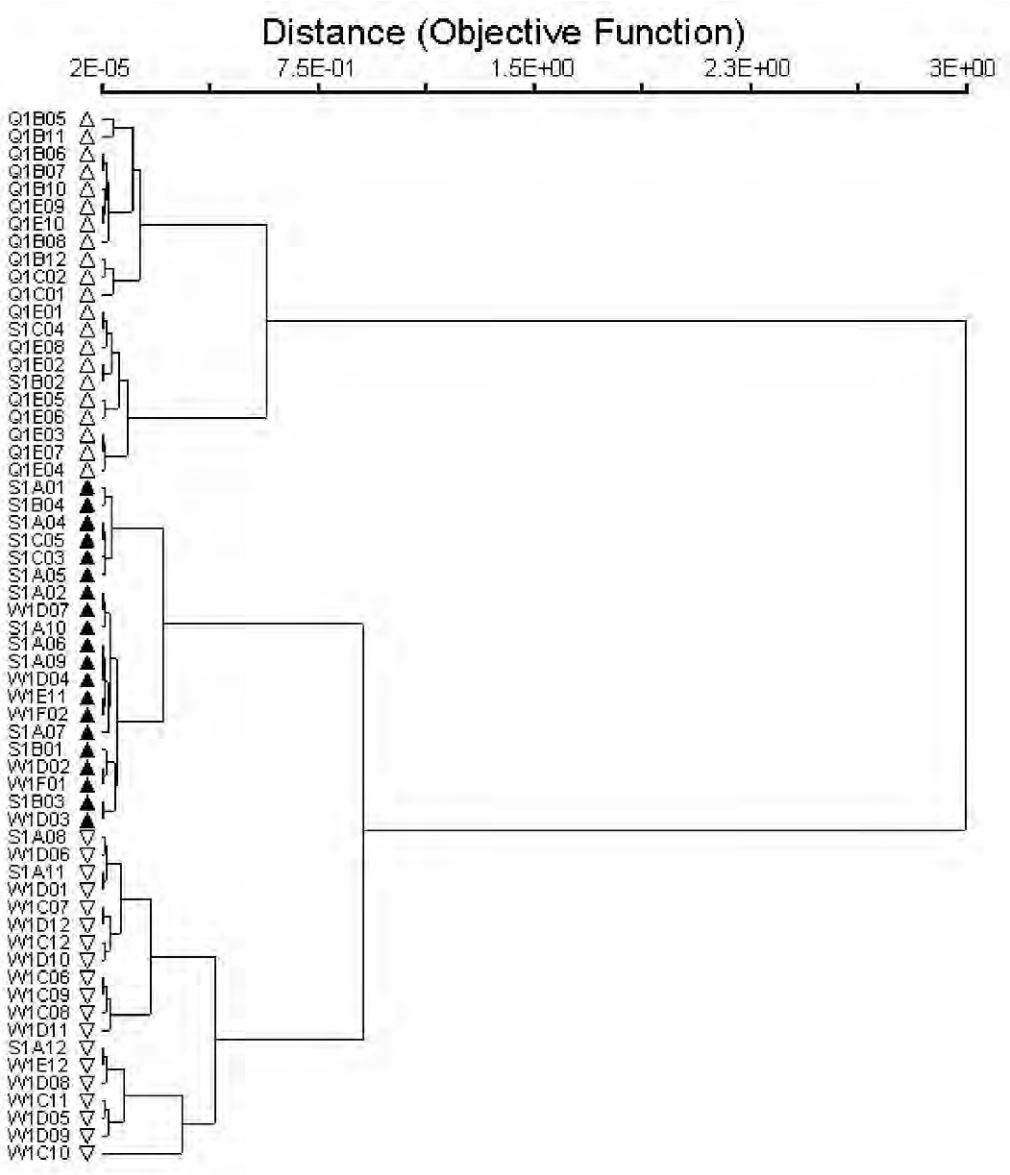


Figure 3.6. Hierarchical cluster analysis dendrogram using elemental composition from the core of the otolith. Triangles indicate clusters assigned to groups. Labels indicate fish identity and location (Q – Queensland, S – South Australia, W – Western Australia).

Results from MANOVA on otolith edge and core element concentrations show that there is a statistically significant difference between populations of fish collected across Australia (Edge: Wilk's $\lambda = 0.449$, $F = 4.264$, d.f.= 12, $P<0.001$. Core: Wilk's $\lambda = 0.58$, $F = 2.717$, d.f.= 12, $P = 0.003$), and both datasets had a high degree of power (>0.99 and 0.975 at $\alpha = 0.05$). Univariate data confirmed the importance of Ba and Mn, which were the only elements showing high (>0.8) statistical power (Table 3.5). The three elements that contributed most towards the DFA were Ba, Mn and Mg. For Mg to have high statistical power in future stock structure studies would require a sample size of at least 40 fish per location.

Table 3.5. Results of univariate analyses of element concentration at the core and edge of otoliths from *S. australasicus* collected from WA, SA and Qld waters with observed statistical power at $\alpha=0.05$.

Element		F	d.f.	P	Observed Power
Edge	Mg	1.040	2	0.360	0.223
	Mn	5.471	2	0.007	0.830
	Rb	2.464	2	0.094	0.476
	Sr	0.346	2	0.709	0.103
	Ba	12.178	2	>0.001	0.994
	Pb	0.211	2	0.810	0.081
Core	Mg	3.704	2	0.031	0.657
	Mn	2.832	2	0.067	0.535
	Rb	0.314	2	0.732	0.098
	Sr	1.148	2	0.324	0.243
	Ba	5.114	2	0.009	0.803
	Pb	1.732	2	0.186	0.349

3.4 Discussion

Each of three stock discrimination techniques used in this study detected significant variation between sample locations. This heterogeneity warrants further fine-scale stock structure analyses. Protocols were established in this study that with small modifications, will be appropriate for further fine-scale stock structure studies using the sample sizes and methods discussed below. The efficacy of each technique is assessed according to three factors: (1) the technique's capability to discriminate stocks; (2) the technique's practicality in terms of sample size and design, sample processing speed and certainty, and availability of equipment and materials; and (3), the type of information that each technique provides and whether that information is meaningful for testing stock structure within the framework of the stock concept. Each of these aims is addressed below in relation to stock discrimination method.

3.4.1 Genetic analysis

This study has identified at least two genetically different populations of *S. australasicus* in Australasian waters. There appears to be a separation between western (WA) and eastern populations (Qld and NZ), but no genetic subdivision within fish from eastern populations. Scoles *et al.* (1998) found distinct North and South Pacific populations and a discrete Red Sea population, but no difference between Australian and New Zealand populations. Their study used mtDNA RFLP analysis and cytochrome b sequencing. Both markers are less sensitive to differences between populations than control region sequences due to their slower rate of change. Additionally, their sample sizes may have been insufficient to detect differences. In contrast, Nesbo *et al.* (2000) could differentiate multiple spawning stocks in eastern Atlantic mackerel (*S. scombrus*) using control region sequences, while cytochrome b sequences only detected transatlantic differentiation. The haplotype diversity and nucleotide diversity in the present study were consistent with those found in a stock structure study of Atlantic (*S. scombrus*) and chub mackerel (*S. japonicus*) using mtDNA control region sequences (Zardoya *et al.* 2004), while the F_{ST} was higher and significant in this study.

Reliable high quality mtDNA control region sequences were obtained using the protocols developed for this study. These sequences were highly variable. Despite the fact that the F_{ST} for this *S. australasicus* population was above average for marine species (Waples 1998), and differentiated some populations, it is highly unlikely that the sample is representative of the genetic diversity within the entire population. Conclusive evidence of detailed stock composition was hindered by small and unequal sample sizes and the relatively small amount of information

contained in the short segment of mtDNA that was sequenced. Further studies should aim to confirm the stock composition by increasing the sample size, sampling more locations, increasing the length of the sequence that is amplified, and importantly, replicating samples over time (Waples 1998).

The efficacy of genetic analysis for investigating *S. australasicus* stock structure was confirmed in this study. The genetic marker employed here was able to discriminate broadly distributed stocks of *S. australasicus*. The sample sizes used in this study were sufficient to detect heterogeneity in the stock, and subsequent stock structure analyses will require only small increases in sample size and temporal and spatial replication. Compared with other techniques, genetic analyses required time-consuming and complex laboratory techniques and data processing. However, this was mitigated by the amount of information provided by molecular sequence data. Genetic stock structure indicates restricted gene flow between populations over an evolutionary timescale. There is likely to be very little interchange between stocks, and consequently if overfishing depleted one stock, other fish in the population would not replenish it. Due to the sensitivity of genetic heterogeneity to small amounts of gene-flow, this technique should be considered the most basic measure of stock structure and the minimum unit for spatial management.

3.4.2 Parasite analysis

Parasites from Australian and New Zealand *S. australasicus* are suitable for use in discriminating stocks. Using multivariate analyses, both parasite abundance and prevalence accurately predicted fish capture location. The parasites found in this study compare with those found in three previous studies of parasite assemblages of *S. australasicus*. Korotaeva (1974) found 18 species of parasite in a sample of 54 *S. australasicus*, 11 of which are likely to be in common with the present study. In a study of 15 *S. australasicus* ectoparasites, Perera (1993) found no evidence of seasonality in parasite infection intensities and very little evidence for a correlation between infection intensity and fish size. It is likely that at least 10 of those species were found in the present study. However, several parasites were only identified to genus or family. Perera found four or five types of didymozoid, which based on her descriptions, are the same as the nematobrothrid types 1-4 found in this study. Due to the difficulty in removing three of these species from the head, fins and mouth, only those infecting the gill should be considered for further studies. Using the same dataset, Hayward *et al.* (1998) concluded that the parasite assemblage for each fish is more likely to be influenced by extrinsic factors such as capture location, environmental conditions and intermediate host availability, rather than the influence of

other parasites in the host population or from other fish. This confirmed the findings of a study of over 100 species of fish, including *S. japonicus,* in which Rohde *et al.* (1995) found that parasite assemblages were influenced less by school behaviour and host size, and more by temperature. This is important because it suggests that parasite assemblage is a signature of capture location and therefore may be used to discriminate fish stock.

There have been several studies of *Scomber* spp. stock structure using parasite data, although most work has been on *S. japonicus* and *S. scombrus*. A study by Rohde (1987) found significant differences between Australian and New Zealand *S. australasicus* on the basis of differences in sclerite size and shape in the monogeneans *Kuhnia* spp. and *Pseudokuhnia* sp.. However, the stock structure of *S. australasicus* within Australian waters was not examined. Both of these parasite species were observed in the present study. Pozdnyakov and Vasilenko (1994) found that parasitological data complemented their discrimination of two stocks of *S. japonicus* in the northwest Pacific using reproductive parameters. Cremonte and Sardella (1997) were able to discriminate populations of *S. japonicus* in the Argentine Sea using multivariate analysis of parasite data. MacKenzie (1990) used trypanorhynch cestode plerocerci effectively as biological tags for Atlantic mackerel *S. scombrus* in the northeast Atlantic. Unfortunately, cestodes were rare parasites in the present study and are unlikely to be of any further use in this region. The success of the present study and previous studies using similar methods for multivariate analysis of parasite data warrants further application of this technique. Future studies should have similar sample sizes to those used here, but cover a greater number of sample locations and, as with genetic analyses, replicate samples over time. Future studies should also focus on those parasite groups and habitats found to be informative in this study.

Parasite analyses proved to be very powerful at discriminating stocks. This technique requires standard laboratory equipment and parasite identification keys, although sorting and identifying parasites is a time consuming process. Sample sizes for future stock structure studies will not need to be much larger than those used in this study. Parasite assemblage data may indicate previous movement of fish through the area where parasites are endemic. Alternatively, in incidences where the parasite has a direct life-cycle, the stock may harbor a population of the parasite through direct transmission between fish. Therefore, parasite assemblage data can provide information about stock identity and movement over the life-span of the fish. The technique provides greater contrast than other stock discrimination techniques through the use of

presence/absence data. Since parasites are acquired throughout the fish's lifetime, parasite assemblages should be regarded as a contemporary measure of stock structure.

3.4.3 Otolith microchemistry

Otolith microchemistry is a feasible technique for stock discrimination of *S. australasicus*. Multivariate analyses confirmed that broadly separated populations could be discriminated, although there was some overlap in the classification of fish. Compared with genetic and parasite analyses, there are few studies on stock discrimination of small pelagic species using otolith microchemistry, and no studies of *Scomber* spp. Several studies have investigated stock structure of pelagic species, although most relate to different sampling instruments or they are based on larger pelagic species. For instance, Edmonds and Fletcher (1997) used stable isotope ratios to discriminate stocks of *Sardinops sagax* in south-western Australian waters. Proctor *et al.* (1995) studied the stock structure of the southern bluefin tuna *Thunnus maccoyii* using probe microanalysis of otolith composition, and attributed their findings of no population differentiation to homogeneity of the pelagic environment and low instrument sensitivity. Examination of ontogenetic variation in otolith elemental composition is one of the most powerful uses of otolith microchemistry (Campana and Thorrold 2001). Analysis of the individual chemical life-history was not possible in this study because of poor ontogenetic resolution. However, it was possible to sample areas of the otolith attributed to the juvenile and most recent periods in the fish's life. This enabled us to test whether fish that were captured at the same location had the same juvenile elemental signature and possibly the same origin, and whether the elemental signature for the period prior to capture could also distinguish between capture locations. Future studies should concentrate on these two sections of the otolith, replicate samples over time, and if possible, compare the elemental signatures of fish from common year-classes. Sample sizes were sufficient for stock discrimination using some elements in this study, but should be increased for future studies to enable the use of a greater range of elements.

The efficacy of otolith microchemistry in this study lies in the ability to discriminate stocks with greater resolution than genetic techniques. Due to the small effect size for detecting significant differences in elemental concentrations between pelagic fish populations, sample sizes may need to be larger. However, because otolith samples can be processed in large batches at a time, the sample processing rate for otolith microchemistry is faster than other stock discrimination techniques. This technique could be limited by the availability of analytical equipment such as the

LA-ICP-MS in some countries. Otolith microchemistry enables stock discrimination based on the past history of the fish. This information is vital for establishing the temporal integrity of fish stocks. Data from the core of the otolith can be used to confirm whether fish collected from different locations have a common or independent origin. Due to the permanency of otoliths, analysis of microchemistry should also be regarded as a contemporary measure of stock structure, although it may be less sensitive than other techniques due to low variability in element concentrations in the open ocean (Campana 1999).

3.5 Conclusions

The three different stock discrimination techniques found consistent patterns in the analyses. There were significant genetic differences between distant populations (WA vs. Qld and NZ) while closer populations (Qld vs. NZ) had no significant difference. Whilst populations were significantly different for both parasite and otolith analyses, there was a small amount of overlap between adjacent sampling locations (WA and SA, SA and Qld) and less between distant locations (WA and Qld).

In general, these patterns show that a majority of *S. australasicus* are more closely associated with conspecifics from the same capture location than those from other areas. The genetic differences between populations separated by larger distances, the potential barriers to movement, and the similarities between closer populations could be interpreted as local movement of fish within the study area. However, it is unlikely that these patterns provide evidence of *S. australasicus* movement between areas. There are several oceanographic and biogeographic features that may influence the spatial heterogeneity of *S. australasicus* such as Bass Strait, the East Australia Current, the Flinders Current and the Leeuwin Current (Godfrey *et al.* 1980; Middleton and Cirano 2002; Cresswell and Griffin 2004). Given the wide geographic scale of this study, these significant biogeographic influences, and the fact that only a small number of fish migrating per generation will extinguish genetic differences between populations, it is likely that the number of misclassified fish were a result of processes other than movement between the locations sampled. It may be due to movement from unsampled locations with overlapping parasite assemblages and otolith chemistry. Further *S. australasicus* stock structure studies should be designed to detect movement between closer locations with consideration of the above oceanographic and biogeographical features.

For the sample sizes used in each technique, the variation within populations was low enough and variation between populations high enough to discriminate between four broadly separated populations across Australia and New Zealand. Power analyses indicate future fine-scale studies of *S. australasicus* stock structure will ideally require sample sizes of 20 fish per location for genetic studies, 20-30 fish for parasite studies, and 40-50 fish for otolith microchemistry studies.

3.6 Acknowledgements

We thank Paul Lewis (WA Fisheries), Peter Smith (National Institute of Water and Atmospheric Research), Jonathan Staunton-Smith (QDPI-Southern Fisheries Centre), and David Fleer and Richard Saunders (SARDI) for collection of samples. Thanks are due to Damien Broderick and Raewyn Street at QDPI-SFC Molecular Lab, and Leanne Wheaton, Ralph Foster and Steve Donnellan at SA Museum Evolutionary Biology Unit for help with genetic work. We also thank Les Kinsley at the Australian National University Research School of Earth Sciences for assistance with otolith microchemistry. Rissa Williams, Kate Hutson Dr Tony Fowler (SARDI) and Dr Adrian Linnane (SARDI) provided valuable comments on drafts of this paper.

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4. Harvest of blue mackerel *S. australasicus* by recreational boat-based fishers off NSW.

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Objective: To estimate the number, size frequency and weight of *S. australasicus* taken by recreational (charter, gamefish and trailer boat) fishers off the New South Wales coast.

Summary: This objective was achieved by conducting surveys of each sector of the boat-based recreational fishery. *Scomber australasicus* and yellowtail scad *Trachurus novaezelandiea* collectively comprised over 90% of the catch of the 17 species harvested for use as bait in the trailer-boat fishery. Total *S. australasicus* catches were estimated at 90.9 t (424,546 fish) and 53.9 t (251,695 fish) in the two years sampled; catches were highest over autumn and in the southern region of NSW. Almost half (49%) the trips made by anglers participating in gamefishing tournaments off NSW collected "live bait". *S. australasicus* was the primary species collected with 88% of successful trips recording this species as the only bait caught. Annual catch estimates ranged between 2.7 t (12,628 fish) and 3.7 t (15,213 fish). Effort varied between tournaments. Tournament anglers caught between 27 and 33 baitfish per boat per hour. Approximately 63% of charter operators regularly fish for bait and 25% direct some effort to bait collection on every trip; *S. australasicus* and *T. novaezelandiea* were harvested on 3.6 to 4.8% of all trips. The annual catch of *S. australasicus* by this sector increased from 6.3 t (18,343 fish) in 2002 to 13 t (32,254 fish) in 2004. Catch and effort data for this sector may be biased by lack of mandatory reporting of some important information. Improvements to the Charter Boat Logbook Program are needed. Annual harvest estimates for all recreational boating sectors ranged between 60.5 tonnes and 107 tonnes for *S. australasicus* and between 38.1 tonnes and 47.5 tonnes for *T. novaezelandiea*. During 2002-2005, the recreational harvest of *S. australasicus* and *T. novaezelandiea* were approximately 12–20% and 10-14%, respectively of the mean annual commercial harvest off NSW. There is considerable spatial and seasonal overlap between the activities of commercial and recreational fishers targeting *S. australasicus* and *T. novaezelandiea* off NSW. Spatial and/or seasonal management arrangements may be needed to alleviate existing conflict between these sectors.

4.1 Introduction

The harvesting of finfish for use as bait is an important component of boat-based recreational fishing in Australia. The Australian National Survey of Recreational and Indigenous Fishing (Henry and Lyle 2003b) estimated that boat-based recreational fishers harvested 11.5 million small baitfish annually. Capture of live-bait is also a component of the commercial longline and purse seine fisheries. Bait is accessed by both commercial and recreational fishers from recognised bait grounds (Glaister and Diplock 1993) usually located on the more easily accessible inshore reefs.

Conflict over allocation of baitfish, in particular, inshore reef associated populations has been the driver for a wider debate, which questions the sustainability of existing and proposed commercial fishing for baitfish and the potential flow on effects associated with the distribution and abundance of key recreational species, such as billfish and tunas. The provision of a management framework, which addresses these concerns, is complicated by the cross-jurisdictional arrangements under which these species are managed and the lack of comprehensive harvest estimates from all sectors.

Catches of baitfish species are likely to increase as the recreational fishery continues to expand (McLeay *et al.* 2002). Whilst order of magnitude information is available regarding recreational baitfish usage (Henry and Lyle 2003b), accurate and precise information, which identifies species and quantifies the total harvest (used at sea and retained) of recreational anglers is needed to develop equitable and sustainable management arrangements and understand changing trends in the recreational catches over time. In NSW waters, recreational boat-based fishing is undertaken in the trailer-boat, game-fishing tournament and charter fishing sectors.

Trailer-boat fishers make up the majority of the recreational boat-based fishing effort in NSW marine waters. It is estimated that over 200,000 trailer-boat trips are made annually from larger NSW ports (Steffe *et al.* 1996). Recreational anglers that use trailer boats are involved in a wide variety of fishing activities, which is reflected in their harvest of over 210 taxa ranging from fishing for prized food species such as snapper (*Pagrus auratus*), flatheads (Family Platycephalidae) and mulloway (*Argysomus japonicus*), as well as large gamefish species, such as marlins (Families Xiphidae and Istiophoridae) and tunas (Family Scombridae) (Steffe and Murphy 1995).

Gamefishing tournaments in Australia are administered by the Gamefishing Association of Australia (GFAA), and State Gamefishing Associations affiliated with the GFAA. The scheduling

of gamefishing events in NSW is generally related to expected migration patterns of billfishes, tunas and sharks. The fishing season for the competition gamefish fishery begins in spring (September) of each year with the first tournaments held at Coffs Harbour in the north and Wollongong in the south. Fishing continues through summer and autumn, with the last tournament held in late May of the following calendar year at Bermagui. The use of "live bait" is regarded by tournament game fishers as an important part of their strategy for targeting key competition species, particularly billfish.

The NSW marine and estuarine charter boat fishery provides a service that enhances fishing opportunities for recreational anglers. It provides fishing expertise and well equipped boats to enable recreational anglers to maximise their fishing success across a range of fishing activities and species and to access areas not normally available to most anglers. Charter businesses that operate in estuarine and/or marine waters are required to record catch data in logbooks. The licensing database and logbook program provide a tool for estimating participation and calculating the harvest for this fishery.

This chapter describes and compares baitfish catches in these trailer-boat, game-fishing tournament and charter fishing sectors and investigates relationships between bait collection, bait type and catch in the trailer-boat and gamefishing tournament sectors. The objectives of this study are: 1) to identify the main bait species in each sector; 2) to describe and compare the spatial and temporal patterns in baitfish catches; and 3) to estimate the total harvest of *S. australasicus* in the recreational boat-based fishery off NSW. Results are used to identify options for alleviating potential conflicts between recreational and commercial fishers that target *S. australasicus*. Information on the size/age composition of catches of this sector are provided in chapter 5 of this report.

4.2 Materials and Methods

The collection of harvest information was tailored for each of the primary boat-based sectors. Information regarding baitfish use by the trailer-boat sector was derived from a state-wide assessment of the daytime recreational fishing effort, harvest and harvest rates of anglers using trailer boats at large access sites over a two-year period. Estimates of baitfish use by the gamefishing-tournament fishery were derived from two independent datasets: (a) scheduled radio contacts of vessels participating in tournaments; and (b) interviews with fishing parties at tournaments. Harvest estimates for the charter sector were developed from logbook data.

4.2.1 Trailer boat fishery

4.2.1.1 Survey Design

The baitfish survey was a component of a wider survey (Steffe *et al.* 1996) designed to quantify the daytime effort and catch of anglers fishing from trailer-boats launching from major ports along the NSW coast. The survey can be described, using the terminology by (Pollock *et al.* 1994), as an access-access design with effort estimated from boat counts and catch estimates generated directly from interview data. During interviews, catches were measured (caudal fork length; FL) and a questionnaire completed. Interviewees were required to nominate any species collected for use as bait, the number and species used and the number and species retained. A detailed description of the survey design, analytical methods used to calculate harvest rates, expansions for total fishing effort and total harvest to obtain seasonal and annual estimates are contained in Steffe et al. (1996).

4.2.1.2 Spatial Frame

The spatial frame of this survey included a total of 34 "large" sites from which recreational anglers can access the marine waters along the NSW coast. An access site was defined as any site, which provides direct access to the recreational fishery in the marine waters off the NSW coast. Details regarding the methodology relating to the selection of sites can be found in Steffe et al. (1996).

4.2.1.3 Regional Stratification

Regional boundaries are based on three bio-physical regions identified by Ortiz and Burchmore (1992). Information regarding catch rates of bait species (number of fish per trip) of the retained and used at sea component of the catch and the number of trips on which bait was collected were limited to the information collected at the nine "primary sites", at which interviews were

conducted. Primary sites were partitioned by region, with four sites within the north coast region (Kingscliff, Evans Head, Coffs Harbour, Crowdy Head), two sites within the central coast region (Sydney and Bellambi) and three survey sites within the South Coast region. (Ulladulla, Bermagui and Eden) (Fig. 4.1).

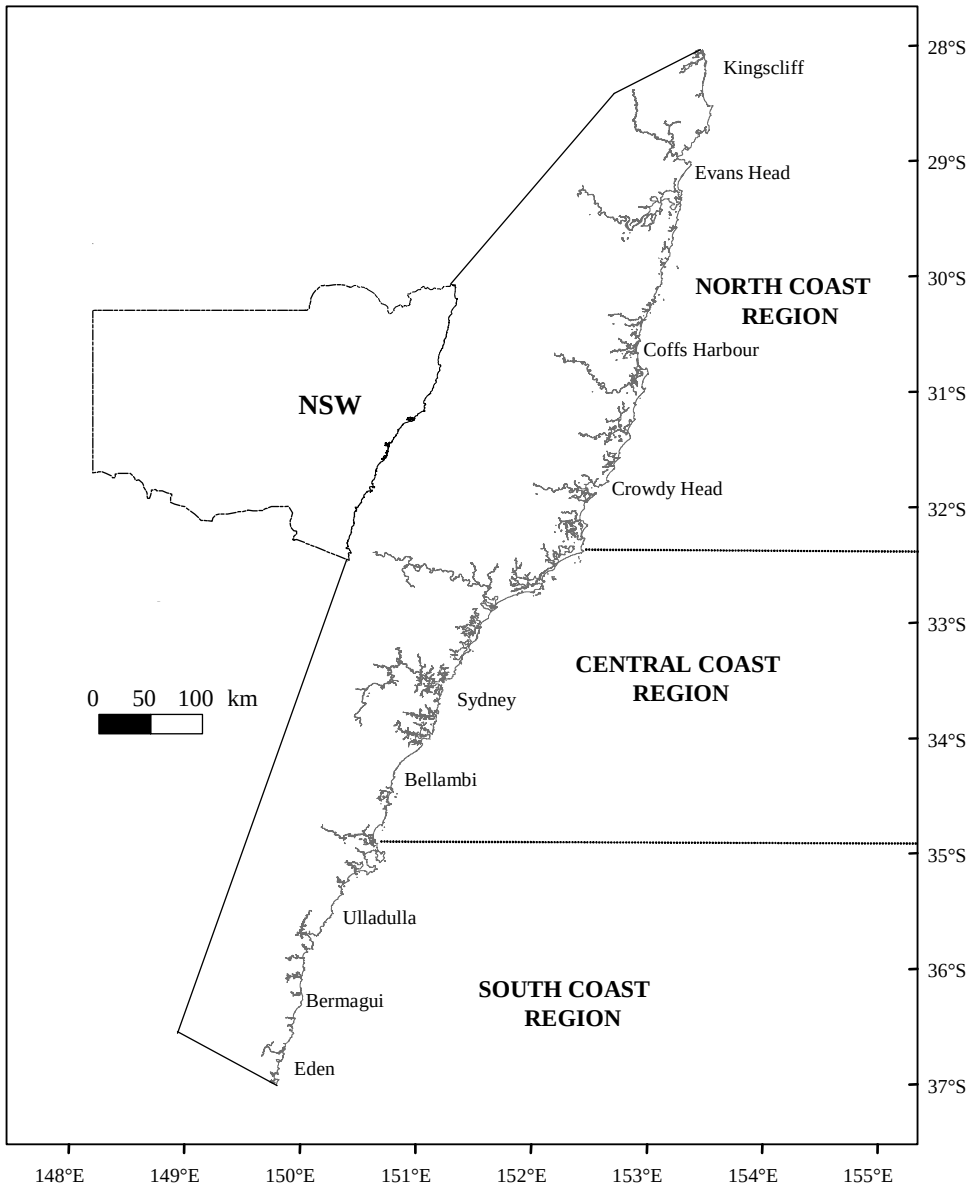

Figure 4.1. Primary sites and regional boundaries for trailer-boat survey and charter fishery.

4.2.1.4 Temporal Frame

The temporal frame of this survey spanned a two-year period, commencing in September 1993 and concluding at the end of August 1995. The design incorporated stratification for seasons within survey years (spring, summer, autumn and winter) and day-types within season (weekdays and weekend days). Public holidays were classified as weekend days. Days were regarded as the primary sampling unit for all stratum levels. By definition, a survey day started at 09:00 hours and ended 15 minutes after sunset. Survey data, which quantified the recreational effort and harvest of trailer-boat anglers, was collected over six replicate survey days per day-type stratum within each season.

4.2.1.5 Estimating Effort and Catch

Two independent datasets were collected and used to estimate recreational fishing effort and harvest. These datasets include: (1) boat count and angler interview data taken by field staff during survey days at each survey site; and (2) daily boat movement logbook data collected by members of many volunteer sea-rescue bases throughout NSW. The first dataset provided information about fishing effort, harvest and harvest rates. The second dataset only provided information about fishing effort. Access sites were defined by the type of data collected at each site. The procedures used to estimate retained, used and total harvest components were determined by the data collected at each site. Harvests were estimated from the calculated means for each strata and summed to provide seasonal and annual estimates.

4.2.1.6 Length Weight Conversions

Harvest estimates were presented in two ways, in terms of abundance (numbers of fish) and in terms of weight (kilograms of fish). Field staff measured the fork length of retained fish (to the nearest cm). Weights for both *S. australasicus* and *T. novaezelandiea* were estimated directly from the length/weight key developed by Stewart and Ferrell (2001a). The remaining unmeasured component of the harvest (i.e. those fish that had been used as bait during the course of the trip) was converted to weight according to two criteria. Firstly, a seasonal mean weight for a site was used to estimate the seasonal mass of the unmeasured component of harvest for each of the primary baitfish species that had measurements for twenty or more individuals collected during a season at that site. Secondly, when less than twenty individuals had been measured during a season, at a site, we used an annual mean weight for that site to estimate the seasonal mass of the unmeasured component of the harvest.

4.2.1.7 Analysis

Differences in catch estimates between regions and seasons were identified by comparison of 95% confidence intervals.

4.2.2 Gamefish Tournament Fishery

4.2.2.1 Survey Design, Sampling Frames and Stratification

An access (effort)-access (catch) survey design (Pollock *et al.* 1994) was used to assess effort directed to the collection of baitfish and catch associated with the gamefishing-tournament fishery. Stratified random sampling methods were used with tournaments regarded as the primary sampling units across all strata. The spatial sampling frame was delineated by the location of New South Gamefishing Association (NSWGFA) sanctioned tournaments within NSW waters, extending from Coffs Harbour to Eden (Fig. 4.2). This area was stratified into three regions (North, Central, South). The temporal sampling frame covered the period from September 2002 to May 2005. This period was stratified into three annual gamefishing periods, each extending from September to May, which represents the tournament gamefishing season off NSW.

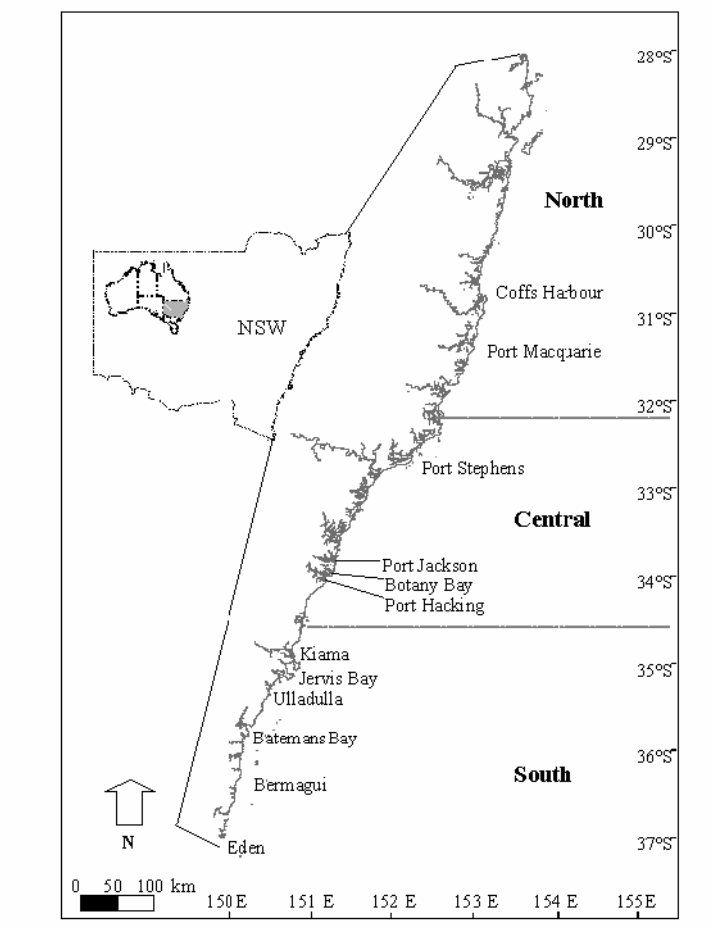

Figure 4.2. Location of ports and regions used in the gamefishing-tournament survey.

4.2.2.2 Data collection

Two independent datasets were collected to estimate baitfish fishing effort and catch: (a) scheduled radio contacts, and (b) completed trip interviews with angling parties at tournaments.

4.2.2.3 Scheduled Radio Contacts

Radio contacts between the tournament organisers and all competing fishing boats are scheduled at regular intervals during each fishing day. These mandatory radio contacts are used to determine the location of each boat and provide the crew with weather updates throughout the day. Additional information is also recorded describing the location and details of all gamefish captures. These scheduled radio contacts provide a census of fishing effort (units of trips) for each tournament.

4.2.2.4 Interviews with Angling Parties

Attempts were made to interview all fishing parties encountered, however, during periods of high activity it was necessary to systematically sub-sample every second or third fishing party (depending on the number of fishing parties available for interview). Data collected included: time spent targeting baitfish; the number of baitfish caught by species; and the number of each species used during the trip. The number of anglers who refused to be interviewed was recorded. Anglers were also asked to provide samples of any *S. australasicus* retained at the completion of their current trips so we could obtain fish weights.

4.2.2.5 Estimation Methods

General equations used for estimating: (a) total tournament fishing effort; (b) baitfish catch rates; and (c) total tournament baitfish catch and their associated variances are provided by Goodman (1960) and Pollock *et al.* (1994; 1997).

4.2.2.6 Effort Estimation

For tournaments where data from scheduled radio contacts were available it was possible to obtain a census of fishing effort in units of boat trips. Direct expansion methods were used to estimate effort for those tournaments that had no data from scheduled radio contacts. A finite population correction was used in the calculation of effort variances. A large tournament is held annually during February or March at Port Stephens (see Fig. 4.2). This tournament is open to all GFAA affiliated clubs and is about three times the size (in terms of the number of competing boats) of any of the other tournaments. Thus, effort data for this tournament was not used in any

calculations of mean effort per tournament, but was simply added to the total regional effort estimate.

4.2.2.7 Catch rate

The "ratio of means" (Jones *et al.* 1995), (Pollock *et al.* 1997) catch rate estimator was used in the estimation of baitfish catch. This estimator is the ratio of mean catch to mean effort for a tournament. These tournament catch rates were in units of fish per trip.

4.2.2.8 Catch

The tournament baitfish catch was calculated as the product of effort and a mean tournament catch rate. The variance of catch was derived from the general equation that describes the variance of a product (Goodman 1960). Whenever strata were combined the variances were additive. Due to low levels of replication in the northern region it was necessary to pool all tournament catch rates from the northern and central regions in order to calculate a mean catch rate for those regions and an associated variance. This was done for each year.

The conversion of catch estimates from units of numbers of baitfish into units of kilograms of baitfish was done by multiplying the initial catch estimate (number of baitfish) by a mean weight (kilograms) per fish. The variance of catch (kilograms) was derived from the general equation that describes the variance of a product (Goodman 1960). The mean weight used for *S. australasicus* was derived from samples provided by tournament fishers. A mean weight was calculated for each tournament at which a minimum of twenty *S. australasicus* were available. The mean weight used in the conversion of catch estimates into weights was obtained by taking the mean of the tournament mean weights (all tournaments in a year were pooled). Weight data for *T. novaezelandiea* were obtained from a previous survey (Steffe *et al.* 1996). A mean weight for use in the conversion of *T. novaezelandiea* catch data was obtained by calculating an overall mean weight and variance by using port-based mean weights as replicates.

4.2.2.9 Indices of Fishing Quality

Two indices of relative fishing quality were derived from tournament interview data in which anglers indicated that they had directed effort towards catching baitfish. *S. australasicus* data only was used to construct these indices. Relative fishing quality was expressed as: (a) the proportion of angling parties who directed effort to the collection of *S. australasicus* for bait but were ***not*** successful; and (b) catch rates of angling parties that directed effort to the collection of *S.*

australasicus for bait. Directed catch rates are expressed as the number of *S. australasicus* per hour. Significant differences between catch rate estimates among tournaments were identified by a comparison of 95% confidence intervals.

4.2.3 Charter Fishery

4.2.3.1 Estimating Effort and Harvest

Currently, a total of 278 operators are endorsed to operate within the NSW charter fishery. As at July 2006, 210 of these have been issued endorsements with the remainder either in abeyance (40), expired (14) or being processed (14). Active fishers were defined as any operator who had lodged at least one catch return within each calendar year. Effort was defined as the number of trips undertaken by each operator over each year of the study. Limitations associated with the format of the logbook did not allow the collection of bait-specific information such as the identification of species for use as bait, the amount of effort directed towards the collection of bait or the number of fish either used or retained. Effort directed at the collection of bait was identified by charter trips on which either *S. australasicus* or *T. novaezelandiea* were reported as harvested. Annual harvest estimates were calculated for *S. australasicus* and *T. novaezelandiea* by summing the relevant catch information from log sheets submitted over each calendar year for the period 2002-2004.

4.2.3.2 Regional Stratification

Regional boundaries are based on three bio-physical regions identified by Ortiz and Burchmore (1992)(Fig.1).

4.2.3.3 Length Weight Conversions

Harvest estimates were presented in two ways: in terms of abundance (numbers of fish) and in terms of weight (tonnes). Lengths provided by charter operators were converted to weights using the relevant length/weight key developed by Stewart and Ferrell (2001a) for both *S. australasicus* and *T. novaezelandiea*. A mean weight was derived from the calculated weights and used in the weight estimates for each species.

4.2.3.4 Telephone Survey

In addition, a survey of randomly selected operators was carried out to: (a) estimate the proportion of fishers that directed effort to the collection of bait; (b) species targeted; (c) the frequency of bait fishing; and (d) broad-scale spatial and temporal nature of baitfishing activity.

4.3 Results

4.3.1 Trailer-boat Fishery

4.3.1.1 Trailer-boat Fishing Effort

Information regarding bait use was derived from interviews of 10,635 trips over the two-year period of the study. Trips on which effort was directed to the collection of bait represented 12.4% (663 trips) of the total interviews in year one and 10.5% (525 trips) of trips in year two. The proportion of "baitfishing trips" identified by interview information was greatest in the southern region in both year 1 (62%) and year 2 (49%). A seasonal pattern of fishing effort was also identified from the interview information in both years of the study with 57% and 46% of baitfishing trips occurring in autumn (Fig. 4.3).

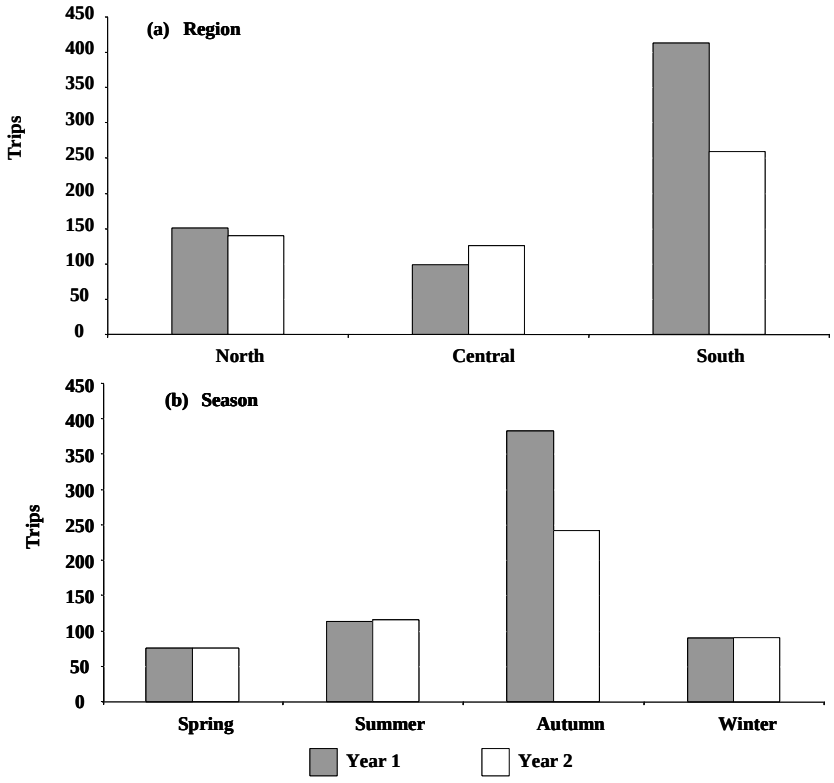

Figure 4.3. Trips that anglers indicated effort directed to the collection of bait for year 1 and 2 by: (a) region; and (b) season.

4.3.1.2 Trailer-boat catch

Anglers identified a total of 17 species that were collected for use as bait over the two-year study period (Table 4.1). *S. australasicus* and *T. novaezelandiea* made up 98% of those fish identified by anglers as used for bait. Estimates of total harvest and the retained and used components of the harvest are restricted to *S. australasicus* and *T. novaezelandiea*.

Table 4.1. Species groups and species harvested by trailer-boat anglers for use as bait

Common name	Species
Blue mackerel	*Scomber australasicus*
Yellowtail scad	*Trachurus spp.*
Long-finned seapike	*Dinolestus lewini*
Ladder-finned Pomfret	*Schuettea scalaripinnis*
Tailor	*Pomatomus saltatrix*
Skipjack	*Katsuwonis pelamis*
Silver sweep	*Scorpis lineolatus*
Garfish	Family Hemiramphidae
Silver trevally	*Pseudocaranx dentex*
Frigate mackerel	*Auxis thazard*
Australian bonito	*Sarda australis*
Mackerel tuna	*Euthynnus affinis*
Nannygai	*Centroberyx affinis*
Silver batfish	*Monodactylus argenteus*
Blackspot goatfish	*Parupeneus signatus*
Yellowfin tuna	*Thunnus albacares*
School whiting	*Sillago flindersi*

Annual catch estimates varied between 53.9 and 90.9 tonnes for *S. australasicus* and between 36.7 and 45.4 tonnes for *T. novaezelandiea*. Total harvest for both species decreased in the second year of the survey, indicating a large amount of inter-annual variation, particularly in catches of *S. australasicus* (Table 4.2). Differences in the retained component of the catch contributed most to the difference in the between year totals for both species.

Table 4.2. Retained and used at sea catch components for trailer-boat fishery with standard errors (s.e.) and corresponding weight (t) estimates of *S. australasicus* and *T. novaezelandiea* for year 1 and year 2 of the survey period.

Blue Mackerel	**Retained**	**s.e.**	**Used**	**s.e.**	**Total**	**Weight (t)**
year 1	256,154	55,177	168,392	22,960	424,546	90.9
year 2	111,559	20,300	140,136	44,601	251,695	53.9

Yellowtail Scad	**Retained**	**s.e.**	**Used**	**s.e.**	**Total**	**Weight (t)**
year 1	115,141	14,159	86,647	11,300	201,608	45.4
year 2	85,133	7,221	77,948	9,261	163,081	36.7

4.3.1.3 Regional Comparisons of Catch

S. australasicus

The majority of the total annual catch in year one (77%) and year two (85%) was taken from the southern zone. A large proportion (40%) of the total catch of *S. australasicus* was used at sea in year one, which increased to 56% over the second year of the study. Catch for both the retained and used at sea components of the *S. australasicus* catch were significantly greater in the southern region (Fig. 4.1) over both years of the study (Fig. 4.4 a & b).

T. novaeazelandiea

Similar patterns of usage were also identified for *T. novaezelandiea* with 43% of the total harvest used during trips in year one and 48% in year two. There was no significant relationship identified between catch of yellowtail and region with both the retained and used at sea components of the *T. novaezelandiea* catch more evenly distributed between regions (Figs. 4.5 a & b).

4.3.1.4 Seasonal Comparisons of Catch

Catch of *S. australasicus* remained relatively stable but low over winter, spring and summer, followed and increased over autumn in both years of the study (Fig. 4.6a). Total catch of *T. novaezelandiea* did not fluctuate to the same degree as *S. australasicus* but did follow a similar pattern, with increasing catches over summer and autumn (Fig. 4.6b).

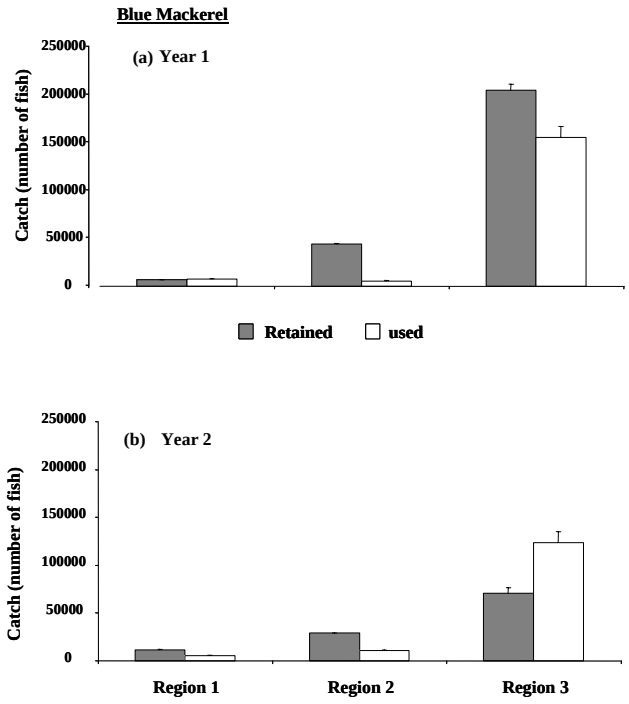

Figure 4.4 Total catch of *S. australasicus* (retained and used at sea) for the trailer-boat fishery (± SE) by region for: (a) year 1 and (b) year 2 of the survey period.

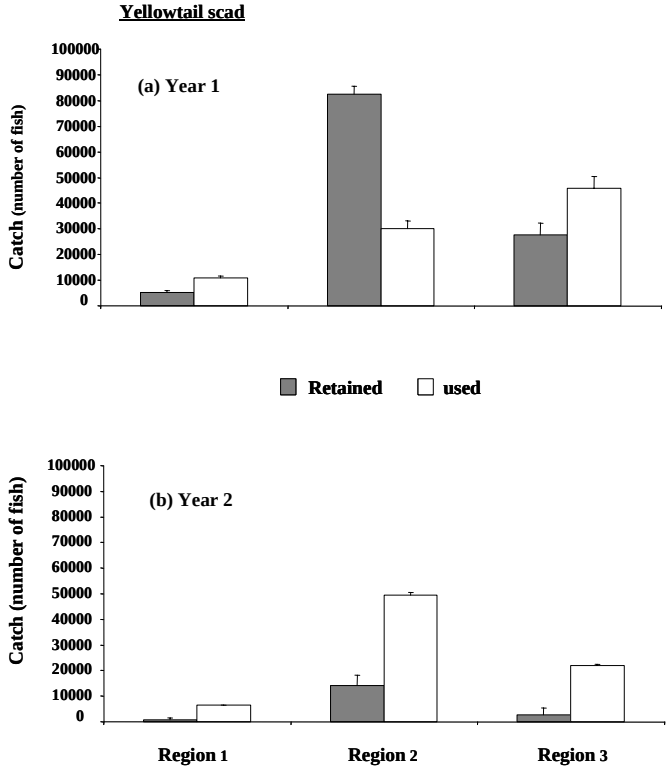

Figure 4.5. Total catch of *T. novaezelandiea* (number of fish) for the trailer-boat fishery (± SE) by region for: (a) year 1, and (b) year 2 of the survey period.

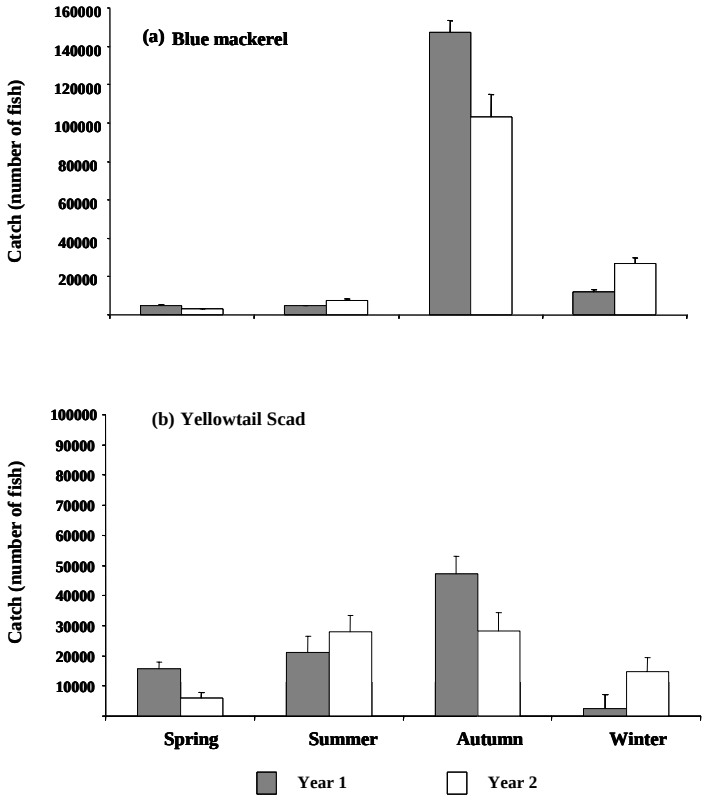

Figure 4.6. Catch of *S. australasicus* and *T. novaezelandiea* for the trailer boat fishery (± SE) by season for: (a) year 1 and (b) year 2 of the survey period.

4.3.2 Gamefish Tournament Fishery

During the three-year survey period 3,146 completed trip interviews were conducted with angling parties. Refusals were less than 1% of total interviews. Almost half (49%) of the trips directed some effort towards the collection of bait. A total of 14 taxa were identified by anglers as species caught for use as bait (Table 4.3). *S. australasicus* was the primary species collected for use as bait with 88% of successful baitfish trips recording *S. australasicus* as the only species caught.

Table 4.3. Species groups and species harvested by gamefishing-tournament anglers for use as bait.

Common name	Scientific name
Blue Mackerel	*Scomber australasicus*
Yellowtail and Jack Mackerel	*Trachurus spp.*
Skipjack	*Katsuwonus pelamis*
Pilchard	*Sardinops neopilchardus*
Leaping Bonito	*Cybiosarda spp.*
Bonito	*Sarda spp.*
Garfishes	*Hyporhamphus spp.*
Flatheads	Platycephalidae
Chinaman Leatherjacket	*Nelusetta ayraudi*
Dolphin fish	*Coryphaena hippurus*
Salmon	*Arripis trutta*
Silver Sweep	*Scorpis lineolatus*
Tailor	*Pomatomus saltatrix*
Silver Trevally	*Pseudocaranx dentex*

4.3.2.1 Gamefishing–tournament effort

The total number of trips remained relatively consistent between years increasing from 2,730 in year one, to 2,966 in year two reaching a maximum in year three of 3,091 trips. Effort varied between regions, reflecting the distribution of tournament activity with the least number of trips occurring in the northern region over all years of the study. The Port Stephens Interclub Tournament dominated the number of trips over all years, with 602 trips (22% of total) in year one, 668 trips (23% of total) in year two and 865 trips (28% of total) in year three. Effort directed towards the collection of bait represented a small proportion (less than 10%) of the average trip. The mean amount of effort directed to the collection of baitfish per trip increased slightly from a mean of 36 minutes in year one to 48 minutes in year one.

4.3.2.2 Gamefishing–tournament catch

Annual catch estimates by weight of *S. australasicus* increased during the study period from a minimum of 2.7 tonnes in year two to 3.7 tonnes in year three. Catch of *T. novaezelandiea* increased from 0.4 tonnes in year one to 1.1 tonnes in year three (Table 4.4).

Table 4.4 Total harvest by Gamefishing–tournament fishery, as weight tonnes (t) (± SE) and numbers of fish (N°) (± SE) for *S. australasicus* and *T. novaezelandiea* for each survey year (2002-2005).

Blue mackerel *(Scomber australasicus*)

	harvest (t)	SE	harvest (N°)	SE
year 1	3.3	1	13,608	3,835
year 2	2.7	0.5	12,628	2,004
year 3	3.7	0.9	15,213	3,755

Yellowtail scad (*Trachurus novaezelandiae*)

	harvest (t)	SE	harvest (N°)	SE
year 1	0.4	0.1	1,620	162
year 2	0.8	0.1	3,453	185
year 3	1.1	0.3	4,739	506

Results did not indicate any consistent pattern in the number of *S. australasicus* caught or the mean weight of *S. australasicus* between regions and years. The number of *S. australasicus* caught in the northern and central regions increased during the three years of the study while catch in the southern region decreased (Fig. 4.7a). Catch of *S. australasicus* reflected effort with the central region recording the greatest number of *S. australasicus* caught in all three years of the study. This was primarily a result of the contribution by the Port Stephens Interclub competition, which recorded significantly greater catches of *S. australasicus* than any of the other tournaments in all three years of the study. During the study period, the mean weights of *S. australasicus* decreased in the northern region, increased in the central region and remained relatively consistent in the southern region (Fig. 4.7b).

4.3.2.3 Fishing Quality

Fishing parties that directed effort to the collection of bait but were not successful accounted for 20% (301) of all angler parties interviewed. The number of unsuccessful parties remained relatively consistent over years with 23% in year one, 22% in year two and 17% in year three. Catch rates varied greatly between tournaments however, mean annual catch rates varied slightly from a maximum of 32 fish per boat per hour in year one to a minimum of 26 fish per boat per hour in year three. Analysis of catch rates between regions and between tournaments within each survey year did not indicate significant differences in mean catch rates.

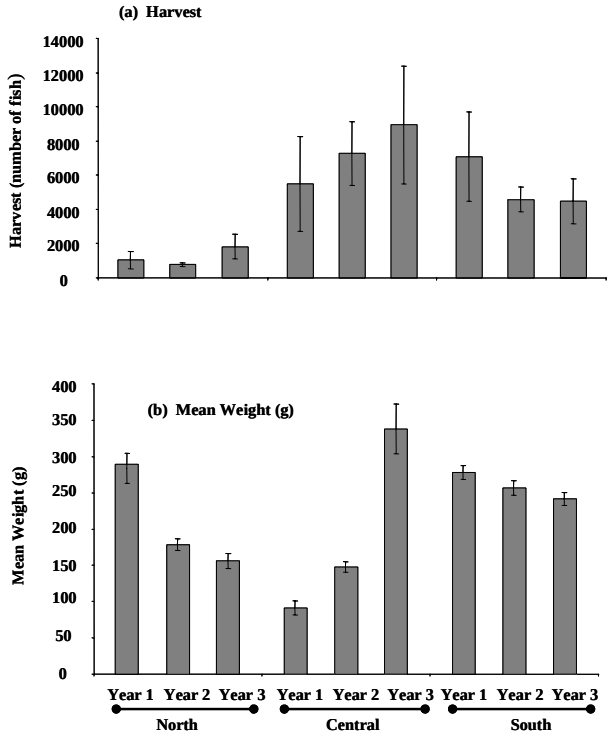

Figure 4.7. (a) Annual estimates of *S. australasicus* (± SE) harvested; and (b) Estimated mean weight (± SE) of *S. australasicus* harvested by the Gamefishing–tournament fishery over the three-year survey period (2002-2005).

4.3.3 Charter Fishing

4.3.3.1 Charter Fishing Effort

The number of active fishers (operators who lodged at least one log sheet per year) varied between years with the number of active fishers decreasing from a total of 190 in 2002 to 159 in 2004. The total number of trips decreased over the study period from 10,961 in 2002 to 8,801 in 2004. Trips on which either *S. australasicus* or *T. novaezelandiea* were collected represented between 12% and 28% of the total annual trips. Effort varied between regions with the least number of trips occurring in the central region (region 2) over all years of the study. The majority of effort associated with the collection of the primary baitfish species occurred in the southern most (region 3) over all three years of the study (Fig. 4.8). Fishing effort associated with the collection of bait species was consistent with the trailer-boat fishery with effort increasing throughout spring and summer then deceasing over autumn (Fig. 4.9).

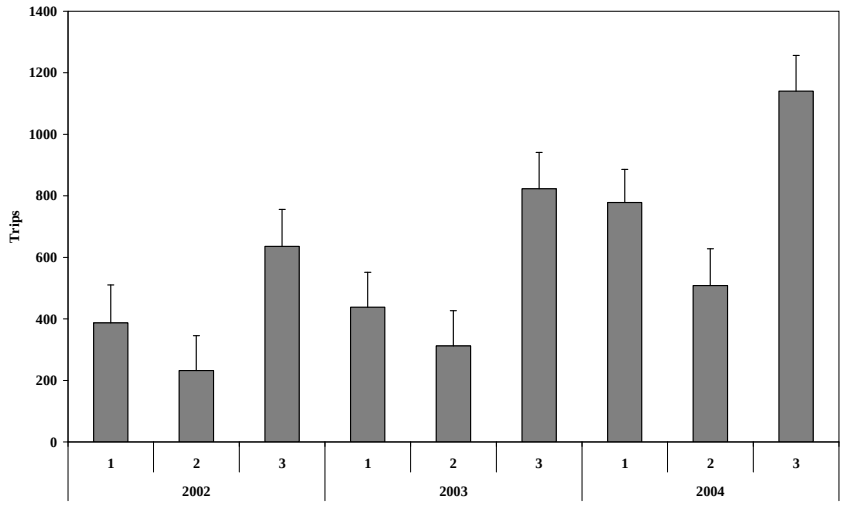

Figure 4.8. Number of trips (+SE) on which *S. australasicus* or *T. novaezelandiea* were harvested by charter operators for each region (1, 2, 3) over the study period (2002-2004).

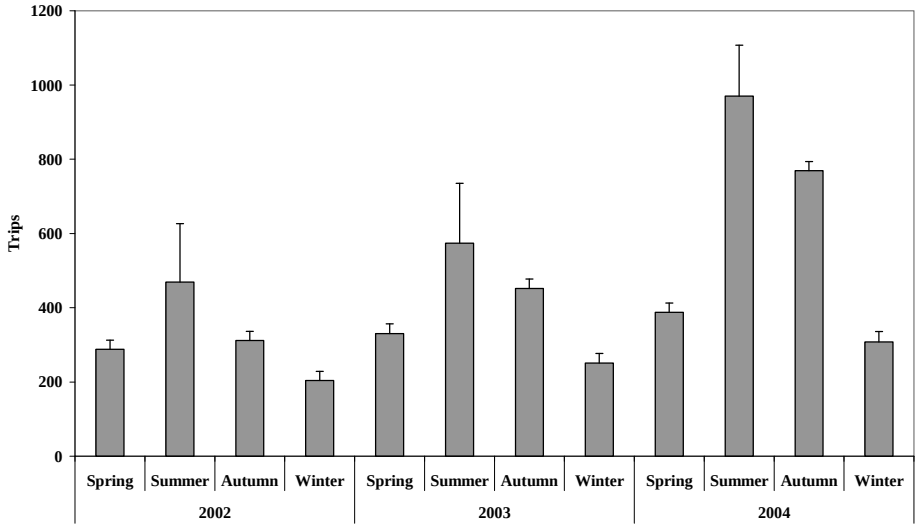

Figure 4.9. Number of trips (+SE) on which *S. australasicus* or *T. novaezelandiea* were harvested by charter operators for each season, over the study period (2002-2004).

4.3.3.2 Charter Harvest

Annual catch estimates of *S. australasicus* increased from a minimum of 6.3 tonnes in 2002 to a maximum of 13 tonnes in 2004 (Table 4.5). Catch of *T. novaezelandiea* underwent a similar proportional increase from 0.7 tonnes in 2002 to 1.4 tonnes in 2004.

Table 4.5. Total harvest for NSW charter fishery by weight tonnes (t) and numbers of fish (No) for *S. australasicus* and *T. novaezelandiea* for each survey year (2002-2004).

Year	Blue mackerel		Yellowtail Scad	
	fish (No)	Weight (t)	fish (No)	Weight (t)
2002	15,734	6.3	3,637	0.7
2003	19,184	7.7	4,460	0.9
2004	32,254	13	6,958	1.4

4.3.3.3 Regional Comparisons of Harvest

Results indicated a consistent pattern in the number of *S. australasicus* caught between regions with the largest catch occurring in the southernmost region three over all years of the study (Fig. 4.10). *T. novaezelandiea* did not indicate any consistent pattern between regions over the survey period with catches more evenly distributed between regions.

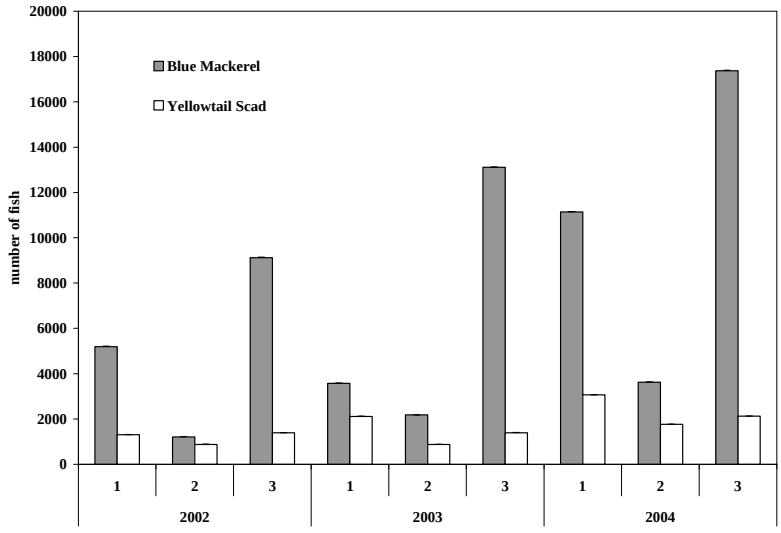

Figure 4.10. Estimated mean catch (+SE) by the NSW Charter boat fishery for *S. australasicus* and *T. novaezelandiea* for each region (1,2,3) and year of the survey period (2002-2004).

4.3.3.4 Seasonal Comparisons of Catch

Seasonal patterns of catch within the charter fishery varied between primary bait species with catch of *S. australasicus* increasing over spring and summer (Fig. 4.11), reflecting an increase in

angler effort. Catch of *T. novaezelandiea* was more evenly distributed across seasons with no consistent pattern between years (Fig. 4.11).

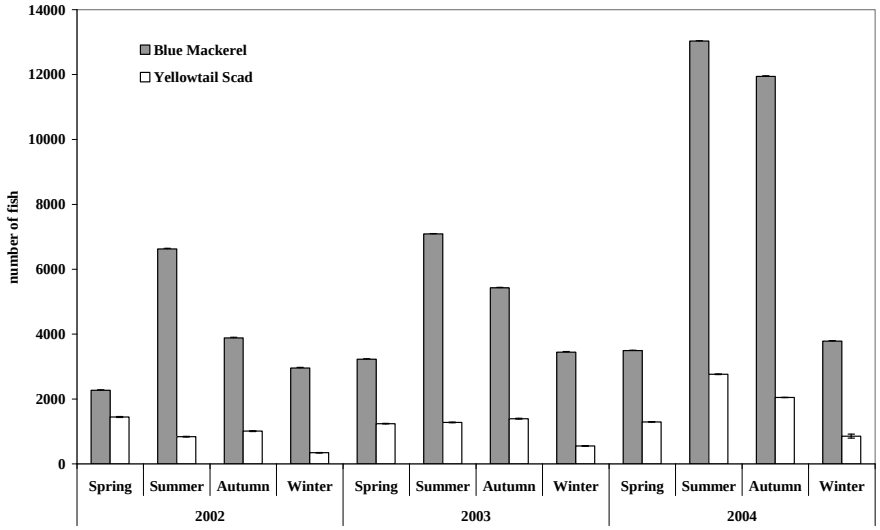

Figure 4.11. Estimated mean catch (+SE) by the NSW Charter fishery for *S. australasicus* and *T. novaezelandiea* for each season over each year of the survey period (2002-2004).

4.3.3.5 Telephone Survey Data

A total of 65 charter operators (23% of the charter fleet) were contacted and 49 operators (30% of active fishers) were interviewed. Thirty-one (63%) operators interviewed indicated that they directed some effort to the collection of bait, with 24% (12) of operators indicating that baitfishing effort was directed towards *S. australasicus* only. The proportion of operators that indicated that they fished for bait on every trip (25%) was on par with the proportion of operators who never fished for bait (27%).

4.4 Discussion

The study indicates that the NSW recreational boat-based sector harvests significant quantities of *S. australasicus* and *T. novaezelandiea*. The catch of *S. australasicus* by the trailer-boat and charter fisheries is characterised by regional and seasonal variation with the majority of *S. australasicus* harvested from the waters of southern NSW over summer and autumn. Catches of *T. novaezelandiea* varied less among regions and seasons and appear to be higher near large population centres, particularly Sydney. The seasonal and regional variations in the catches of these two species are the result of: (a) associated variations in the life history and behavioural ecology of the bait species; (b) movement patterns of the target species; and (c) the response of anglers who seek to maximise catch of both bait species and target species.

Fisheries in which *S. australasicus* and *T. novaezelandiea* species are primarily used for bait have an additional level of complexity. Effort directed towards bait species does not necessarily coincide with periods or locations of peak abundance of the bait species. Effort is more likely to be associated with peaks in the abundance of target species or, in the case of recreational fishers, holidays or periods of favourable weather. Increases in both total catch and number of interviews of trailer-boat anglers during autumn, probably reflected the combined effects of good weather for offshore fishing over this period and the annual migrations of the principal target species (billfish and yellowfin tuna).

The seasonal fluctuations in the catch of *S. australasicus* may also be related to changes in fish behaviour. The New Zealand commercial fishery targets mid-water schools of *S. australasicus* by trawling over winter and targets surface schools with purse seines over the remainder of the year (Taylor 2002b). The seasonal shift in method is believed to reflect a movement into deeper water over the winter months. Recreational fishing methods principally rely on targeting surface schools, therefore, lower catches of *S. australasicus* by the trailer-boat fishery over winter may be indicative of a similar behaviour off NSW.

Despite being encountered in similar locations and generally grouped together as baitfish by most fishers, *S. australasicus* and *T. novaezelandiea* have very different life histories. The growth rates of *S. australasicus* are relatively high (Stewart and Ferrell 2001a) and catches off NSW are comprised of a few young age classes (see chapter 5 of this report) and vary between years and months (chapter 2). In contrast, the growth of *T. novaezelandiea* is relatively slow and landings are consistent among years and between seasons. *T. novaezelandiea* may not undertake large scale

movements like *S. australasicus* (Stewart and Ferrell 2001a) which may explain the lack of seasonality in the harvest of *T. novaezelandiea*.

Seasonal and regional differences in the harvest of bait species by the trailer-boat fishery are also accompanied by differences in the way baitfish are used in this sector. Total catch for each of the primary bait species can be described in terms of the "retained" and "used at sea" components of the harvest. The division of the harvest for *T. novaezelandiea* remains relatively consistent between years with only minor variations in the proportion of the catch retained and used. The *S. australasicus* catch is characterised by greater variability, with the retained proportion of the catch contributing most to differences in the total catch between years. Annual variability in the proportion of *S. australasicus* retained may reflect inter-annual differences in availability with anglers retaining larger amounts of *S. australasicus* when the fish are caught readily. Currently, there are no size or bag limits on either *S. australasicus* or *T. novaezelandiea* off NSW. Results of this study suggest that input controls such as bag limits could minimise the potential for anglers taking large amounts of bait during periods of high abundance and reduce the real or perceived risk of localised depletion of recreational bait grounds.

Compared to the trailer-boat fishery, anglers participating in gamefish tournaments take only a minor proportion (1-3%) of the annual boat-based recreational baitfish catch. Effort by tournament anglers is primarily directed towards *S. australasicus* with the majority of fishers (88%) reporting *S. australasicus* as the only bait species harvested. The available information regarding use of bait by the gamefishing-tournament fishery indicates that the harvest of *S. australasicus* is relatively stable between years. A survey conducted by Murphy et al. (2002) estimated a total harvest of between 2.4 and 2.6 tonnes of *S. australasicus* over 39 tournament days. These figures, which represent the majority of fishing days during the gamefishing season, are of the same order of magnitude as harvest estimates obtained in the current study (3.3-3.7 tonnes), suggesting that the harvest of *S. australasicus* by the gamefishing-tournament sector may not be characterised by large inter-annual fluctuations.

Effort directed towards the collection of bait by tournament anglers is concentrated both in space and time. The majority of boats target bait at specific "bait grounds" typically at the start of the days fishing, resulting in fleet-wide pulses of effort that typically comprise less than 10% of each fishing trip. The perception amongst gamefishing-tournament anglers that there is over-exploitation of the primary bait species at a local scale may be in part the result of the relatively

small proportion of effort directed towards collection of baitfish species and the compression of effort into discrete time periods (usually early morning).

More than 95% of the commercial catch of *S. australasicus* and *T. novaezelandiea* off NSW is taken in the Ocean Haul Fishery (see Chapter 2 of this report). Commercial catches of *S. australasicus* have ranged between 300 and 600 tonnes for most years (Fig. 4.12). Commercial catches of *T. novaezelandiea* peaked at 504 tonnes in 1997-98 and have ranged between 300 and 500 tonnes in recent years (Fig. 4.12). Recreational harvest estimates between 2002-2005 for *S. australasicus* (60.5-107 t) and *T. novaezelandiea* (38.1-47.5 t) are 12–20.3% and 10.6-13.5%, respectively of the mean annual commercial harvest of these species in the NSW Ocean Haul Fishery. Since 2003, the commercial longline fishery off NSW has take annual catches of 15 tonnes of *S. australasicus* and 65 tonnes of *T. novaezelandiea* (NSW Fisheries, unpublished data).

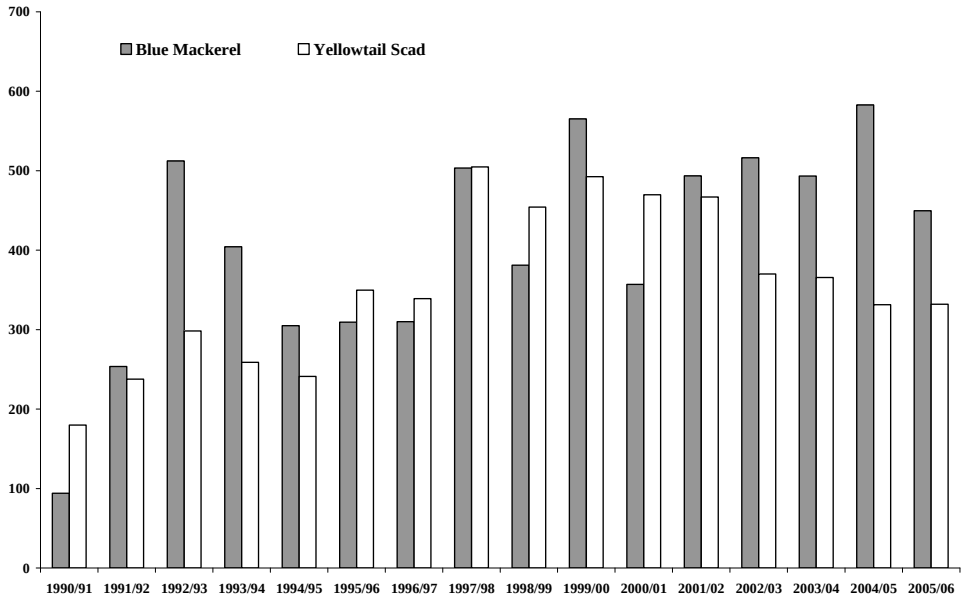

Figure 4.12. Commercial catch (Ocean Haul) of *S. australasicus* and *T. novaezelandiea* (1990/91 - 2005/06).

Information provided in chapter 2 of this report suggest that current total catches of *S. australasicus* and *T. novaezelandiea* in the commercial and recreational fisheries off NSW are unlikely to have detrimental effects on the total abundance or reproductive capacity of these populations. However, the large numbers of primary bait species harvested by different sectors of the commercial and recreational fisheries emphasises the importance of collecting reliable information relating to the harvest of these species. The need for this information is highlighted by the well-documented disputes between recreational and commercial fishers over the allocation of these resources off NSW.

Both *S. australasicus* and *T. novaezelandiea* are taken throughout the year in the NSW Ocean Haul Fishery (Fig. 4.13). Recreational catches of these species in the trailer-boat and charter sectors are highest over summer and autumn. In the gamefishing–tournament sector the main season is from early spring to the end of autumn, when target species are in greater abundance. These results show that there is considerable overlap in the seasonality of fishing in the commercial and recreational fisheries off NSW.

Commercial harvests of *S. australasicus* and *T. novaezelandiea* are concentrated in southern NSW with over 95% of the mean catch (2003-2005) caught in waters south of Sydney and over 90% of the *T. novaezelandiea* harvested from Ocean Zone 7, which lies between Sydney and Wollongong (Table 4.6). Similar patterns were observed in the recreational fishery with between 77% and 85% of the annual harvest of *S. australasicus* of the trailer-boat fishery being taken from the southern zone and most of the harvest of *T. novaezelandiea* by trailer-boats being taken near large population centres such as Sydney.

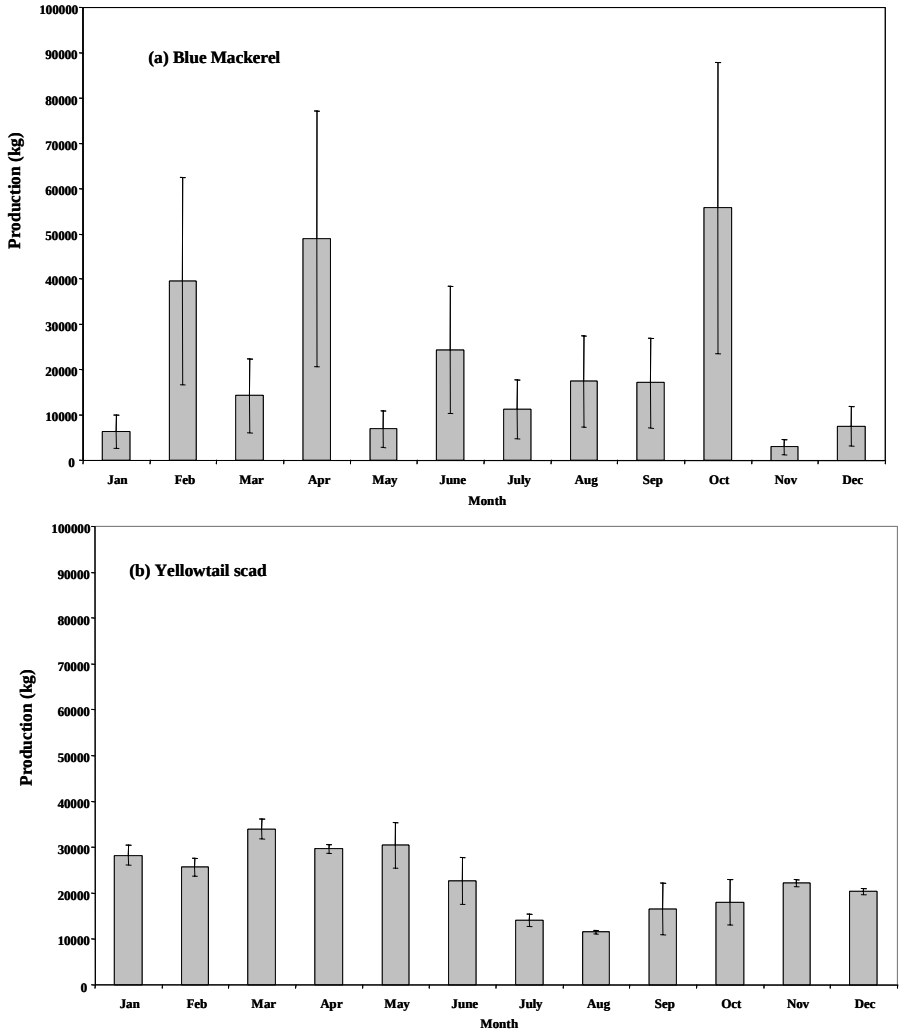

Figure 4.13. Estimated mean catch (+SE) by the NSW Ocean Haul Fishery for: (a) *S. australasicus*; and (b) *T. novaezelandiea* for each season over each year of the survey period (2003-2005).

Table 4.6. Estimated mean catch (kg) by the NSW Ocean Haul Fishery and proportion of the total catch for (a) *S. australasicus* and (b) *T. novaezelandiea* for each Ocean Zone over the survey period (2003-2005). Locations of the latitudes referred to in this table are shown in Fig. 4.1.

	Blue Mackerel		Yellowtail Scad	
Ocean Zone	**Harvest (kg)**	**%**	**Harvest (kg)**	**%**
Zone 1-QLD/NSW - 29^{0}S	1677	0.3	3675	1.3
Zone 2 -29-30^{0}S	190	0.0	200	0.1
Zone 3 30-31^{0}S	38	0.0	76	0.0
Zone 4-31-32^{0}S	17	0.0	344	0.1
Zone 5-32-33^{0}S	843	0.2	3025	1.1
Zone 6-33-34^{0}S	0	0.0	0	0.0
Zone 7-34-35^{0}S	336677	62.1	246773	90.2
Zone 8-35-36^{0}S	15326	2.8	9817	3.6
Zone 9-36-37^{0}S	137493	25.4	9725	3.6
Zone 10-37-38^{0}S	49552	9.1	27	0.0

The recreational boat-based fishery harvests significant quantities of *S. australasicus* and *T. novaezelandiea*, and the location and timing of fishing overlaps significantly with the commercial fishery. This overlap is most pronounced over inshore reefs, which are favoured by both sectors. The concentration of effort in these areas suggests that there is potential for localised depletion. The effects of recreational and/or commercial fishing on local aggregations of baitfish are poorly understood but are likely to reflect the rate at which fishing pressure is offset by migration of fish into the area.

Commercial fishing for bait species can negatively affect angler satisfaction and has the potential to affect angler participation in areas where conflict is greatest. Under current levels of harvest, management of the baitfish resource should primarily focus on resolving allocation disputes between the commercial and recreational sectors. Management responses that may alleviate conflict between the commercial and recreational sectors may include the designation of commercial and recreational bait fishing grounds. Delineating bait-fishing areas would have the dual benefit of separating effort within the fishery and reducing total effort on some local populations. This approach would also provide opportunities for research on the relative impact of recreational and commercial fishing on baitfish populations.

4.5 Conclusions

Catch estimates for the trailer-boat fishery exceeded those of the gamefishing-tournament and charter fisheries combined. Despite differences in the size of harvest, consistent spatial and temporal patterns in catch and effort were identified across fisheries particularly for *S. australasicus*, with peaks occurring over summer and autumn. The results of this study indicate that the 'used at sea" component of the bait fish catch is large and should be incorporated into the design of future monitoring programs for recreational fishing. Results of this study suggest that bag limits may be an effective tool for preventing anglers from taking large quantities of baitfish during periods of high abundance and reduce both the real and perceived risks of localised depletion.

The NSW boat-based recreational fishery is a significant user of baitfish resources with harvest estimates comprising between 12-20% and 10-14% of the total annual NSW commercial harvest of *S. australasicus* and *T. novaezelandiea* respectively. Our results show that there is considerable spatial and seasonal overlap in the activities of commercial and recreational fishers targeting

S. australasicus and *T. novaezelandiea* off NSW. Spatial and/or seasonal management arrangements may be needed to alleviate existing conflict between these sectors.

4.6 Acknowledgements

We sincerely thank the efforts of all recreational fishers in NSW who took part in surveys and assisted in data collection for this chapter. Thanks also to Dr Shane Roberts (SARDI) and Dr Adrian Linnane (SARDI) for useful comments on drafts of this chapter.

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5. Spatial and temporal patterns in the size, age and growth of blue mackerel *Scomber australasicus* in southern and eastern Australia

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Objectives: To describe the spatial and temporal patterns of age and growth and compare the age structure of commercial catches and fishery-independent samples of *S. australasicus* from southern and eastern Australia and; to compare the spatial and temporal patterns of age of commercial and recreational catches samples of *S. australasicus* taken from NSW.

Summary: A total of 11,026 blue mackerel *S. australasicus* was sampled from commercial and recreational catches and using fishery-independent methods between southern Queensland and south-western Western Australia between 1986 and 2005. Fish collected ranged between 110 and 420 mm. Large fish (>300 mm) were commonly collected from Tas, SA and Vic, whereas smaller fish dominated samples from NSW, southern Qld and WA. A total of 8,457 otoliths collected from all states were used for age determination. Age determination of *S. australasicus* is challenging using the standard approach as the majority of otoliths are difficult to read, and these difficulties increase as fish age increases. If age distributions are determined from zone counts from readable otoliths alone the proportion of fish in young age classes (especially the 0+ year class) is over-estimated. A readability index (RI) was established and age-otolith weight regressions were established using whole otoliths with good and excellent readabilities. Only 2.8% of otoliths were assigned the highest RI score of 1 and 17.4% were assigned a score of 2. Young fish (0+ to 2+ year classes) were common in samples NSW, southern Qld and WA, whereas older fish were present in samples from SA (1+ to 7+ year classes) and Tasmania (2+ to 5+ year classes). The size/age distributions of samples from commercial and recreational catches off NSW were similar. Growth rates and trajectories of males and females from SA ($\male k$ =0.21. yr^{-1} $\male L_\infty$ = 453.08 mm, $\female k$ = 0.50. yr^{-1}, $\female L_\infty$ = 384.61 mm) and NSW ($\male k$ = 0.48. yr^{-1}, $\male L_\infty$ = 365.86 mm,

♀k = 0.46. yr^{-1}, ♀ L_{∞} = 373.39 mm) were similar. Both sexes grow rapidly during the first 2 years of life, reaching ~250 mm FL after ~2 years. Growth curves for fish obtained from NSW did not include an asymptotic growth phase, which reflects the absence of large fish in samples from this location. There is no evidence to conclusively determine whether this result reflects the absence/rarity of large, old *S. australasicus* off NSW or is simply a result of limitations in the sampling program. A gradient in the size distribution of *S. australasicus*, with smaller fish occurring mainly inshore and larger fish being more abundant offshore was observed in SA. The paucity of large fish in samples from NSW could reflect the inshore concentration of sampling effort in that location. Determining whether or not large/old *S. australasicus* occur in waters off NSW is the highest priority for research on the age and growth this species. Studies of the age and growth of larval and juvenile *S. australasicus* are also needed to refine current knowledge.

5.1 Introduction

Data on the patterns of age and growth of fish form a critical component of the scientific information used to underpin the sustainable management of fisheries resources (Jobling 2002). Age information provides the framework for quantitative investigations of population dynamics and is a key structural element of population models (Murray and Gaughan 2003) that are used to assess the responses of populations to environmental change (Lluch-Belda *et al.* 1992; Alheit and Niquen 2004), fishery exploitation (Wolf 1992), and to monitor recovery from disease outbreaks (Hyatt *et al.* 1997; Ward *et al.* 2001).

Growth increments in otoliths provide a means to estimate the age and growth patterns of teleost fishes (e.g. Beamish and McFarlane 1983). When these structures are used to estimate age it is important that seasonal timing and frequency of deposition are validated (Beamish and McFarlane 1983). Direct age validation using biochemical markers is often difficult in small pelagic fishes due to low survival rates and logistical difficulties associated with maintaining captive specimens for extended periods (Fletcher 1995; Stewart *et al.* 1999; Hoedt 2002; Rogers *et al.* 2003).

Considerable effort has been expended investigating the age and growth of members of the genus *Scomber*, including *S. japonicus* which is closely related to *S. australasicus.* In *S. japonicus* off South Africa and California the deposition of opaque and translucent zones occurs at the rate of one of each per year (Gluyas-Millan and Quinonez-Velazquez 1997). *S. japonicus* reaches up to ~410 mm total length (TL), lives for 8-10 years and has highly variable growth rates (Baird 1977; Perrotta 1992; Lorenzo *et al.* 1995; Gluyas-Millan and Quinonez-Velazquez 1997). The growth of *S. japonicus* appears to be rapid during the first year when it reaches sizes between 150 and 200 mm (Lorenzo *et al.* 1995) and remains high prior to sexual maturity. Von Bertalanffy growth parameters vary widely among studies and regions but the asymptotic size is generally attained at ~4 to 6 years of age.

Stevens *et al.* (1984) found that *S. australasicus* attained sizes of up to 440 mm fork-length (FL) in the GAB and estimated that fish were aged up to ~8 years. Stewart *et al.* (1999) showed that off eastern Australia an opaque zone is deposited during winter in the otoliths of one-year old *S. australasicus*, and that zones became visible in early summer (Stewart *et al.* 1999). Stewart and Ferrell (2001) estimated the ages and growth rates of *S. australasicus* taken off southern NSW in commercial purse seine operations and in a fishery-independent sampling program. Most fish in

the commercial catches were 1–3 years old and the maximum age was ~7 years. A study of *S. australasicus* in New Zealand waters (North Island) included larger fish (400–500 mm FL) than were recorded in the two previous studies in southern Australian waters (Morrison *et al.* 2001). The modal age in New Zealand waters was estimated to be ~8–10 years and fish were estimated to live for up to 23 years (Morrison *et al.* 2001). However, the age determination method used by Morrison *et al.* (2001) was based on zone counts in sectioned otoliths, which has been shown to be problematic for this species (Stewart and Ferrell 2001).

Estimating the age of small pelagic fishes is commonly problematic (Butler *et al.* 1996; Gaughan and Mitchell 2000; Welsford and Lyle 2003; Rogers and Ward 2007). Otolith-weight based methodologies have proven to be cost-effective and practical for estimating the age of fish with otoliths that are difficult to read (Boehlert 1985; Pawson 1990; Cardinale *et al.* 2000; Cardinale and Arrhenius 2004; Francis and Campana 2004; Francis *et al.* 2005). This approach involves obtaining estimates of age by counting annuli in otoliths considered to provide accurate information about age. The relationship between age and otolith weight determined from these high quality otoliths is then used to estimate the age of specimens for which accurate otolith weights are known, but for which annuli counts cannot be obtained or are considered to be unreliable (e.g. Worthington *et al.* 1995).

In this study, we describe and compare the size, age and growth patterns of *S. australasicus* from southern (WA, SA, Vic and Tas) and eastern (NSW and southern Qld) Australia. We also evaluate methods for estimating the age distributions of *S. australasicus* in Australian waters; compare the size and age distributions of commercial catches and fishery-independent samples in these states and compare the size and age distributions of catches taken by recreational and commercial fishers off NSW.

5.2 Materials and methods

5.2.1 Sample collection

A summary of sampling methods, regions, numbers of samples and numbers of individuals is shown in Table 5.1. Sampling locations are provided in Figure 5.1.

In SA, fishery-independent samples were collected from Gulf St Vincent, Backstairs Passage, Investigator Strait, southern Spencer Gulf and the eastern Great Australian Bight (GAB) between January 2001 and March 2006 (Fig. 5.1, Table 5.1). Schools were located near underwater features using sonar on *RV* Pagrus, *RV* Odyssey and *RV* Ngerin. The vessel was then anchored and light berley was dispersed from a pot or bag. Adults and juveniles were taken using lines with either baited hooks or baitfish jigs.

In NSW, juveniles and adults for age determination were collected from recreational catches, including gamefishing tournaments and research surveys. Samples were collected using hand-lines and by rod and line using lures, small baits and or baitfish jigs.

Samples of juveniles and adults were also collected opportunistically from commercial catches in SA, WA, Vic, Tas, NSW and Qld. Samples were also purchased from fish markets in NSW. Sub-samples from the commercial catches were frozen fresh and dissected at NSW DPI and SARDI Aquatic Sciences. Biological samples, including otoliths and gonads, and data relating to dissections were sent to SARDI Aquatic Sciences for further analysis.

5.2.2 Laboratory analysis

Fish were measured to the nearest mm (FL) and weighed to ±0.01g. Both otoliths (sagittae) were removed from the semi-circular canals using fine forceps. Whole otoliths were soaked overnight in 10% sodium hypochlorite solution to remove excess tissue, rinsed in distilled water and dried in IWAKI™ plastic micro-plates. Otoliths were dried in the oven for 24 hours at 50°C and weighed to ±0.00001 g. Counts of opaque zones were made for one whole otolith from each specimen. To determine the best otolith preparation methodology a pilot study was conducted to compare the readabilities of whole and sectioned otoliths (n = 157). Sectioned otoliths could not be interpreted with a suitable level of confidence as ancillary structures and growth checks made it difficult to interpret opaque zones (See Figs 5.2 and 5.3). Whole otoliths were analysed in distilled water against a black background using light microscopes at magnifications up to 60x.

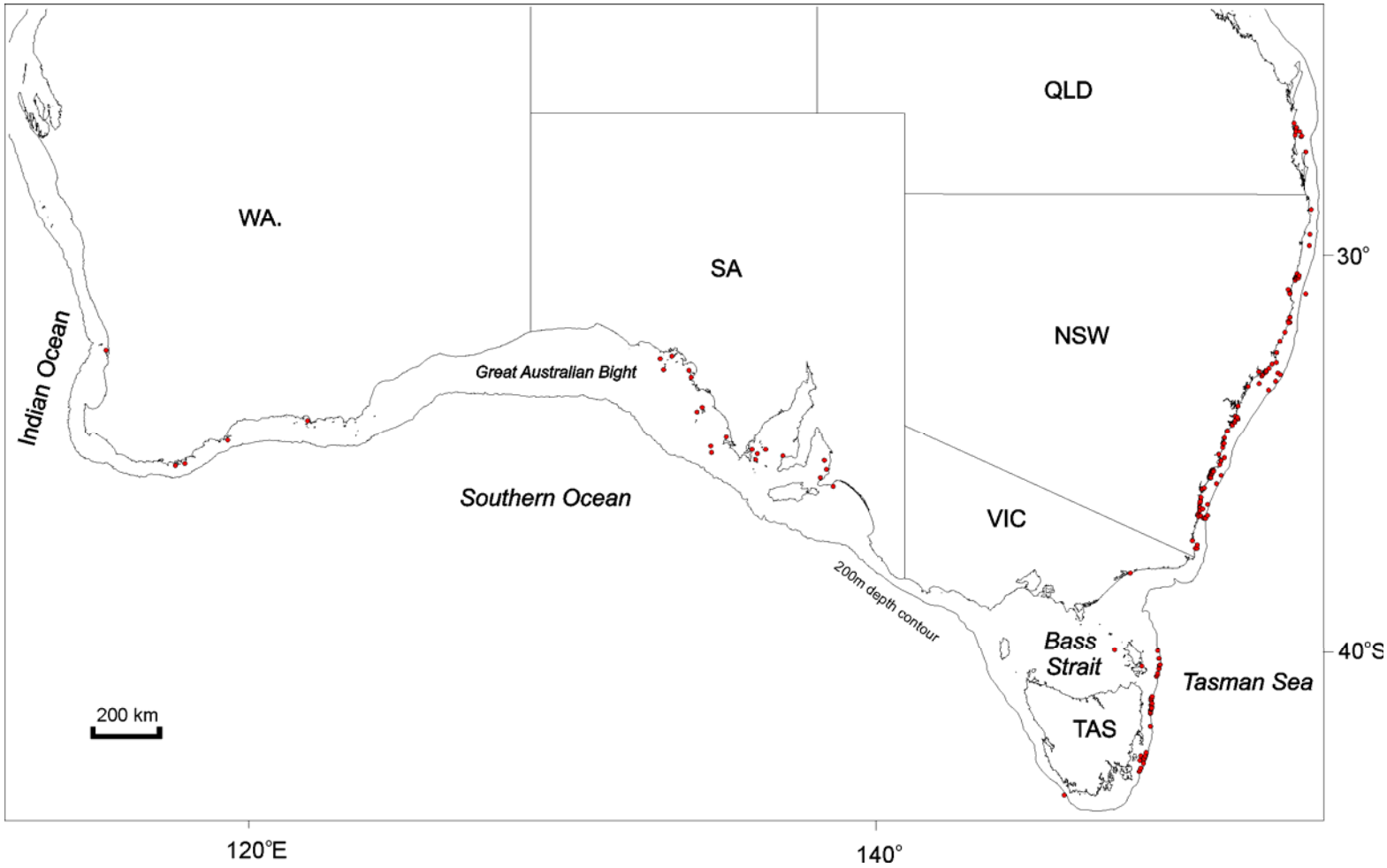

Figure 5.1. Map showing locations where samples of *S. australasicus* were collected during this study.

Table 5.1. Sample sources, methods, regions and numbers of *S. australasicus* collected between 1986 and 2005 (based on all fish measured). FIMGN = Fishery-independent multi-panelled gill-net, FIL = fishery-independent line fishing, MT = Mid-water Trawl, MN = Mesh net, Purse seine = PS, Prawn Trawl = PT. CCS = Commercial catch samples from market, GN = gillnet, NA = gear type unknown.

State	Year	Sampling method	n individuals
Western Australia	2002	NA	457
		Total	**457**
South Australia	2001	PS	3
	2002	PS, FIL, FIMGN	178
	2003	FIL, FIMGN	788
	2004	FIL, FIMGN	1,343
	2005	FIL, FIMGN	530
		Total	**2,842**
Victoria	2002	PS, MWT	79
	2003	PS, MT, MN, PT	154
		Total	**233**
Tasmania	1986	MT	106
	1987	MT	21
	2001	MT	25
	2003	MT	223
		Total	**375**
New South Wales	1995	CCS	17
	1996	CCS	420
	1997	CCS	235
	2002	FIL, NA	468
	2003	FIL, PS, NA	1,885
	2004	FIL, PS, NA	3,022
	2005	FIL, PS, MT, NA	988
		Total	7,035
Queensland	1993	NA	26
	1995	MT	9
	1996	PS	9
	1998	PS, GN	13
	2003	NA	27
		Total	84
		Grand Total	**11,026**

5.2.3 Data analysis

5.2.3.1 Otolith edge analysis

Seasonal patterns of translucent and opaque zone formation at the posterior edge of whole otoliths were analysed using sub-samples collected in South Australia and New South Wales. Transmitted light (16-40x magnification) was used and outer zone edges were classified as opaque or translucent. If light refraction made identification of edge types difficult the otolith edge type was not classified (un-class).

5.2.3.2 Otolith readability (RI)

An otolith readability index (RI) was established and each whole otolith was assigned a readability score where; 1 = excellent (absolute confidence), 2 = very good (confidence of ±1), 3 = average (confidence of ±2), 4 = poor (confidence of ±3) and 5 = unreadable. Zone counts were undertaken by two independent readers for a subset of whole otoliths. Where the zone counts differed, the count of the first (most experienced) reader was used in the subsequent analysis.

5.2.3.3 Estimation of between reader error

Opaque zone counts were made by two independent readers for a subset of otoliths from NSW to estimate average percent error (APE). APE was calculated using methods in Beamish and Fournier (1981), where:

$$APE = \frac{100}{N}\sum_{i=1}^{R}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij}-X_{j}\right|}{X_{j}}\right]$$

and N was the number of fish aged, R is the number of times each otolith was aged by different readers, Xij was the ith age estimation for the jth individual, and Xj was the mean age for the jth individual.

5.2.3.4 Age estimation

To estimate age distributions from opaque zone counts in whole otoliths, median birth-dates of January 1 in southern Australia (WA, SA, VIC, TAS) and September 1 in eastern Australia (Qld, NSW) were assigned to individual fish to estimate a decimal age. These dates were chosen based on information on spawning seasonality presented in Chapter 6 of this report. Opaque zone formation occurs at the same time as the spawning season off eastern Australia, i.e. winter-spring (Stewart and Ferrell 2001) and was assumed to occur between spring and summer off southern

Australia (based on edge analysis). Based on the findings of the tank validation by Stewart *et al.* (1999), opaque zones were assumed to approximate annuli. Decimal ages were calculated based on the number of zones counted and the difference between the capture date and the assumed median birth date.

5.2.3.5 Age distributions from zone counts and otolith weight

To compare age distributions estimated from zone counting using the 'best' otoliths (RI = 1 and 2) and otolith weight regressions, ages were calculated using linear relationships between otolith weight and age (RI = 1 and 2) for fish from SA and NSW. Two sample Kolmogorov-Smirnov (ks) tests were used to test if age distributions from otolith weight-age regressions and otolith zone counts were from the same distribution. Otolith weight-age regression equations for fish from SA and NSW were used to estimate age distributions. Box plots of otolith weight in each age class were used to indicate maximum and minimum values, lower and upper quartiles and median otolith weight for the 'best' otoliths. Ages estimated using the otolith weight-age regressions were rounded and expressed as age class+ (e.g. *x*+ year old). Differences between age distributions of samples collected from commercial and recreational catches in NSW were tested using two-sample ks tests ($\alpha<0.05$).

5.2.3.6 Growth patterns

The Von Bertalanffy growth function (*VBGF*) (Bertalanfy 1938) was fitted to the length at age datasets and is represented by the equation:

$$L_t = L_\infty \left[1 - \exp(-k(t - t_0))\right]$$

where L_t is the mean length at age t (yrs), L_∞ is the asymptotic length (mm) predicted by the equation, k is a constant describing the rate (.yr^{-1}) at which the asymptotic length is reached, and t_0 is the theoretical age at zero length. *VBGF* fits were estimated by minimising the sums of squares using the *Solver* function in MS Excel. *VBGF* fits by sex were compared by analysis of the residual sums of squares (Haddon 2001). *VBGF* growth curves are presented by sex and with sexes combined for SA and NSW. Size at age data from WA, SA, Vic. and Tas. were then combined to model growth in the southern Australia and data from NSW and Qld were combined to comprise eastern Australia.

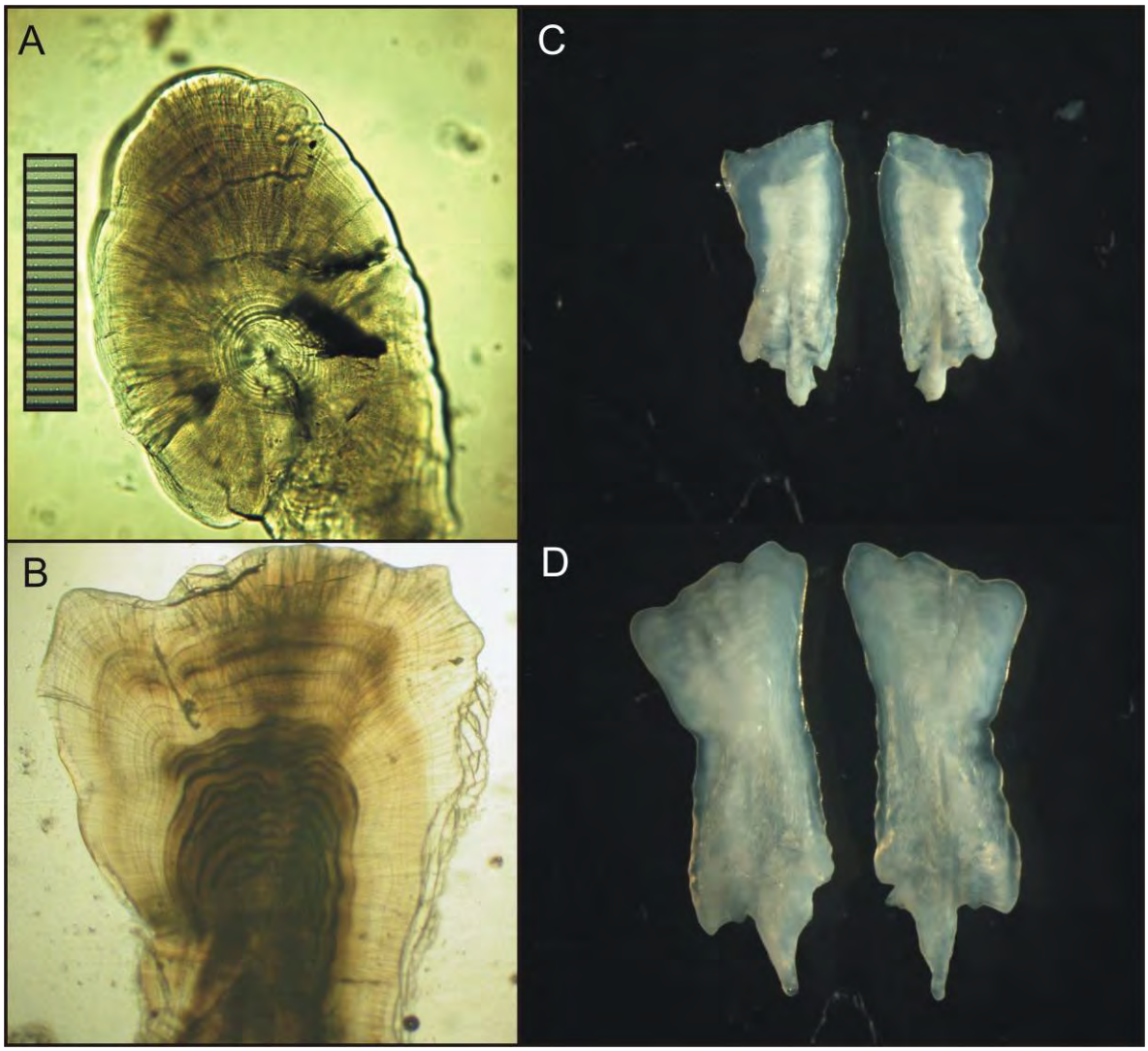

Figure. 5.2. **A.** Ground sagittal section of otolith from an early juvenile *S. australasicus* showing assumed daily increments (scale bar = 1 mm, small increments are 100 μm), **B.** Ground sagittal section of otolith from an adult fish showing numerous growth checks and irregularities and the characteristic large central opaque region radiating out from the primordium, **C**. Whole sagittae from a late stage juvenile fish (*n* = 0 opaque zones) showing the large inner opaque region that represents larval and early juvenile growth. **D.** Whole sagittae from an adult fish showing the alternating opaque (*n* = 6 opaque zones) and translucent zones.

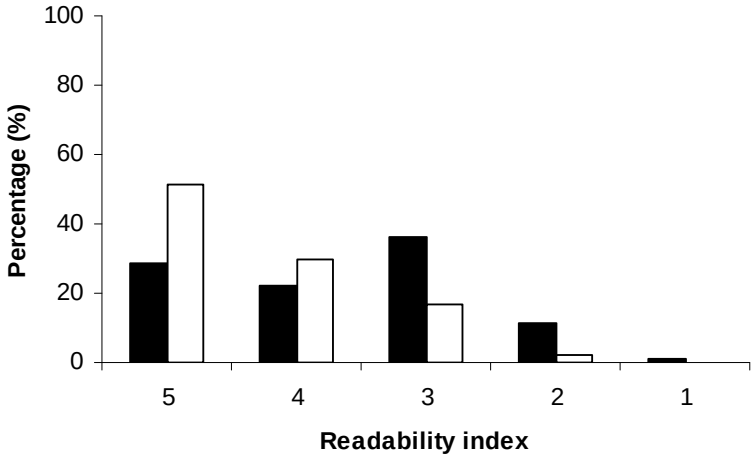

Figure 5.3. Pilot comparison of readability of whole (black bars) and sectioned (white bars) otoliths (n = 157).

5.3 Results

5.3.1 Size distributions

5.3.1.1 Spatial patterns

S. australasicus collected in Australian waters between 1993 and 2005 ranged between 110 and 420 mm FL. Fish >300 mm FL were more common in samples collected from SA, Vic and Tas than other states. Size distributions in each state were frequently comprised of multiple modes (Fig. 5.4).

Western Australia

Fish sampled in WA ranged between 120 and 360 mm in 2002 (Fig. 5.4). The mean size was 199 mm (±2.1). The size distribution showed at least five size modes.

South Australia

Size distributions (n = 2,842) in SA were dominated by fish taken by fishery-independent sampling that ranged between 110 and 420 mm with a mean size of 296 mm (±0.97). Most samples comprised fish in the 200 to 400 mm FL size classes (Fig. 5.4). Size distributions were characterized by several modes (up to 4). Fish >300 mm were mostly found in southern Spencer Gulf and offshore waters of the eastern GAB.

Victoria

Fish from commercial catches in eastern Vic ranged between 120 and 380 mm between 2002 and 2003 (Fig. 5.4). The mean size was 260 mm (±4.8). As in SA and WA, distinct modes were present. However, unlike the other states where size classes overlapped, Vic size distributions were discontinuous, with small size classes (mostly <300 mm) taken in purse seine catches and larger size classes (300–380 mm) taken in mesh nets and by mid-water trawling.

Tasmania

The mean size of fish collected from mid-water trawl catches in Tas waters was 358 mm (±1.2) and fish ranged in size between 280 and 410 mm between 1986 and 2003 (Fig. 5.4).

New South Wales

Fish collected in NSW waters ranged from 115 to 420 mm between 1995 and 2005 (Fig. 5.4). Most samples were collected from commercial and recreational catches and by fishery-independent methods. Common size classes were between 200 and 320 mm; the mean size was

263 mm (±0.57). There were three modes apparent at the 165 mm, 225 mm and 295 mm size classes.

Queensland

Fish collected in Qld waters ranged from 150 to 240 mm between 1993 and 2003 (Fig. 5.4). Samples were collected from commercial purse seine catches, gill-net and mid-water trawl catches. Common size classes were between 155 and 200 mm and the mean size was 182 mm (±1.96). There were three modes present at 165, 190 and 210 mm size classes.

5.3.1.2 Temporal patterns

South Australia

In SA, there were two to three strong size classes in samples collected between 2002 and 2005 (Fig. 5.5). There was minimal evidence of any modal size progressions between years. Size classes between 250 and 350 mm were dominant, except in 2002, when a size class at ~185 mm was strong.

New South Wales

In NSW there were typically two to three strong size classes in samples collected between 1996 and 2004 (Fig. 5.6). Size distributions were generally either bi- or tri-modal and there was little or no evidence of progressions in size modes between years. Size classes between 220 and 300 mm were dominant in most years.

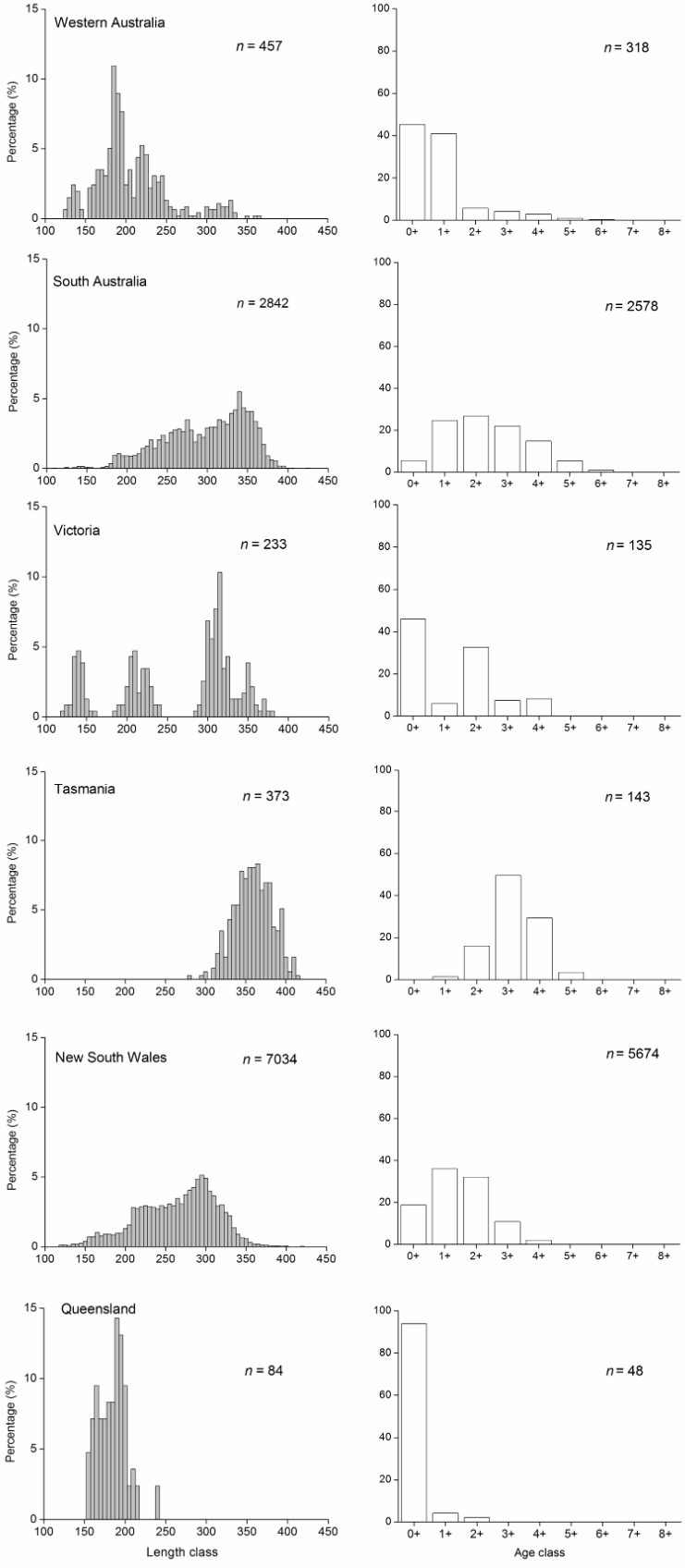

Figure 5.4. Size and age distributions for *S. australasicus* sampled in WA, SA, Vic, Tas, NSW and Qld between 1995 and 2005.

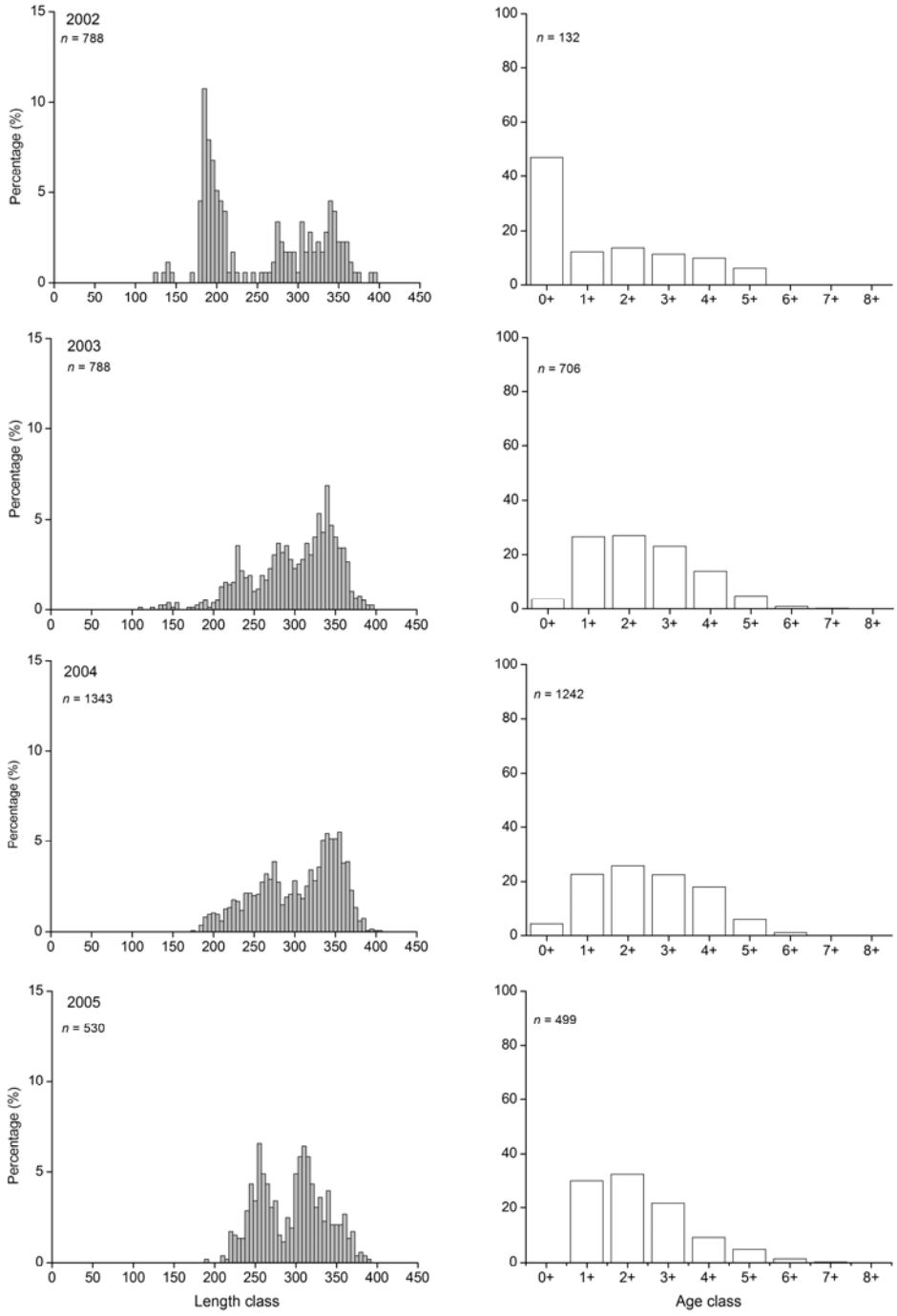

Figure 5.5. Temporal patterns in size and age distributions in SA between 2002 and 2005.

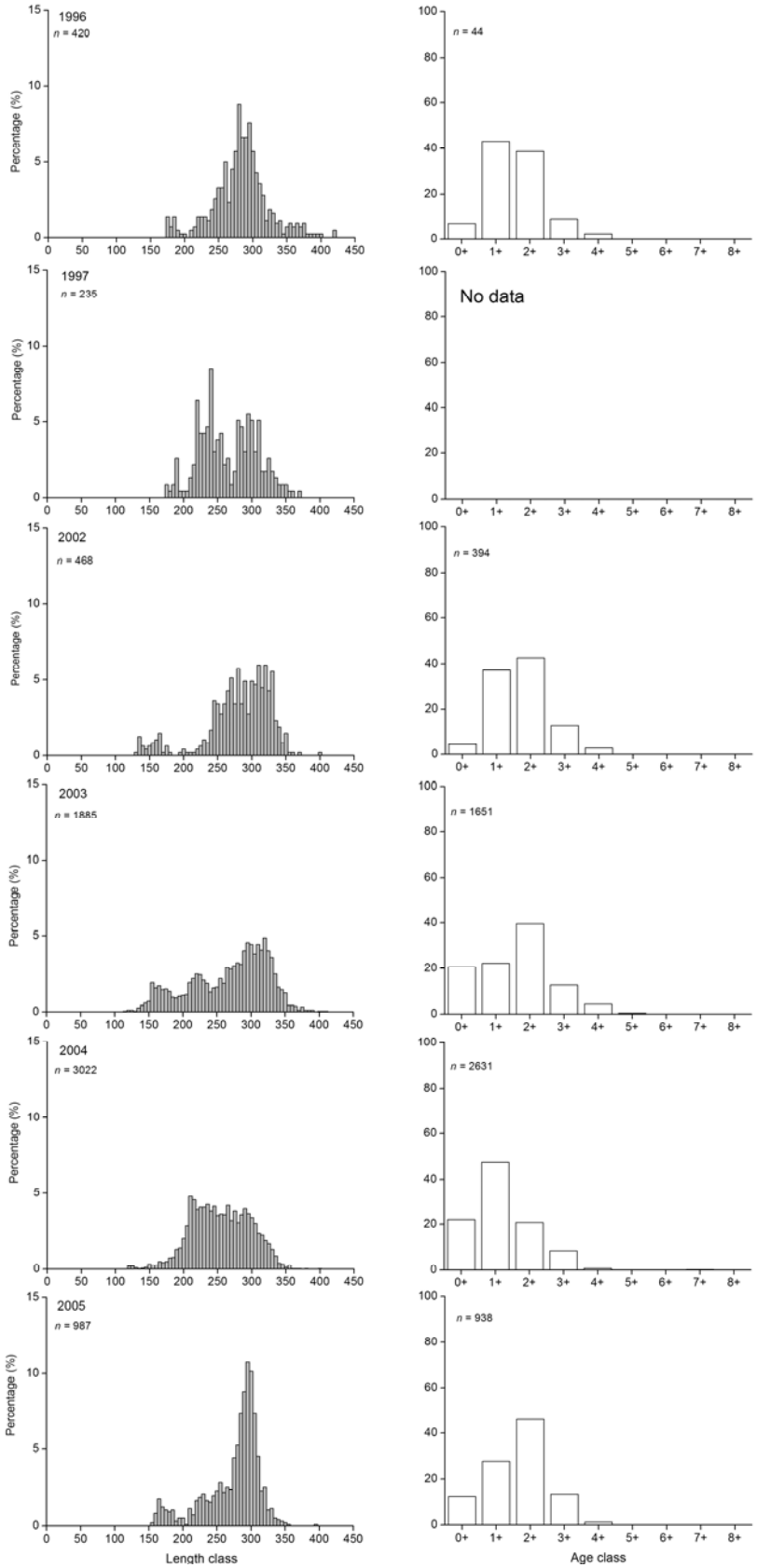

Figure 5.6. Temporal patterns in size age distributions of *S. australasicus* in NSW between 1996 and 2004.

5.3.2 Otolith edge analysis

5.3.2.1 South Australia

For otoliths collected in SA (*n* = 2,842), opaque edges were most common in August and September (33% and 76% of edges classified, respectively) and were common from August to December (Fig. 5.7). Edge types were difficult to classify between February and June. Analysis of otoliths collected between July and August were based on small sample sizes (n<20).

5.3.2.2 New South Wales

Analysis and classification of edges of otoliths (*n* = 7,034) collected in NSW showed translucent edges were dominant throughout most of the year. The presence of identifiable opaque edges was highest (≥35% of edges classified) in otoliths collected between December and March (Fig. 5.7). Translucent edges were most common in July (>80% of edges classified). Edge types were most difficult to classify between June and August. This information supported the validation of Stewart *et al.* (1999). Based on this evidence it was assumed that opaque zones were deposited in spring/summer.

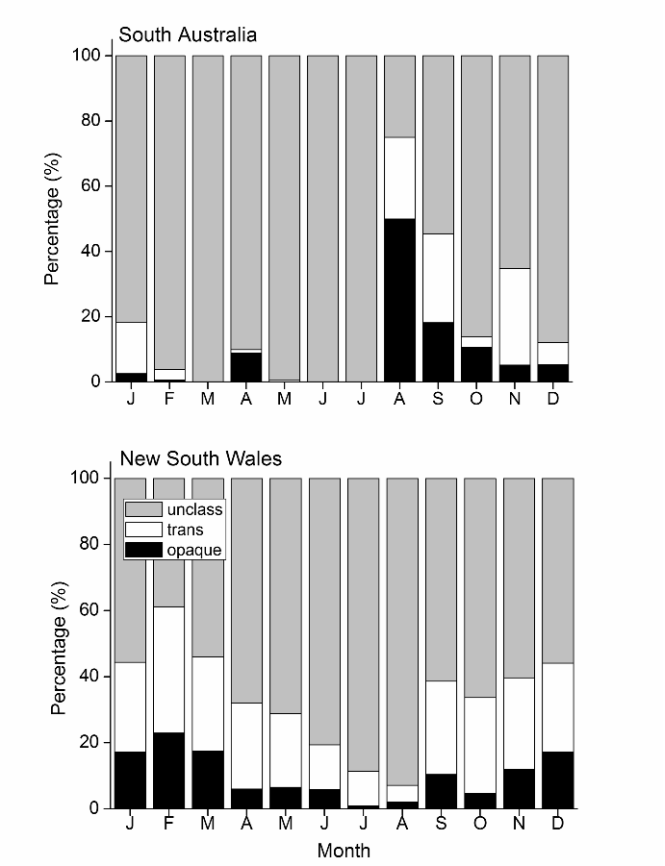

Figure. 5.7 Edge analysis of *S. australasicus* otoliths examined from South Australia (2002 to 2005) and New South Wales (1996 to 2005).

5.3.3 Otolith readability index (RI)

A total of 8,457 whole otoliths from all states were analysed and assigned RI scores of between 1 and 5 (Fig. 5.8). Of these, 2.8% were assigned a RI score of 1. A further 17.4% were 2s, 34.7% were 3s, 16.6% were 4s and 28.6% were 5s or unreadable. With the exception of otoliths collected from Vic and Qld (which had lower sample sizes) readability scores were predominantly 2s to 5s. Readabilities generally declined (from 1 to 5) with increases in the number of opaque zones present in the otolith (Fig. 5.9).

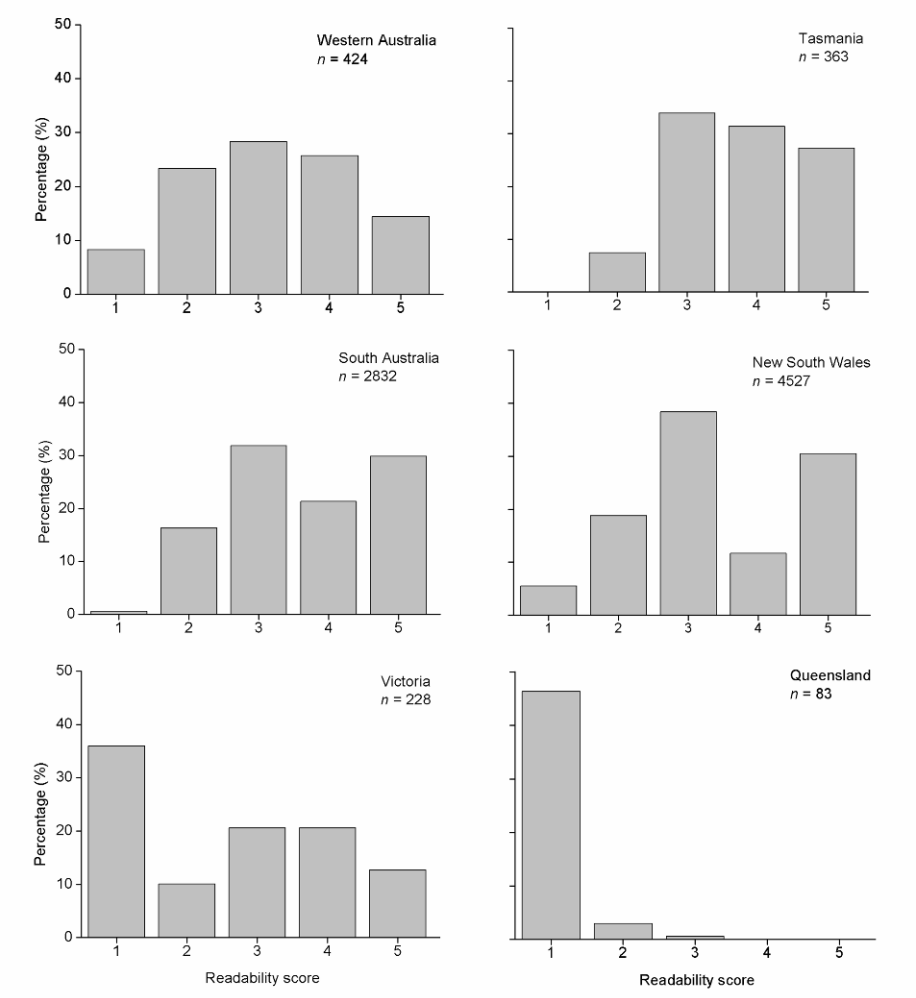

Figure 5.8. Readability index scores for *S. australasicus* otoliths examined for each state.

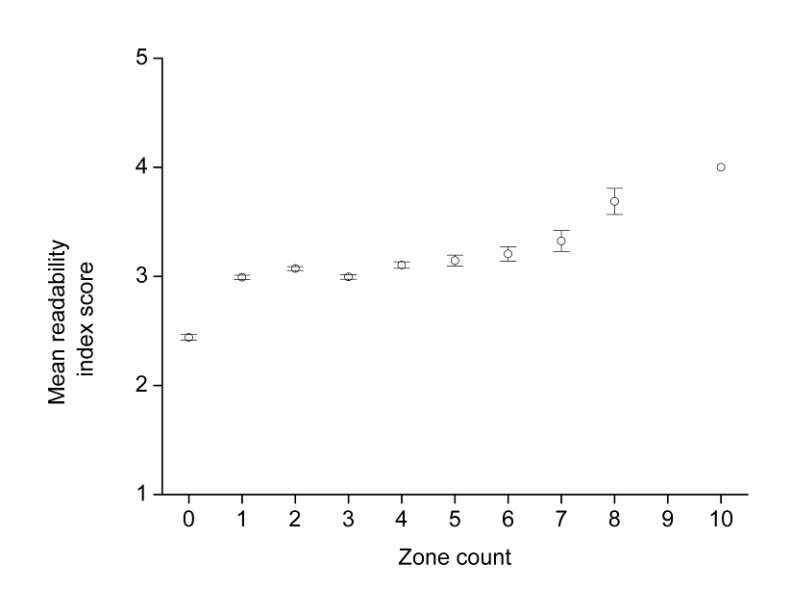

Figure 5.9. Mean readability with age for all otoliths examined (error bars = ±1 s.e.).

5.3.4 Between reader error (APE)

APE estimated for a sub-sample (n = 400) of otoliths collected from NSW was 13.82% (95% CI = 13.62 –14.02) and age estimates between readers were significantly different (*ANOVA*, p = 0.003, F = 8.9). Power analysis suggested this test had adequate statistical power (0.84) at α = 0.001.

5.3.5 Age distributions from zone counts and otolith weight – age regressions

The relationship between otolith weight and age from the 'best' otoliths from SA (RI scores of 1 and 2) was described by the regression equation, O.wt = 1.27.Age + 2.34 (r^2 = 0.66, n = 440). The regression between age and otolith weight, Age = 0.52.O.wt - 0.36 (r^2 = 0.66, n = 440), was used to estimate ages for fish with reliable otolith weights from SA, WA, Vic and Tas.

The relationship between otolith weight and age for NSW was described by the equation, O.wt = 1.29.Age + 2.1 (r^2 = 0.69, n = 616). The regression between age and otolith weight, Age = 0.54.O.wt – 0.72 (r^2 = 0.69, n = 616) was used to estimate ages from otolith weight.

Box and whisker plots clearly show otolith weight increases linearly with age and fish in each age class had a wide range of otolith weights (Fig. 5.10). Ages estimated from otolith weight-age regressions ranged between 0 and 7 years.

Age distributions estimated using the otolith weight-age method were not significantly different to those estimated from the subset of 'best' otoliths in SA (ks = 0.55, p = 0.075) (Fig. 5.11) and NSW (ks = 0.44, p = 0. 352). However, the zone counting method using the 'best' otoliths led to a consistent positive bias in the assignment of fish to the 0+ age class when compared to the otolith weight based method.

5.3.6 Age distributions

5.3.6.1 Spatial patterns

Southern Australia (WA, SA, Vic, Tas)

S. australasicus collected in WA waters ranged between 0+ and 6+ years of age (Fig. 5.4). The 0+ and 1+ year old age classes were dominant and each comprised ≥40% of the age distribution. Samples from WA were only collected over two years and were dominated by relatively small, young fish (0+ and 1+ age classes). In SA, fish ranged between 0+ and 7+ years of age and the 1+ to 4+ age classes were dominant; in Vic, fish ranged between 0+ and 4+ years of age and the 0+ and 2+ age class were dominant. In Tas, fish ranged between 1+ and 5+ years of age and the 3+ and 4+ age classes were prominent.

Eastern Australia (NSW, Qld)

Off NSW, fish ranged in age between 0+ and 4+ years (Fig. 5.4). The 1+ and 2+ age classes were prominent. Samples collected from Qld were dominated by 0+ year old fish and were predominantly small (155–200 mm).

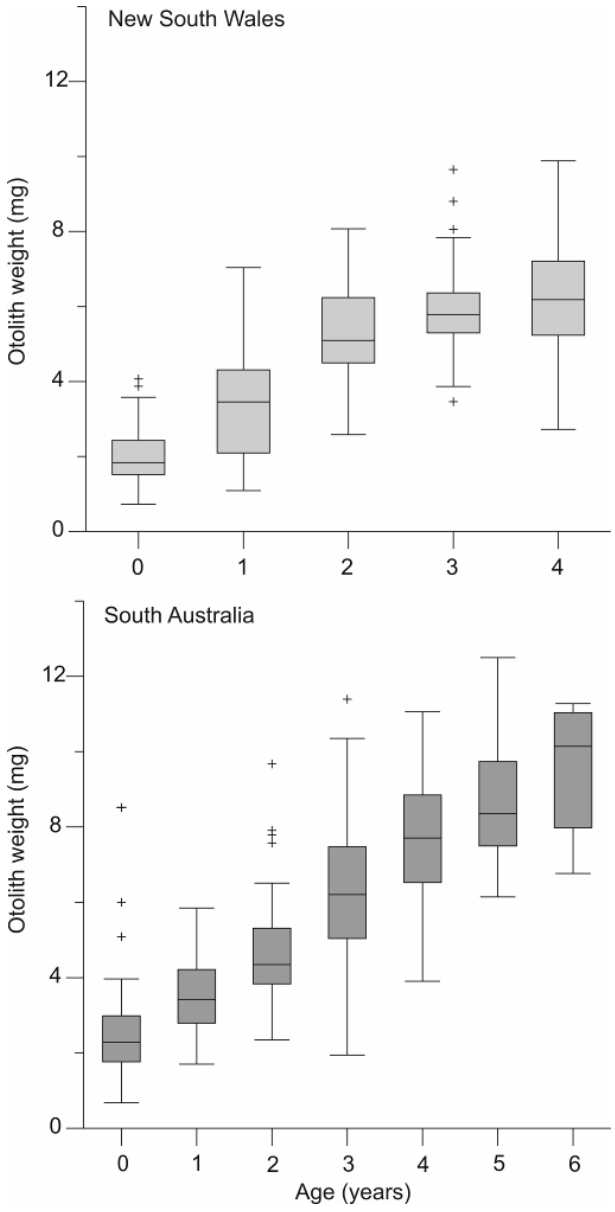

Figure. 5.10. Box and whisker plot of otolith weights by age class for 'best' otoliths (RI scores 1 and 2). The box is defined by the lower and upper quartiles and the centre line is the median. Outliers are represented by crosses.

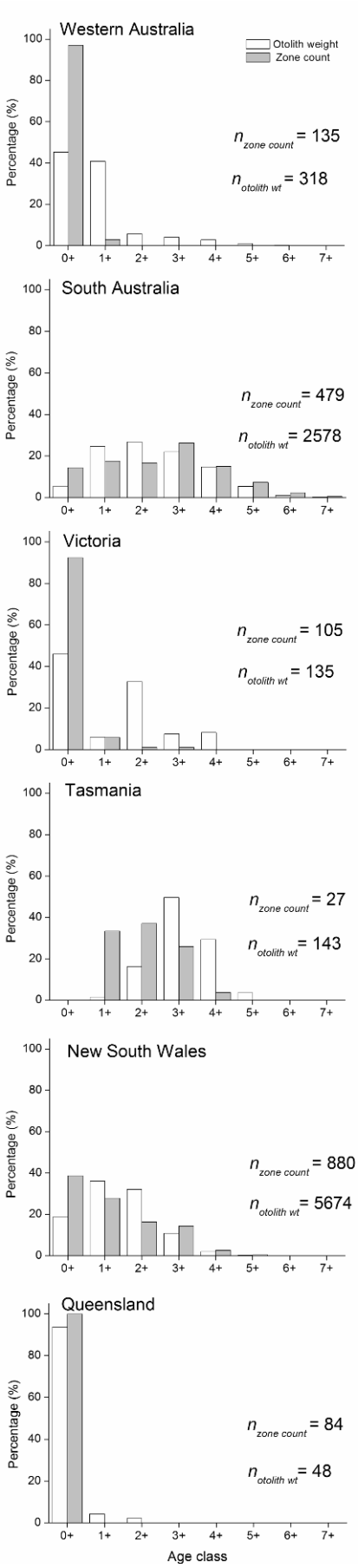

Figure 5.11. Comparison of age distributions estimated using the best estimates of age from zone counts and otolith weight-age relationships for *S. australasicus* sampled in WA, SA, Vic, Tas, NSW and Qld between 1995 and 2005.

5.3.6.2 Temporal patterns

Temporal patterns in age distributions were only assessed for SA and NSW due to the limited temporal coverage and low sample sizes in the other states. In SA there were typically strong 1+ to 4+ age classes present in samples (Fig. 5.12). These age classes were dominant except in 2002 when a strong (0+) age class was present in samples.

Off NSW, 0+ to 2+ year old age classes dominated samples collected between 1996 and 2005 (Fig. 5.13).

5.3.6.3 Comparison of size and age distributions of recreational, commercial and fishery-independent samples

Age distributions of commercial, recreational and fishery-independent samples collected in NSW between 1995 and 2004 are shown in Fig. 5.14. The 0+, 1+ and 2+ age classes were the most abundant in recreational and commercial catches and most samples comprised 0+ to 4+ age classes. There was no significant difference (ks = 0.18, *p*-value = 0.099) between the size distributions of fish from commercial and recreational catches (Fig. 5.14), whereas the fishery-independent samples were substantially different to those taken by recreational (ks = 0.42, *p*-value = 0.0000) and commercial (ks = 0.32, *p*-value = 0.0002) fishers. Similarly, there was no significant difference (ks = 0.22, *p*-value = 0.99) between age distributions of samples collected from the commercial and recreational sectors.

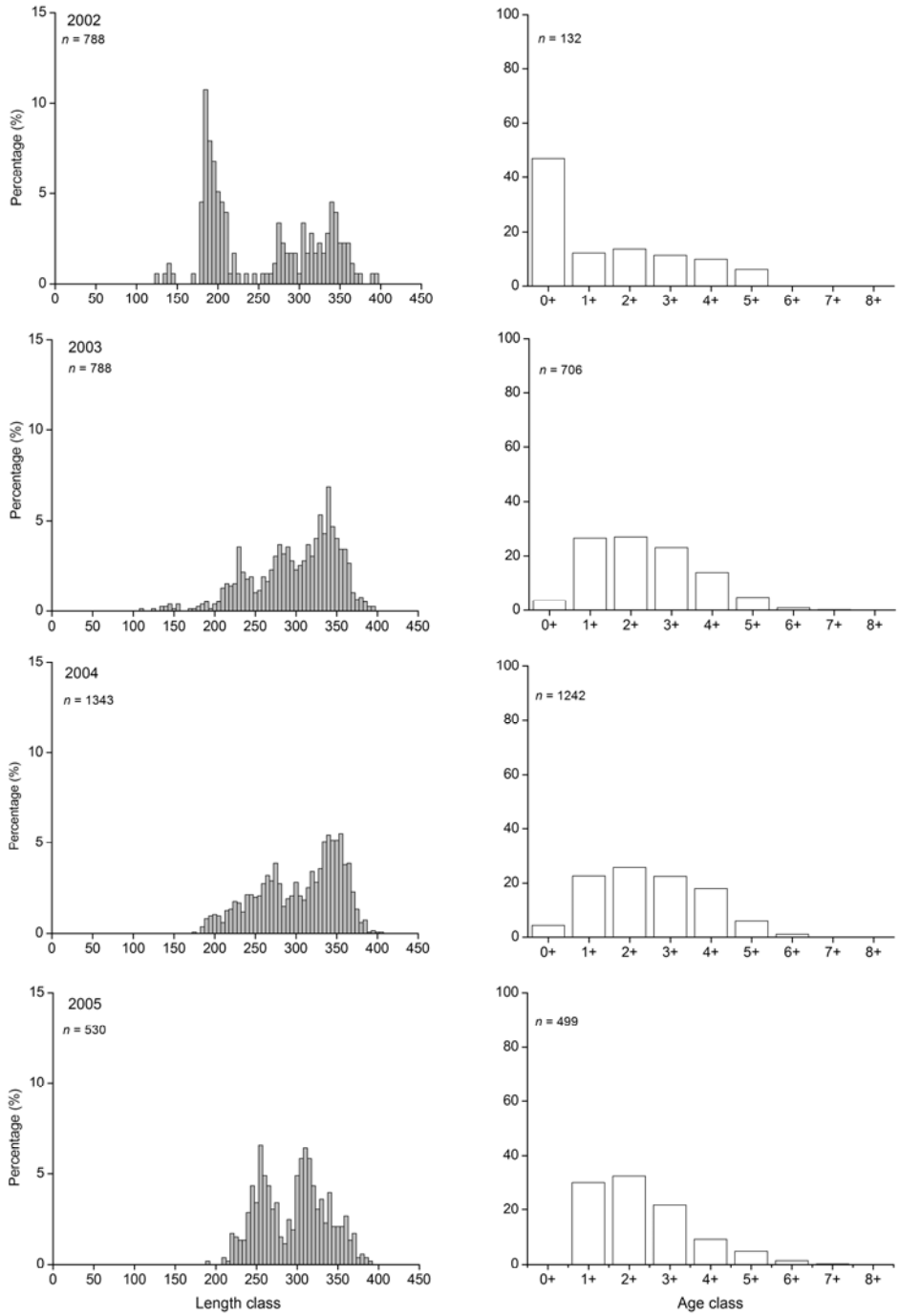

Figure 5.12. Temporal patterns in size and age distributions of *S. australasicus* in SA between 2002 and 2005.

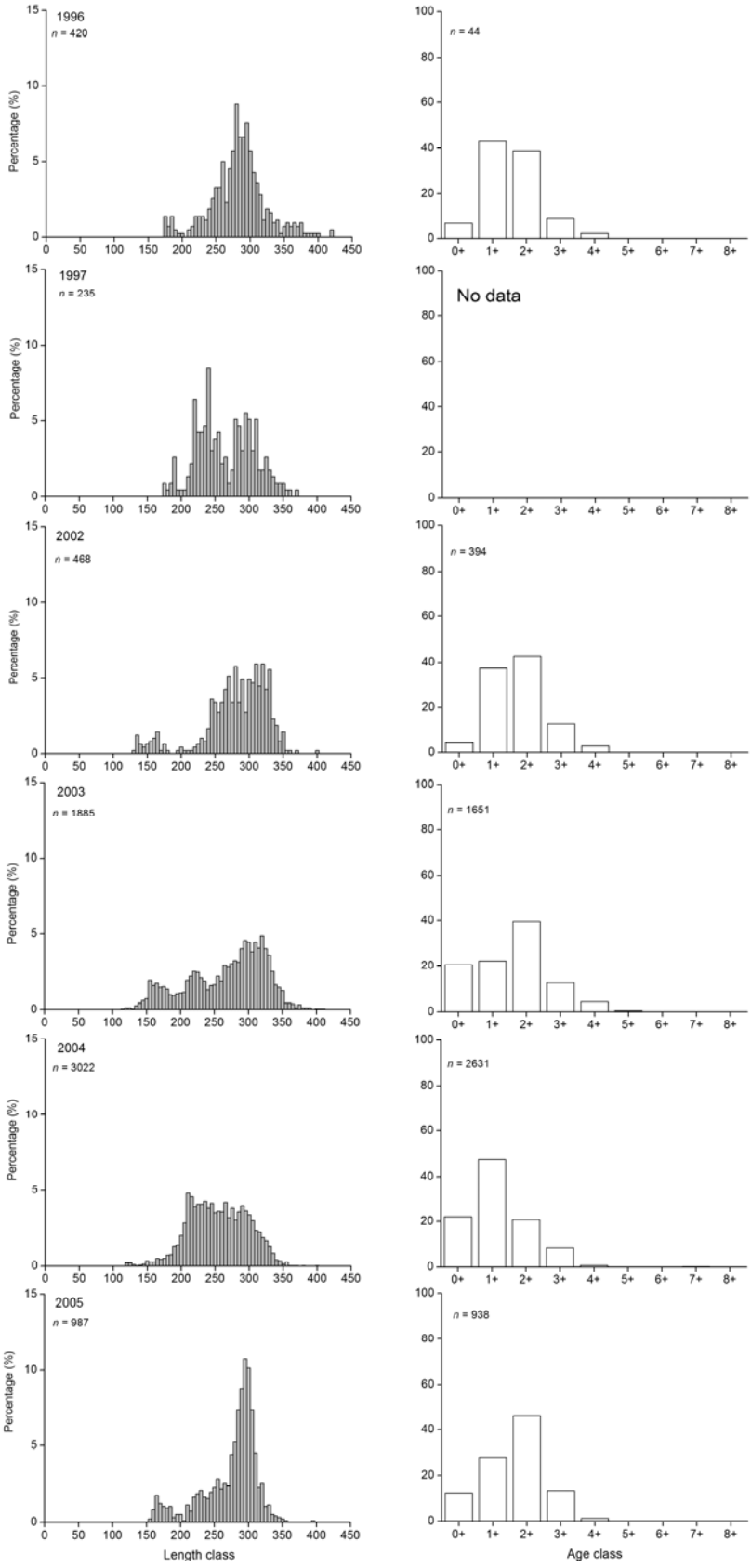

Figure 5.13. Temporal patterns in size and age distributions of *S. australasicus* in NSW between 1996 and 2005.

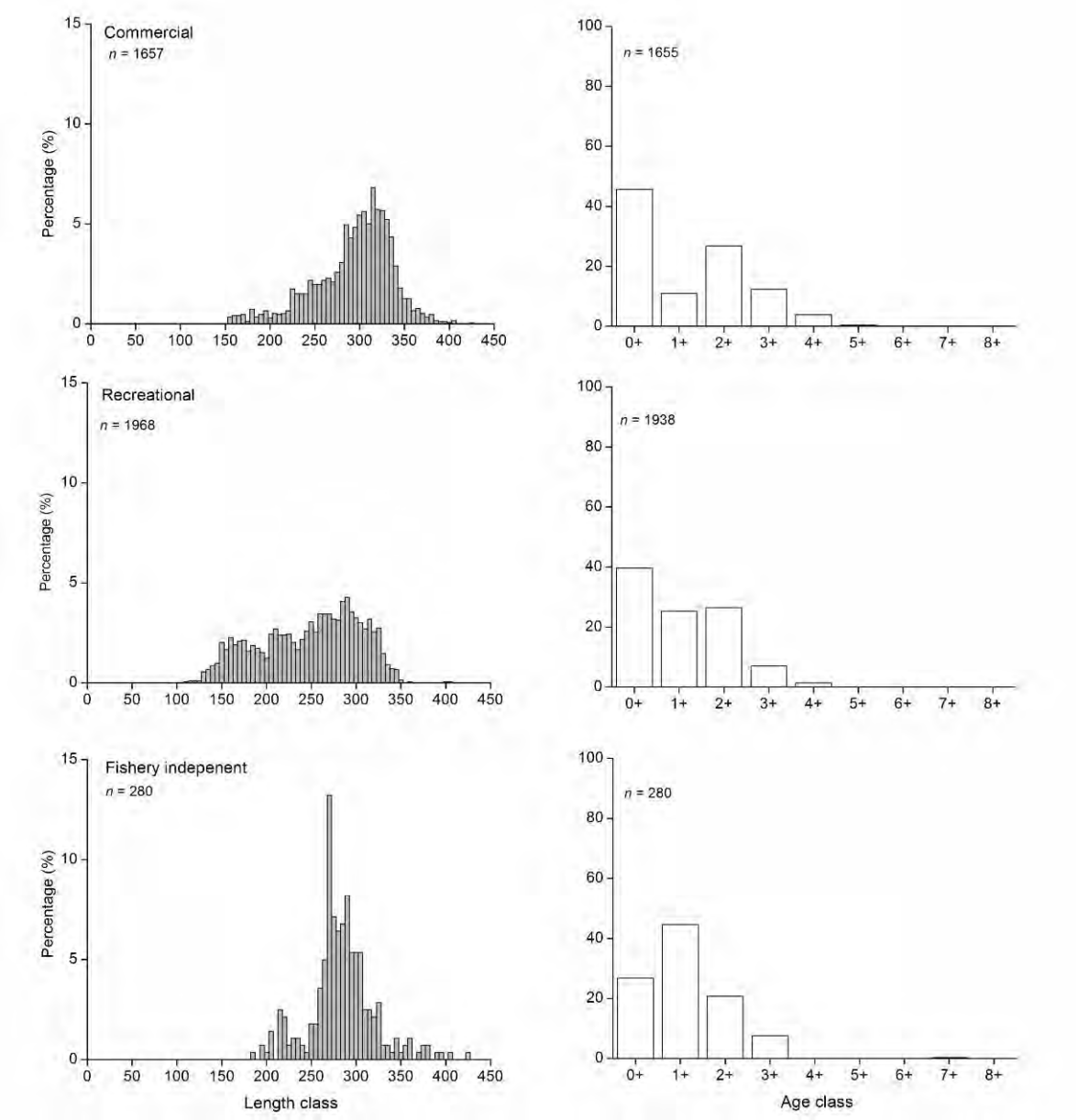

Figure 5.14. Size and age distributions of commercial and recreational catches and fishery-independent samples off NSW.

5.3.6.4 Growth patterns

The maximum age of males collected from southern and eastern Australia was 7 and 5 years, respectively. Females collected from southern and eastern Australia had maximum ages of 7 and 6 years, respectively. Von Bertalanffy parameters for SA (♂k =0.21.yr^{-1} ♂ L_∞ = 453.08 mm, ♀k = 0.50.yr^{-1}, ♀L_∞ = 384.61 mm) and NSW (♂k = 0.48.yr^{-1}, ♂ L_∞ = 365.86 mm, ♀k = 0.46.yr^{-1},♀ L_∞ = 373.39 mm) were similar and suggest that both sexes grew rapidly and reached sizes between 170 mm and 225 mm during the first year. Growth parameter estimates of mean sizes are shown in Table 5.2. Growth curves for South Australia and southern Australia are shown in Figure 5.15, and those for NSW and eastern Australia are shown in Figure 5.16. Growth slowed during the second to third year in both sexes and regions. Asymptotic growth was generally apparent in growth curves for SA and southern Australia (Fig. 5.15) but less evident for NSW and eastern Australia (Fig. 5.16). In SA, females grew slightly faster that males and had higher mean sizes, whereas in NSW the opposite occurred. There were no significant differences in growth trajectories between sexes in either state (SA, p = 1, d.f. = 2,146; NSW, p = 1, df = 4,748). Data was combined by sex and within region to provide for a broader spatial comparison of growth. In southern Australia, fish reached larger asymptotic sizes (L_∞ = 392.64 mm) and had slightly higher growth coefficients (k = 0.45.yr^{-1}) than those in eastern Australia (L_∞ = 378.88 mm, k = 0.43.yr^{-1}). Growth curves were not compared statistically due to the differences in the age distribution in southern and eastern Australia.

Table 5.2. Von Bertalanffy parameter estimates for *S. australasicus* sampled in eastern and southern Australian waters.

Location	**Sex**	L_∞	t_0	k	**Mean observed. Length**	**Mean Expected Length**	**r²**	n
South Australia	♂	453.08	-2.41	0.21	311.69	311.69	0.75	1174
	♀	384.61	-0.48	0.50	313.42	313.30	0.86	978
	♂+♀	382.95	-0.53	0.49	312.44	312.44	0.85	2147
Southern Australia		392.64	-0.61	0.45	288.16	288.11	0.92	3175
New South Wales	♂	365.86	-0.99	0.48	277.22	277.19	0.84	1485
	♀	373.39	-1.00	0.46	273.52	273.52	0.88	3269
	♂+♀	371.12	-1.00	0.46	274.67	274.62	0.86	4754
Eastern Australia		378.88	-1.12	0.43	265.79	265.74	0.90	5705

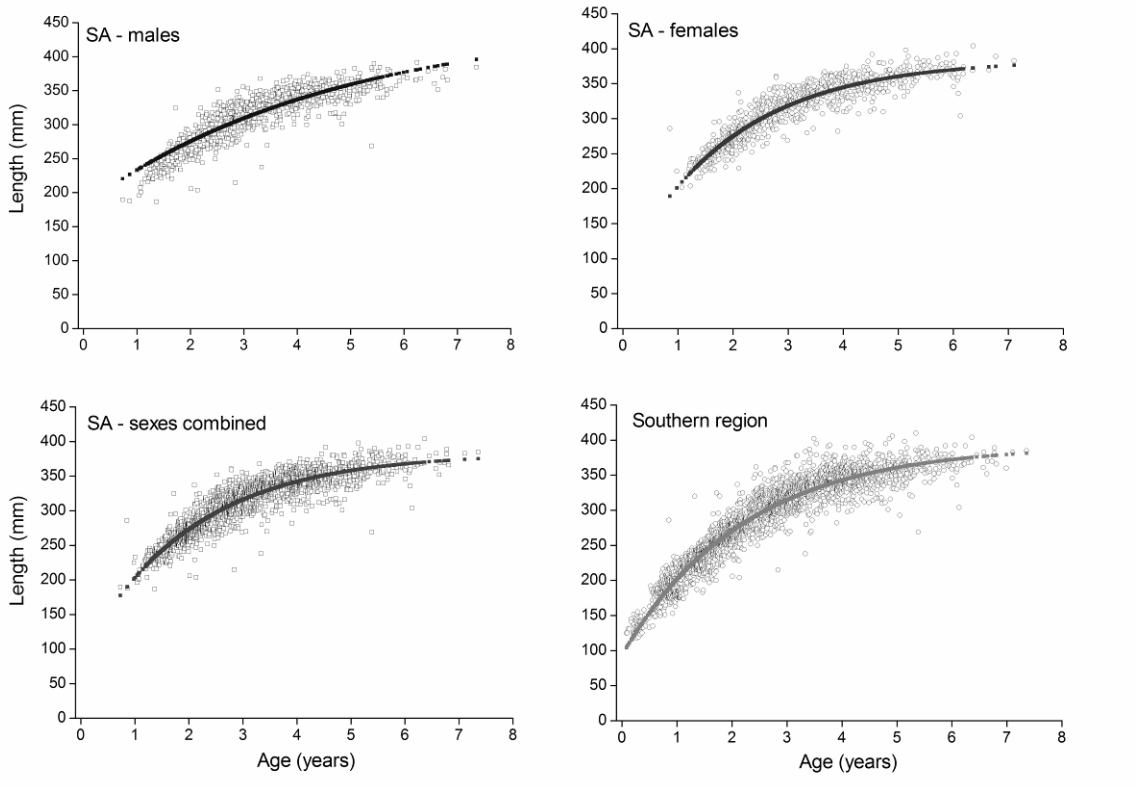

Figure 5.15. Length at age data with Von Bertalanffy growth curve fits by sex and for sexes combined for SA and southern Australia.

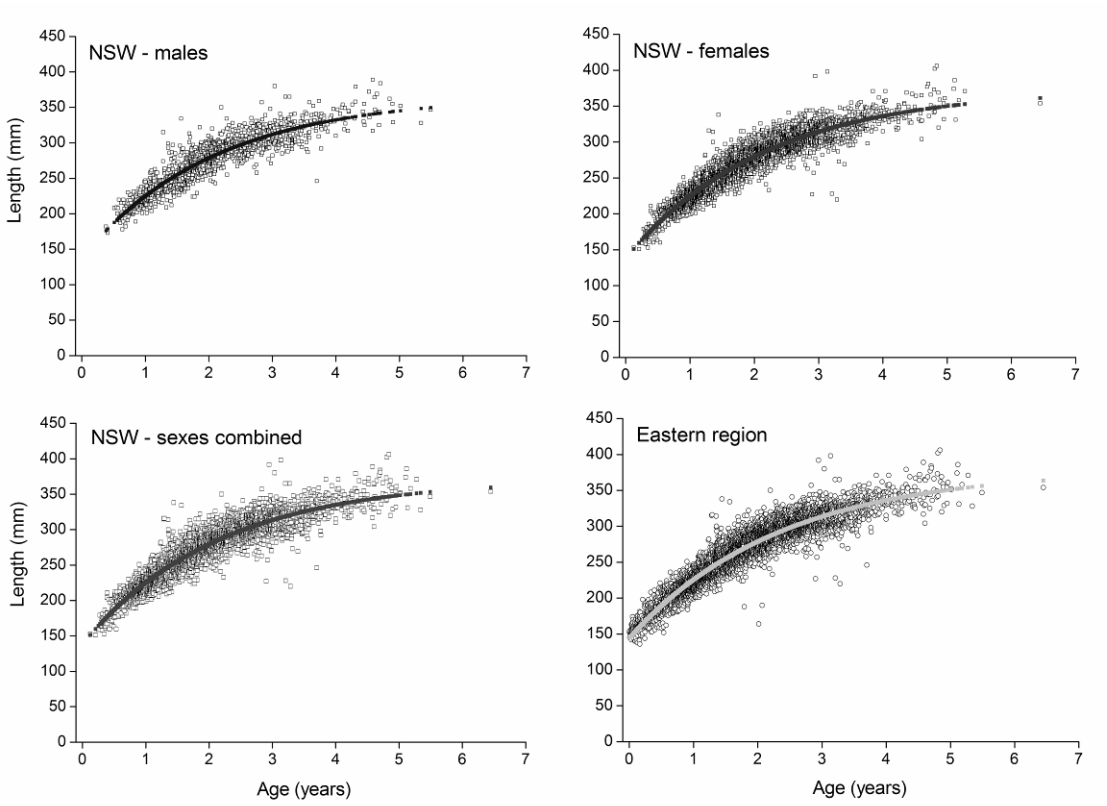

Figure 5.16. Length at age data with Von Bertalanffy growth curve fits by sex and for sexes combined for NSW and eastern Australia.

5.4 Discussion

In this study opaque edges were visible on otoliths of NSW fish mainly between December and March, which supports the findings of Stewart *et al.* (1999) who suggested that opaque zones start to form in winter in NSW and become visible after December. In SA, opaque edges were commonly visible in otoliths sampled from August to December. As the peak spawning season of *S. australasicus* is during August-September off NSW and December-March off SA (see Chapter 6 of this report), we assumed that in both eastern and southern Australia the first opaque zone was deposited after approximately one year of life, and that each subsequent zone represented another year of growth.

Results of the pilot project conducted during this study strongly supported the assertion of Stewart and Ferrell (2001) that sectioned otoliths of *S. australasicus* are more difficult to interpret than whole otoliths. However, whole otoliths are also difficult to read with most of the otoliths in the present study being assigned average or low readabilities. Readability scores generally declined as fish age increased, and this trend explains much of the difference in readabilities between locations. States such as Tas and SA, which had higher proportions of older fish in samples, had more otoliths with low readabilities than states where samples were dominated by young fish. The low readabilities of otoliths partly explained the high APE (13.82%), which is poor compared to many other teleosts but similar to estimates for several other small pelagic fishes (Campana 2001).

We also agree with the assertion by Stewart and Ferrell (2001) that there is significant uncertainty in the identification of the first zone in some specimens of *S. australasicus*. We found that this first zone can be embedded within the large opaque mass that lies at the centre of the otoliths of *S. australasicus* (Fig. 5.2). This characteristic is one of several factors that make the otoliths of *S. australasicus* difficult to read and increases the potential for under-estimating the age of fish, especially those with otoliths assigned low readabilities.

This uncertainty is one of the reasons that we used the age-otolith weight approach to estimate the age of fish with otoliths that were assigned low readability scores. The success of this method relies on having reliable regressions with which to estimate ages from otolith weight. We achieved this outcome by only using otoliths with high readability scores to establish the relationship. For the large SA and NSW datasets, the age distributions estimated using the otolith weight-age method were not significantly different to those estimated from the 'best' otoliths, but there were

clear differences in the age distributions obtained using the two methods in smaller datasets from the other states. In all cases, including SA and NSW, it was clear that the age distributions obtained from opaque zone counts alone included a higher proportion of fish in the 0+ age class than the age distributions obtained using otolith weight-age method (Fig. 5.11). This difference between the distributions reflects the decline in readability scores as fish age increases, which means that age estimates are available for a higher proportion of younger fish than older fish. This result effectively skews the age distributions obtained from opaque zone counts alone to the left.

One of the clear advantages of using the otolith weight-age method to estimate the age distributions of fish with difficult otoliths is that it reduces the potential for size-based biases. Hence, our results support previous findings that suggest that the otolith weight-age approach is a suitable and cost effective method for estimating fish age for *S. australasicus* (Fletcher 1995; Worthington *et al.* 1995; Fletcher and Blight 1996; Gaughan *et al.* 2002; Cardinale and Arrhenius 2004). However, it is important to note that although otolith weight increases linearly with age, a wide range of otolith weights was recorded for fish in each age class and further work is required to develop unbiased age class 'splitting' techniques. This should involve Bayesian approaches (e.g. OTOFAN) that incorporate data on fish length, otolith weight and zone counts to estimate age distributions (Francis and Campana 2004; Francis *et al.* 2005).

S. australasicus >300 mm FL were commonly collected from Tas, SA and Vic but were rarely collected from NSW, southern Qld or WA. The largest individual collected during the study was 422 mm FL and was taken in SA. However, this specimen was considerably smaller than both the Australian record of 650 mm TL (Hutchins and Swainston 1986) and the 510 mm FL fish recorded in a New Zealand study of this species (Morrison *et al.* 2001). Fish in excess of 450 mm have been taken by purse seining in the GAB (SARDI Aquatic Sciences, unpublished data). In SA, samples taken from inshore waters were comprised mainly of small fish whereas larger fish were more common in samples taken from offshore waters (see Chapter 6). Most of the fish sampled off eastern Australia were taken from the inner shelf, which may explain why the mean size of fish in these samples was relatively low.

The size distributions of fish from commercial and recreational catches off NSW were similar, presumably because both sectors predominately use this species as bait for predatory fishes. The

similarity in the size/age of fish targeted by these two sectors off NSW further emphasises the ongoing potential for conflict between these groups (see Chapter 3 of this report).

Our results suggest that *S. australasicus* reaches at least 7+ years of age in southern Australia, which is similar to the findings of Stevens *et al.* (1984) who collected fish up ~8 years old from the GAB. However, evidence that larger specimens occur in this region suggests that our results may underestimate the potential longevity of this species. Morrison *et al.* (2001) suggested that in the waters off the North Island of New Zealand *S. australasicus* lives for up to 23 years and modal ages were typically 8–10 years. The samples analysed by Morrison *et al.* (2001) included large fish (>500 mm) and the estimates of age may reflect the longevity of *S. australasicus* in NZ. However, as the study by Morrison *et al.* (2001) was based on the analysis of sectioned otoliths, which Stewart and Ferrell (2001) and ourselves found to be more difficult to interpret than whole otoliths, and the timing of zone deposition was not validated directly, the NZ results should be interpreted with some caution. It is notable that most studies of *S. japonicus* also suggest that this species lives for approximately 10 years (e.g. Ward *et al.* 2003).

In SA, females grew slightly faster that males and had higher mean sizes, whereas in NSW the opposite trend was apparent. *VBGF* estimates for SA and NSW suggest that both sexes grew rapidly during the first 2 years of life. Our results suggest that in southern Australia, *S. australasicus* reaches larger sizes (L_∞ = 392.64 mm) and has slightly higher growth coefficients (k = 0.45.yr^{-1}) than in eastern Australia. However, the large differences in the size of fish sampled in the two locations limits the inferences that can be drawn from these comparisons.

Our estimates of growth parameters are similar to those provided by Stevens et al. (1984) for *S. australasicus* from the GAB (L_∞ = 441 mm and k = 0.24. yr $^{-1}$), but could not be directly compared to the growth parameters of Stewart and Ferrell (2001) who used Schnute's growth models. The estimates of L_∞ provided by Morrison *et al.* (2001) for *S. australasicus* in NZ (♂L_∞ = 487.7 mm; ♀L_∞ = 511. 1 mm) were larger than our estimates, which reflect the large size of fish collected during that study. In contrast, the growth coefficients (k) provided by Morrison *et al.* (2001) were approximately half those obtained in the present study, which reflects the effect that estimates of age have on growth coefficients (i.e. long-lived fish have lower growth coefficients than similar-sized short-lived fish).

The absence of large fish in samples from eastern Australia warrants further investigation. At this stage there is no evidence to conclusively determine whether this result is a reflection of the true absence/rarity of large old *S. australasicus* off NSW or is simply a result of limitations in the sampling program. As noted above, there is commonly a gradient in the size distribution of pelagic fishes with smaller fish mainly occurring inshore and larger fish being more abundant offshore. Hence, the paucity of large fish in samples from NSW could simply reflect the concentration of sampling effort in that location in inshore areas. Until the reason for the absence of large/mature fish in samples from NSW is determined our knowledge of the biology of *S. australasicus* in this region will remain inadequate for stock assessment.

Other research topics that need to be addressed in future studies of the age and growth of *S. australasicus* include the uncertainties surrounding the location and timing of deposition of the first opaque zone. These and other questions could be usefully addressed by investigations of the age and growth patterns of larvae and early juveniles (see Rogers and Ward 2007).

5.5 Conclusions

Age determination of *S. australasicus* is challenging using the standard approach as the majority of otoliths are difficult to read, and these difficulties increase as fish age increases. If age distributions are determined from zone counts from readable otoliths alone, the proportion of fish in young age classes (especially the 0+ year class) is over-estimated. To overcome this bias, we used an age-otolith weight relationship developed from otoliths with excellent and good readability to establish unbiased age structures of *S. australasicus* in southern and eastern Australia. Specimens >300 mm were commonly collected from Tas, SA and Vic but were rarely collected from NSW, southern Qld or WA. The oldest fish collected in this study was in the 7+ year class. Growth rates of males and females were similar and both grew quickly during the first two years of life, reaching ~250 mm FL after ~2 years. Growth rates and trajectories were similar among regions. However, an asymptotic growth phase was less evident for growth curves calculated for fish obtained from NSW, which reflects the absence of large fish in samples from this location. Determining whether large/old *S. australasicus* occur in waters off NSW is the highest priority for future research on the age and growth, as this information is critical for understanding the population dynamics of this species in this region. Current understanding of the age and growth of *S. australasicus* would be enhanced by studies of the otoliths of larvae and early juveniles.

5.6 Acknowledgments

The authors gratefully acknowledge the efforts of Mr Lachlan McLeay, Mr David Fleer, Mr Richard Saunders, Mr Wetjens Dimmlich, Mr Paul Van Ruth and Mr Alex Ivey (SARDI Aquatic Sciences) for their technical assistance in the laboratory, field and for their help with maintenance and management of the datasets. We thank the master of *RV* Ngerin, Neil Chigwidden and crew Mr Dave Kerr, Mr Chris Small, and Mr Ralph Putz, for their efforts during the research surveys. We also wish to thank the numerous recreational, commercial and game-fishers who helped collect fish samples. We also thank Dr Jeremy Lyle, Mr Dirk Welsford, Dr Johnathon Staunton-Smith, Dr John Stewart, Ms Danielle Williams and Dr Francisco Neira for collecting samples, and providing otoliths and datasets from Tasmania, Queensland and New South Wales. Dr Stephen Mayfield (SARDI) and Dr Rowan Chick (SARDI) reviewed drafts of this chapter

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6. Reproductive biology and spawning dynamics of blue mackerel *Scomber australasicus* off southern and eastern Australia

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Objective: To describe reproductive biology, especially spawning fractions and batch fecundity, of *S. australasicus* in south-eastern Australia.

Summary: This objective was addressed by describing and comparing aspects of the reproductive biology and spawning dynamics of blue mackerel *Scomber australasicus* in samples from commercial catches and fishery independent surveys conducted off southern and eastern Australia. Analyses of microscopic characteristics of ovaries and oocyte size frequency distributions indicated that *S. australasicus* is a serial spawner with asynchronous oocyte development and indeterminate fecundity, and is a suitable species for stock assessment using the Daily Egg Production Method (DEPM). Samples collected from southern Australia included fish of a wide range of sizes (109–422 mm fork-length (FL)) and appeared to be representative of the adult population, whereas samples from eastern Australia were mainly <350 mm FL and did not include large fish that are known to occur in this region. Gonosomatic indices and macroscopic stage data suggest that *S. australasicus* spawn between November and April off southern Australia and between July and October off eastern Australia. In South Australia, ~50% of males and females were sexually mature at 236.5 and 286.8 mm FL, respectively. Size at ~50% maturity could not be estimated reliably for eastern Australia due to the small proportion of large fish in samples. Mean spawning frequencies ranged from 2 to 11 days in southern Australia; variations in this parameter were not related to fish size, month, SST or depth of sampling location. Mean batch fecundity was 69,894 ±4,361 oocytes per batch and 134 oocytes per g of weight. Fecundity increased exponentially with fish length and weight, which explained 71% and 68% of the variability in estimates of batch fecundity, respectively. Estimates of the timing and duration of the spawning season, size at maturity, spawning frequency and batch fecundity for *S. australasicus*

off southern Australia were similar to findings during previous studies of *S. japonicus* in the northern Pacific and Atlantic Ocean. We consider that the estimates of adult reproductive parameters provided for *S. australasicus* off southern Australia are suitable for use in application of the DEPM, whereas estimates of these parameters for eastern Australia may not be suitable for this purpose. Collecting representative samples of mature fish from waters off eastern Australia during the spawning season is a high priority future for stock assessment of this species. The degeneration rates of the post-ovulatory follicles of *S. australasicus* in Australian waters also need to be quantified to ensure that estimates of spawning fraction are robust.

6.1 Introduction

Information on the reproductive biology and spawning dynamics of fishes is needed to assess the status of commercially exploited species. Knowledge of reproductive biology is particularly critical for the application of egg-based stock assessment methods, such as the Annual or Daily Egg Production Methods (AEPM and DEPM, respectively) (Saville 1964; Lasker 1985; Alheit 1993; Priede and Watson 1993). For example, the AEPM is applicable to fishes with determinate fecundity where total egg production can be measured prior to the spawning season, whereas the DEPM is suitable for species with indeterminate fecundity, where the cohorts of oocytes present at the time of sampling provide no information for estimating total seasonal fecundity. Application of egg-based stock assessment methods also requires other information on other reproductive characteristics, including timing of the spawning season, size at maturity, spawning frequency and batch fecundity (e.g. Lasker 1985).

Identification of the spawning mode of a species is critical in determining the suitability of egg-based stock assessment approaches (Hunter and Macewicz 1985). The spawning mode of members of the genus *Scomber*, has been the subject of considerable debate (Greer Walker *et al.* 1987; Dickerson *et al.* 1992). Previous studies have shown that *S. japonicus*, which is closely related to *S. australasicus* (Scoles *et al.* 1998; Infante *et al.* 2006), has indeterminate fecundity. Ovaries of pre-spawning females with indeterminate fecundity contain a series of different-sized developing and yolked oocytes, and high frequencies of atretic oocytes that indicate surplus oocytes reached vitellogenesis near the cessation of the spawning season (West 1990; Dickerson *et al.* 1992; Walker *et al.* 1994; Yamada *et al.* 1998). Other studies have suggested that *S. scombrus* also has indeterminate fecundity (Watson *et al.* 1992; Priede and Watson 1993).

There have been few studies of the reproductive biology and spawning dynamics of *S. australasicus*. Prior to the present investigation, the only study of this species in Australian waters determined the size at sexual maturity in the Great Australian Bight (Stevens *et al.* 1984). In New Zealand waters, *S. australasicus* were found to spawn between November and April (summer) at water temperatures between 15 and 23°C (Taylor 2002). No information is currently available on the mode of spawning, spawning season, spawning frequency and batch fecundity of *S. australiasicus* in southern or eastern Australia. We hypothesize that the reproductive characteristics and spawning dynamics of *S. australasicus* are similar to those of *S. japonicus*.

The spawning seasonality of teleosts can be determined by analysis of the physical characteristics of ovarian tissue (West 1990). Macroscopic characteristics are based on the structure, colour and relative size of gonads, whereas microscopic characteristics include the formation, ovulation and degeneration of oocytes (Wallace and Selman 1981; Hunter and Macewicz 1985). Knowledge of the seasonality of spawning season of *S. australasicus* in Australian waters is required to ensure that egg-based stock assessment surveys (DEPM) are conducted during the spawning season. Previous studies suggest that *Scomber* spp. have extended spawning seasons that vary between locations (Priede and Watson 1993; Priede *et al.* 1995; Hernández and Ortega 2000; Watanabe and Yatsu 2006).

Macroscopic and microscopic characteristics of gonads are also used to determine the size of fish at sexual maturity. Information on size at maturity is needed to define the size classes that comprise the spawning stock and to assess biologically sustainable, target size ranges for fisheries. Size at maturity has also been used previously for other small pelagic fish species in the context of assessment of temporal and spatial variability in relation to density dependent effects (van der Lingen *et al.* 2006), variation in growth rates, sampling issues (Butler *et al.* 1996) and fluctuations in biomass e.g. *S. japonicus* (Watanabe and Yatsu 2006). In the context of egg-based stock assessment, this information is required to identify regions where aggregations of mature-sized individuals occur in order to collect samples for estimation of adult reproductive parameters.

Spawning frequency (i.e. average number of days between spawning by individual females) is derived from estimates of spawning fraction, a critical parameter for estimating spawning biomass using the DEPM. To estimate spawning frequency, knowledge of the rate of degradation of post-ovulatory follicles (POFs) is required. The period over which POFs can be identified varies between species and with temperature (Fitzhugh and Hettler 1995). Dickerson *et al.* (1992) found that in waters of ~20^{o}C, POFs could be identified in the ovaries of *S. japonicus* for up to 34 hours after spawning, and that POFs over 48 hours old were indistinguishable from atretic cells. Atresia typically occurs towards the end of the spawning season and its presence can reduce the accuracy of estimates of spawning frequency (Hunter and Macewicz 1985). Previous estimates of mean spawning frequency for *S. japonicus* were once per 2–11 days off Japan (Watanabe *et al.* 1999) and once per 12 days off California (Dickerson *et al.* 1992).

Batch fecundity is also a critical reproductive parameter for application of the DEPM (Hunter *et al.* 1985). Estimates are multiplied by estimates of sex ratio and spawning fraction, which together

comprise the denominator of the equation used to estimate spawning biomass. In serial spawning fishes, batch fecundity is the number of oocytes released per batch (Hunter *et al.* 1985) and is usually estimated by enumerating the number of hydrated oocytes in ripe (stage IV) ovaries. Estimates of the batch fecundity of *S. japonicus* off California and Japan have ranged from 35,807 to 120,537 and 14,900 to 150,000 oocytes per batch, respectively (Dickerson *et al.* 1992; Watanabe *et al.* 1999; Watanabe 2006).

This study describes and compares the reproductive biology and spawning dynamics of *S. australasicus* in waters off southern and eastern Australia and assesses the suitability of this species for application of the DEPM. The study identifies the spawning mode of *S. australasicus* and compares its spawning seasonality, size at maturity, spawning frequency and batch fecundity in two Australian regions with information available for *S. japonicus* in the northern Pacific Ocean.

6.2 Methods

6.2.1 Collection and processing of samples

In South Australia, *S. australasicus* (n =1,837) were collected from southern and northern Gulf St Vincent (GSV), Investigator Strait (IS), Spencer Gulf (SG) and the eastern Great Australian Bight (GAB) between 2002 and 2006 (Fig. 6.1, Table 6.1). Sampling locations in southern Australia were Corny Point (SG.)= 1, Clarries Wreck (GSV) = 2, Ulonga Wreck (GSV) = 3, 7-mile reef (EB) = 4 and Greenly Island (GAB) = 5. Fish were measured by fork length (FL, ±1 mm), from the tip of the snout to the fork in the caudal fin. Samples collected from South Australia included fish sizes ranging from 109–422 mm, FL. Off eastern Australia, *S. australasicus* (n = 5,626) were collected by market sampling, during gamefishing tournaments, from commercial vessels and by fishery-independent sampling between 1996 and 2006 (Fig. 6.1, Table 6.1). Samples collected from eastern Australia included fish of sizes ranging from 114–419 mm FL (>95% were <350 mm, FL). Figure 1 shows the specific locations where samples were collected. Field samples were collected with hand-lines and by rod and line using lures, small baits and or baitfish jigs. In southern Australia, samples were also collected using a monofilament gillnet (mesh size 65 mm).

After FL measurements were recorded, fish were weighed to ±0.1 g. Gonads were removed from mature females and fixed in 5% buffered formaldehyde solution. Immature (Stage I) females and males were frozen. All gonads were weighed to ±0.01 g. Microscopic characteristics of ovaries, oocyte size frequencies, spawning frequency and batch fecundity were determined only for southern Australian samples. Macroscopic staging, GSI and length at maturity were co-determined for both regions.

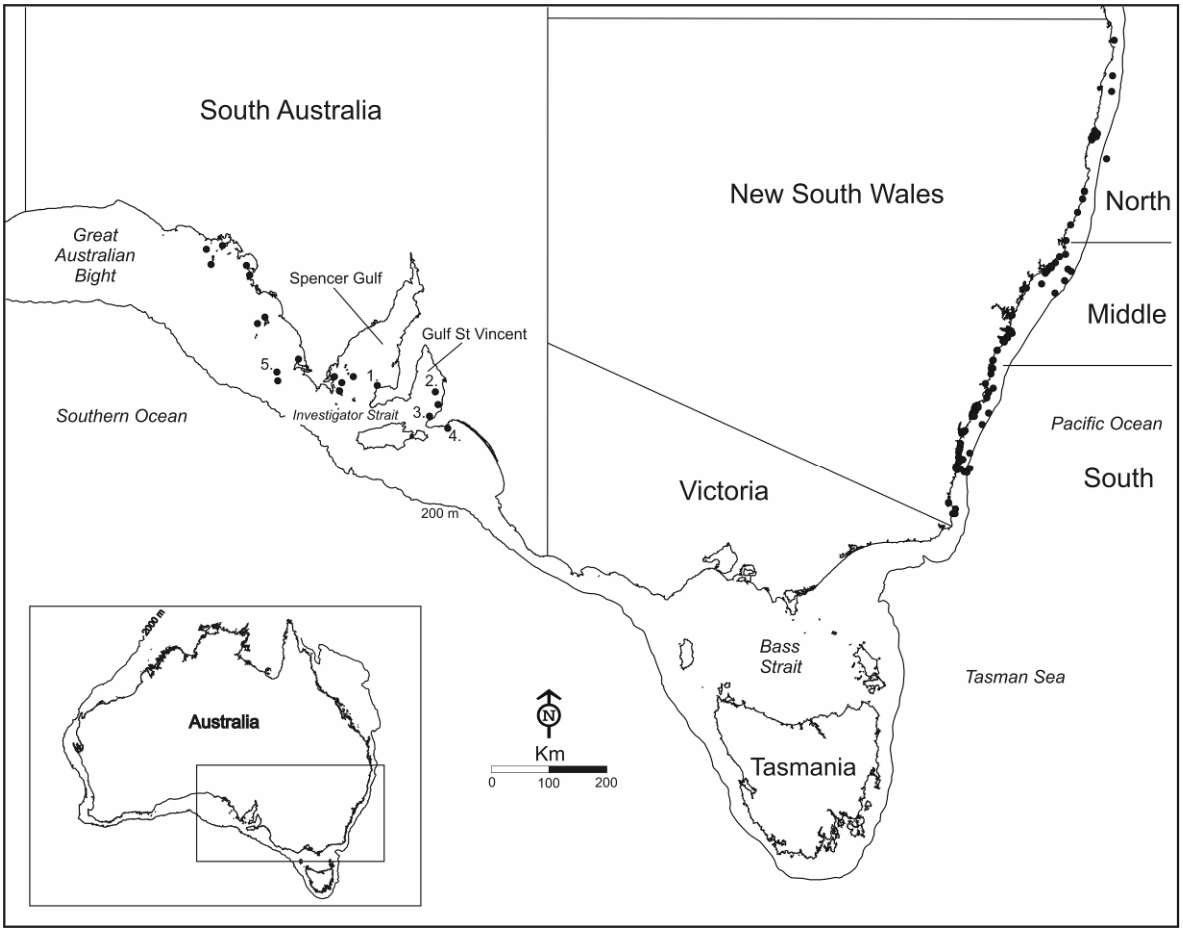

Figure 6.1. Locations, indicated with solid circles, in southern and eastern Australia where samples of *S. australasicus* were collected for reproductive analyses. Numbers on map in South Australia represent the following locations where samples were collected: Corny Point = 1, Clarrie's Wreck = 2, Ulonga Wreck = 3, 7-mile reef = 4 and Greenly Island = 5.

Table 6.1. Summary of samples collected in southern and eastern Australian waters between 1995 and 2006. Sampling location codes are: IS-Investigator strait, SG-Spencer Gulf, EB-Encounter Bay, GSV-Gulf St Vincent, GAB-Great Australian Bight, Un – unknown, N- northern region, M-mid region and N-northern region of eastern Australia (refer to Fig. 6.1).

Region	Year	Location code	N males	N females	Sample size	N samples
South Australia	2002	IS	19	27	46	1
	2002	SG	26	22	48	1
	2003	EB	17	13	30	2
	2003	GSV	181	153	334	10
	2003	SG	47	116	163	4
	2004	EB	11	14	25	1
	2004	GAB	124	93	217	4
	2004	GSV	173	105	278	11
	2004	SG	201	173	374	7
	2005	GSV	54	29	83	6
	2005	SG	167	60	227	4
	2006	SG	5	7	12	1
Total			**1,025**	**812**	**1,837**	**48**
Eastern Australia	1995	Un	9	8	17	1
	1996	Un	89	215	304	1
	1997	Un	18	111	129	1
	2002	M	150	643	793	2
	2002	N	30	25	55	1
	2002	S	21	74	95	1
	2002	Un	2	7	9	1
	2003	M	203	302	505	1
	2003	N	50	190	240	1
	2003	S	60	357	417	1
	2003	Un	50	94	144	2
	2004	M	21	19	40	1
	2004	N	372	638	1010	1
	2004	S	119	284	403	1
	2004	Un	316	548	864	3
	2005	Un	227	374	601	1
Total			**1,737**	**3,889**	**5,626**	**20**
Grand total			**2,762**	**4,701**	**7,463**	**68**

6.2.2 Spawning mode

Spawning mode was investigated by examining the microscopic characteristics of ovarian tissue and the modal size progressions of developing oocytes. Fish with indeterminate fecundity and asynchronous oocyte development typically have ovaries with several stages of developing oocytes that represent continuous or semi-continuous size classes as opposed to those with determinate fecundity and synchronous oocyte development, which have notable gaps present between batches of developing oocytes (Wallace and Selman 1981; Hunter and Macewicz 1985). Microscopic characteristics of ovaries were described from gonad samples fixed in 5% seawater formalin solution. Samples were sectioned using a microtome, stained with haematoxylin and eosin dyes and fixed to microscope slides. Microscopic characteristics and oocyte developmental stages were identified and assigned based on the criteria outlined in Hunter and Macewicz (1985) and Dickerson *et al.* (1992). Oocyte size frequencies were estimated from ovaries that were classified as macroscopic stages II–V. Oocyte diameters were measured in each histological section over areas of 1000 x 1400 μm using ImagePro© software.

6.2.3 Spawning seasonality

The spawning season was identified in both regions using macroscopic staging of gonads and a gonosomatic index.

6.2.3.1 Macroscopic stages

Gonads of fish of both sexes were assigned macroscopic stages based on physical characteristics described in Table 6.2. Microscopic characteristics of ovaries assigned to these macroscopic stages (I–V) were described and compared using histologically prepared ovary samples.

6.2.3.2 Gonosomatic Index

Mean monthly gonosomatic indices (GSI) were calculated by the equation:

$$GSI = \left[\frac{Gwt}{Fwt_{gonadfree}} \right].100$$

where Gwt is gonad weight and $Fwt_{\text{gonadfree}}$ is gonad free fish weight for fish with gonads of macroscopic stages ≥2. Error was estimated as ±1 s.e.

.

Table 6.2. Criteria for assigned macroscopic stages to gonads of *S. australasicus* of both sexes collected in each state. Male stages range from I–III and females range from I –V.

Stage		Macroscopic appearance/characteristics
I	Immature/virgin	Testis and ovaries thin (over 2 to 3 mm in diameter) and thread-like, adhered to the swim-bladder, translucent and nearly colourless, oocytes and blood vessels not visible, sexes sometimes indistinguishable.
II	Maturing virgins or recovering spent	Gonads developing and filling half of the body cavity. Ovaries more rounded (over 3 – 8 mm diameter), and beginning to enlarge, colour translucent pinkish, oocytes and blood vessels not visible. Testis thin and strap-like, beginning to thicken and of whitish colouration.
III	Maturing	Gonads maturing and filling approximately two-thirds of the body cavity. Ovaries yellow or pale orange, with abundant blood irrigation. The ova are visible small and opaque. Diameter of 0.3 – 0.8 mm. Testis at maximum size, opaque white with milt present. Milt extruded by pressure on abdominal wall.
IV	Ripe	Ovaries at maximum size and filling body cavity. Ovaries dark yellow or orange; pressing of ventral side causes the extrusion of translucent oocytes. Translucent (hydrated oocytes distributed throughout ovary between advanced yolked and yolked oocytes. Roe and milt running (spawning). Advanced oocytes range in diameter from 0.9 – 1.29 mm.
V	Spent	Ovaries slack and bloodshot. Small proportion of hydrated oocytes visible.

6.2.4 Size at sexual maturity

Lengths at 50% sexual maturity (L_{50}) were estimated for samples collected in southern Australia. L_{50} by fitting a logistic model to the percentages of maturing and mature (gonad stages ≥ 2) fish grouped into 2 mm size classes during the spawning season. The logistic curve fitted is represented by the equation:

$$P_L = 1/\left[1+e^{(a+bL)}\right]$$

where P_L is the proportion in each size class and a and b are constants estimated by minimizing the sum of squares using the Solver function in Excel™ (Microsoft Corporation, www.microsoft.com.) Length at 50% maturity was estimated from the parameter estimates of the logistic fit, e.g. $L_{50} = -a/b$.

6.2.5 Spawning frequency

Estimates of spawning frequency were made from 702 mature females collected in southern Australian waters between 2002 and 2006. Several histological sections from each ovary were examined to determine the presence/absence of post-ovulatory follicles (POFs). POFs were assigned approximate ages according to the criteria developed by Dickerson *et al.* (1992) for *S. japonicus* and Hunter and Macewicz (1985) for northern anchovy *Engraulis mordax*. Spawning frequency of each sample was estimated from the mean proportion of females with hydrated oocytes, day 0 POFs (*d*0) (assumed to be 0–23 hrs old), and day 1+ POFs (*d*1+) (assumed to be 24+ hours old). Three estimates were provided, which included; (i) those with hydrated oocytes (day 0 oocytes) and what were estimated to be day 0 POFs, (ii) those with day 1+ POFs only and, (iii) those with hydrated oocytes (day 0 oocytes), and what were estimated to be day0 POFs and day 1+ POFs. Estimates of mean weighted spawning frequency ($\overline{S}$) were calculated from the reciprocal of estimates of spawning fraction (the numbers of fish with ovaries with hydrated oocytes, day 0 and or day1+ POFs combined, divided by the total number of fish with mature ovaries). We used regression analysis ($p < 0.05$) to examine the relationships between estimates of mean spawning frequency, mean female weight, length, location, depth, mean sea-surface temperature (3-day means), for each sampling location and month.

6.2.6 Batch fecundity

Batch fecundity was estimated for 58 females with stage IV (hydrated) ovaries using methodologies based on Hunter *et al.* (1985). Samples for batch fecundity were collected from southern Australian waters (Fig. 6.1, Table 6.1). Both ovaries were weighed and the number of hydrated oocytes in three ovarian sub-sections were counted and weighed. The batch fecundity for each female was calculated by multiplying the mean number of oocytes per gram of ovary segment by the total weight of the ovaries. The relationships between ovary-free fish weight, fish length and batch fecundity were determined by linear and allometric regression analysis.

6.3 Results

6.3.1 Spawning mode

6.3.1.1 Microscopic characteristics of ovaries

Immature (stage I) ovaries had unyolked oocytes that were encapsulated in longitudinal folds of granulosa/connective tissue and were not undergoing atresia (Fig. 6.2). Maturing (stage II) ovaries contained un-yolked and partially-yolked oocytes that were eosinophilic and contained developing yolk droplets. Mature (stage III) ovaries contained a range of oocyte sizes and oocytes in the *UY*, *PY* and advance yolked (*Y*) stages, and post-ovulatory follicles. POFs were assumed to have formed on the day of sampling (day 0 POF) and 1–2 days prior to sampling (day 1+ POF). POFs classified as day 0 had intact granulosa cells and thecal layers that exhibited minimal shrinkage.

Oocytes with migratory nuclei were also present in some stage III ovaries, indicating spawning was imminent at the time of sampling. Hydrated (stage IV) ovaries typically contained all developing oocyte stages in addition to hydrated oocytes. Fish with hydrated oocytes were collected between 12:00 and 18:00 hours. Spent ovaries (stage V) contained POFs and various oocyte stages in states of atresia, indicating that a substantial proportion of oocytes that had reached vitellogenesis were probably not going to be released. Individual oocytes in spent ovaries often had larger interstitial spaces between them than those in stage III ovaries.

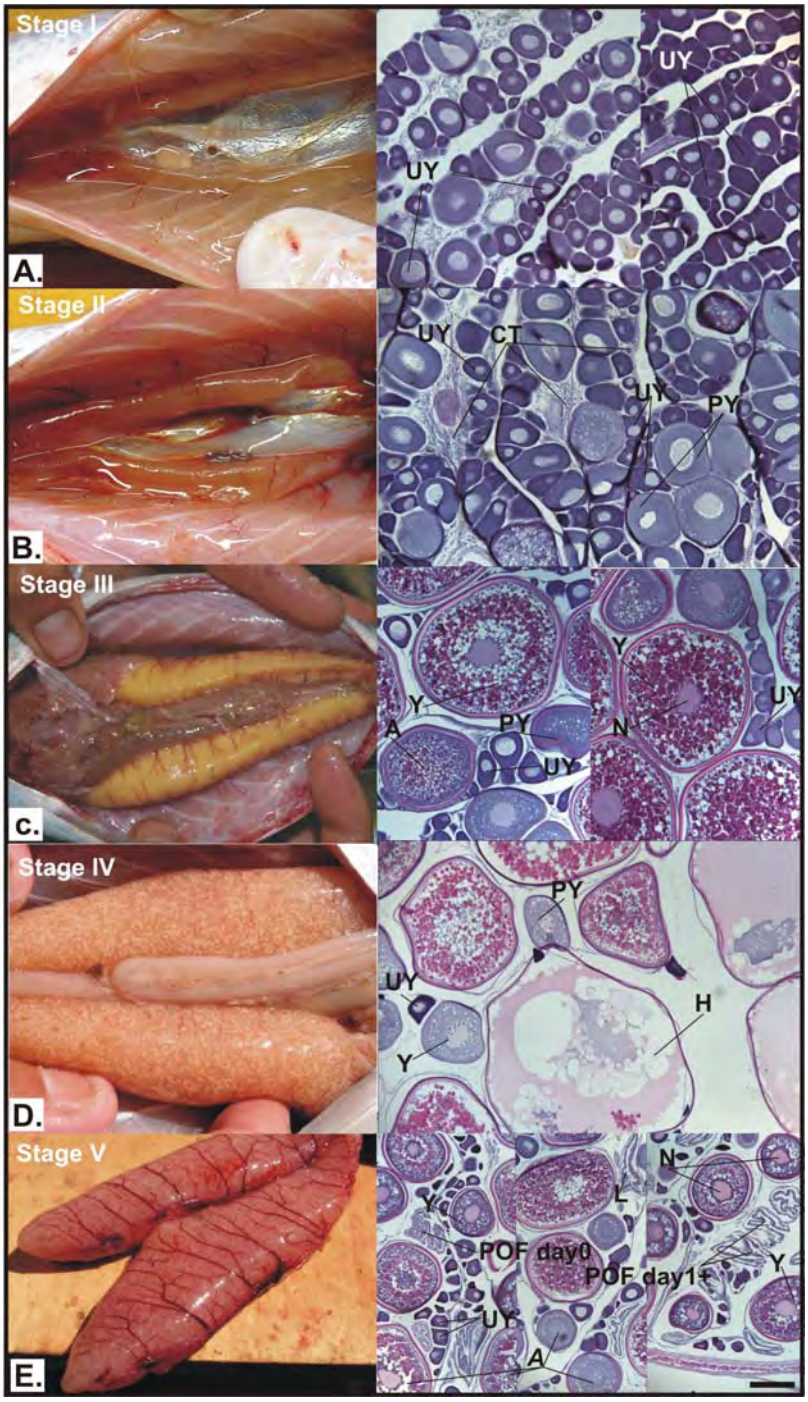

Figure. 6.2. Macroscopic stages I–V and comparison of examples of these stages showing microscopic characteristics. Histologically prepared ovarian sections showing developing oocytes in macroscopic stages, I–V. **(A)**. Immature, stage I ovary with developing oocytes in unyolked (Uyo) stages, **(B)** and **(C)**. Macroscopic stage II and III ovary sections with unyolked (*UY*), partially yolked (*PY*), and advanced yolked (*Y*) oocytes. Nucleoli (*N*) and connective tissue (CT) are visible. **(D)**. Macroscopic stage IV ovary, with partially hydrated (*H*), un-yolked, partially yolked and yolked oocytes co-existing with day 0 and day 1+ post-ovulatory follicles (POF day 0 and day1+). **(E)**. Stage V ovary with day 0 POFs, indicating recent spawning (<~24 hours before capture) and day 1+ POFs, showing advanced breakdown of the POF structure. Shows lumen (*L*) of day1+POF and atretic cells and atresia (*A*) in yolked oocytes (Scale bar = 150μm).

6.3.1.2 Modal size progressions of developing oocytes

Developing and mature ovaries from *S. australasicus* collected in southern Australian waters contained oocytes with diameters ranging from 17 to 522 µm (Fig. 6.2, Table 6.1). A broad range of unyolked, partially yolked and advanced-yolked oocytes were present in samples collected before and during the spawning season (Fig. 6.3). A continuous range of size classes was apparent in unyolked (17–138 µm), partially yolked (82–338 µm) and advanced-yolked (218–522 µm) oocytes. In summary, the physical characteristics and size progressions of developing oocytes from samples analysed during this study suggest *S. australasicus* has a spawning mode that includes asynchronous development of oocytes and indeterminate fecundity.

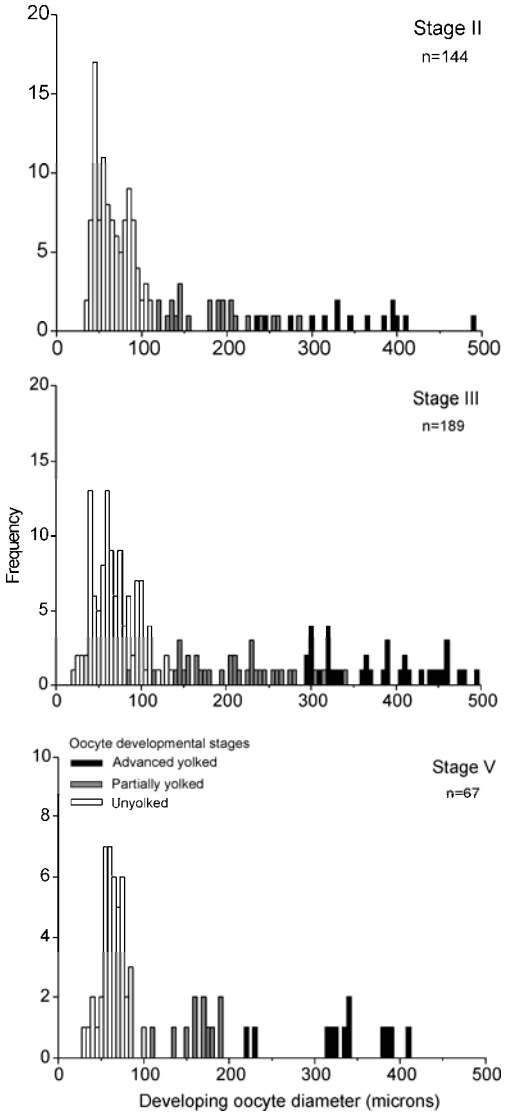

Figure. 6.3. Size frequencies of three oocyte developmental stages (unyolked, partially yolked and advanced yolked) from stage II–V *S. australasicus* ovaries collected in southern Australia.

6.3.2 Spawning seasonality

6.3.2.1 Macroscopic stages

In southern Australia, ~90–100% of males had immature stage I testes between June and August (Fig. 6.4A). Males with maturing (stage II) testes were dominant in September (61%) and October (70%) and the frequency of this stage declined to 48% and 10% in November and December, respectively as males prepared to spawn. The relative frequencies of males with mature stage III testes were highest (>50%) between December and March and declined rapidly between April and May from 47.1% to 7.4%.

Females with stage I gonads were prominent in samples in June and August (>50%) and fish with maturing (stage II) gonads were present throughout the year, but dominant both at the prelude to the start (September), and end (May) of the spawning season. Stage III gonads were prominent in August (26%) and September (35%). The presence/dominance of stage III ovaries in October followed the progression of stage II ovaries in the previous month. Stage III ovaries remained dominant between November (78%) and March (64%). Stage IV (hydrated ovaries) first appeared in samples in November (1.8%) and their occurrence increased linearly until March (10.4%) before declining to ~2% in April.

The first appearance of stage V ovaries in December directly followed the first appearance of hydrated oocytes in November (Fig. 6.4A). Following this, females with stage V ovaries were present during all other months when hydrated ovaries were sampled, which was between December and April. The highest proportion of spent ovaries was present in April, which indicates that autumn represents the end of the spawning season.

Off eastern Australia, >20% of males had immature stage I testes between January and June and in October /November (Fig. 6.4B). Males with stage II testes were prominent (>20%) in most months and relative frequencies of this stage were highest in May (56%), October (60%) and November (56%). Relative frequencies of males with stage III testes were highest in August (61%) and September (48%) and lowest in May (4%) and October (15%).

Females with stage I gonads were prominent in samples in January (65%) and February (66%) and October (63%) (Fig. 6.4B). Fish with maturing (stage II) gonads were dominant between April and July and stage III gonads were prominent in August (26%) and September (35%). No stage IV (hydrated) females were collected in eastern Australian waters. Females with stage V

(spent) ovaries were common in July (24%) and August (14 %); however there was a higher degree of uncertainty in assigning this stage for samples from this region (see comment below). Low frequencies of spent gonads (<10%) were also present during all other months. Interpretation of the stage V data for the eastern Australian dataset should be treated with caution; no histological sections were taken for these ovaries, measurements of gonad weight were particularly low (<1.5 g) in a substantial proportion (33%) of fish sampled and 28% of gonads assigned Stage V were from fish with lengths < L_{50} for females (269 mm in SA).

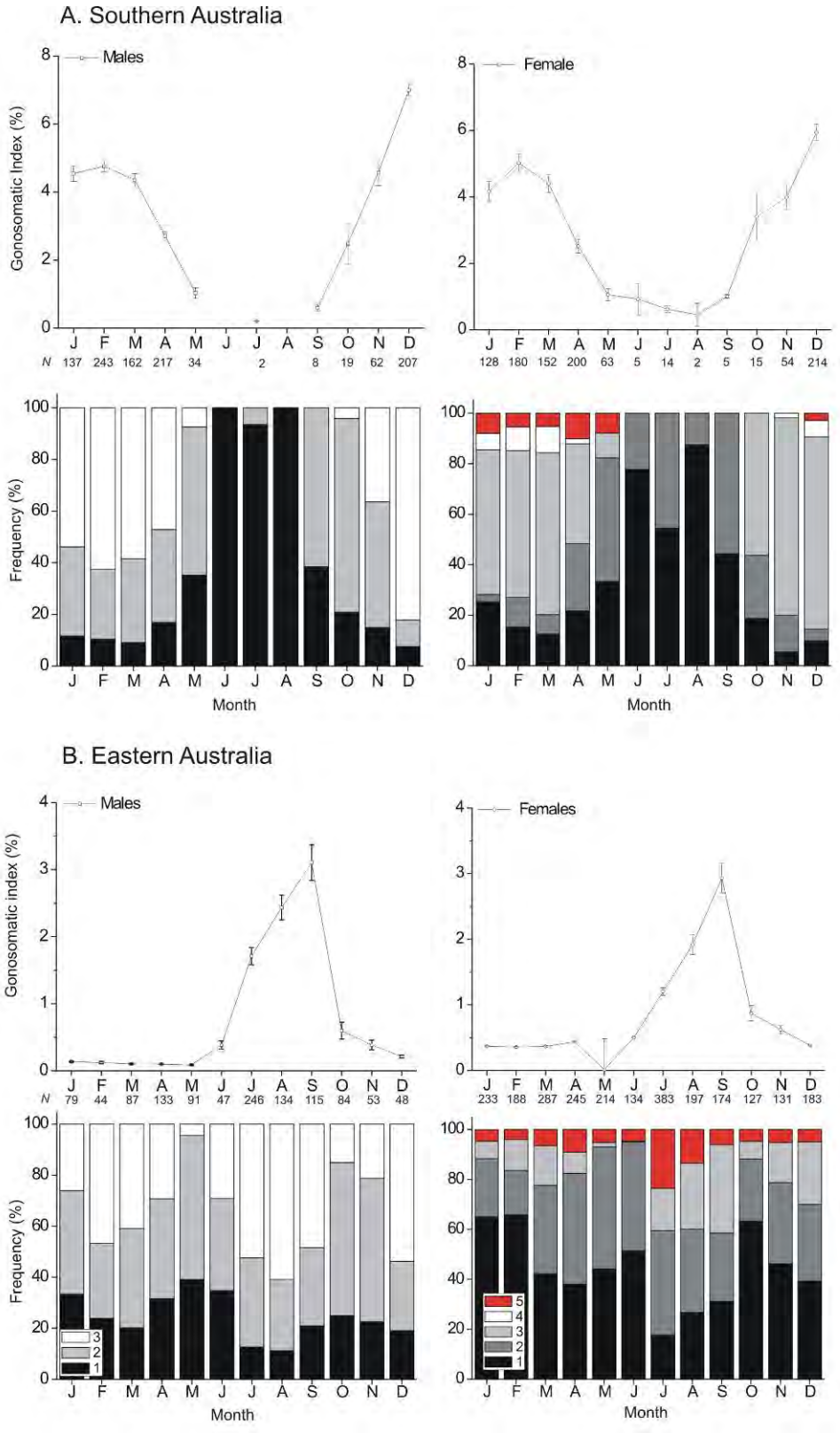

Figure 6.4. Monthly frequency distribution of mean gonosomatic index (±1s.e.) (upper) and macroscopic gonad stages (I–V) for male and female (lower) in (A) eastern, and (B) southern Australia. Numbers along x-axis on GSI plot represent number of individuals in each mean monthly GSI.

6.3.2.2 Gonosomatic Indices

In southern Australia, mean GSI was high (>4%) for males and females between November and March, indicating that there was a protracted spawning season of 5–6 months. This differs from the pattern observed in eastern Australia (Fig. 6.4). In southern Australia GSI peaked in December at 7% for males and 5.9% for females. Mean GSI was lowest ≤1% in both sexes between May and September and increased substantially between September and November. Patterns of GSI of females did not directly reflect the macroscopic stages as the highest prevalence of stage IV gonads occurred in February and March. This suggests that the weight represented by the high proportion of females with stage III ovaries in December had a greater influence on the mean GSI than that of the stage IV gonads, which were slightly more common in February and March and highlights the importance of measuring different parameters when assessing spawning seasonality.

In eastern Australian waters, mean GSI was highest for males (3.1%) and females (2.9%) in August and September (spring) and indicated there was a relatively short reproductive period (Fig. 6.4B). Mean GSI was <1% between October and June and increased rapidly between June and August.

6.3.3 Size at sexual maturity

In southern Australia, the first male and female *S. australasicus* had mature (stage II♂ and III♀) gonads in the 216 and 236 mm size classes. Mature (stage III–V) females ranged in size between 236–422 mm, and had a mean size of 330 ±1.2 mm. Maturing and mature (stage II–III) males ranged in size between 215–392 mm and had a mean size of 318±1.01 mm. Approximately 50% of males and females reached sexual maturity at 236.53 and 286.78 mm, respectively (Fig. 6.5).

In eastern Australian waters, the first males and females had mature stage II♂ and III♀ gonads in the 172 and 178 mm size classes, respectively. Logistic fits to the these data were poor due to the substantial overlap in size classes classified as having immature and mature gonads (Fig. 6.6) and are not presented. Maturing and mature (stage II–III) males ranged in size between 171–398 mm and had a mean size of 280 ±1.04 mm. Mature stage III–V females ranged in size between 178–394 mm and also had a mean size of 280±1.4 mm.

Size distributions of mature fish were not significantly different (*KS-test, P>0.05*) between sexes in southern Australia, but were for fish sampled off eastern Australia. Size distributions of mature females were significantly different (*KS-test*, *P<0.05*) between regions.

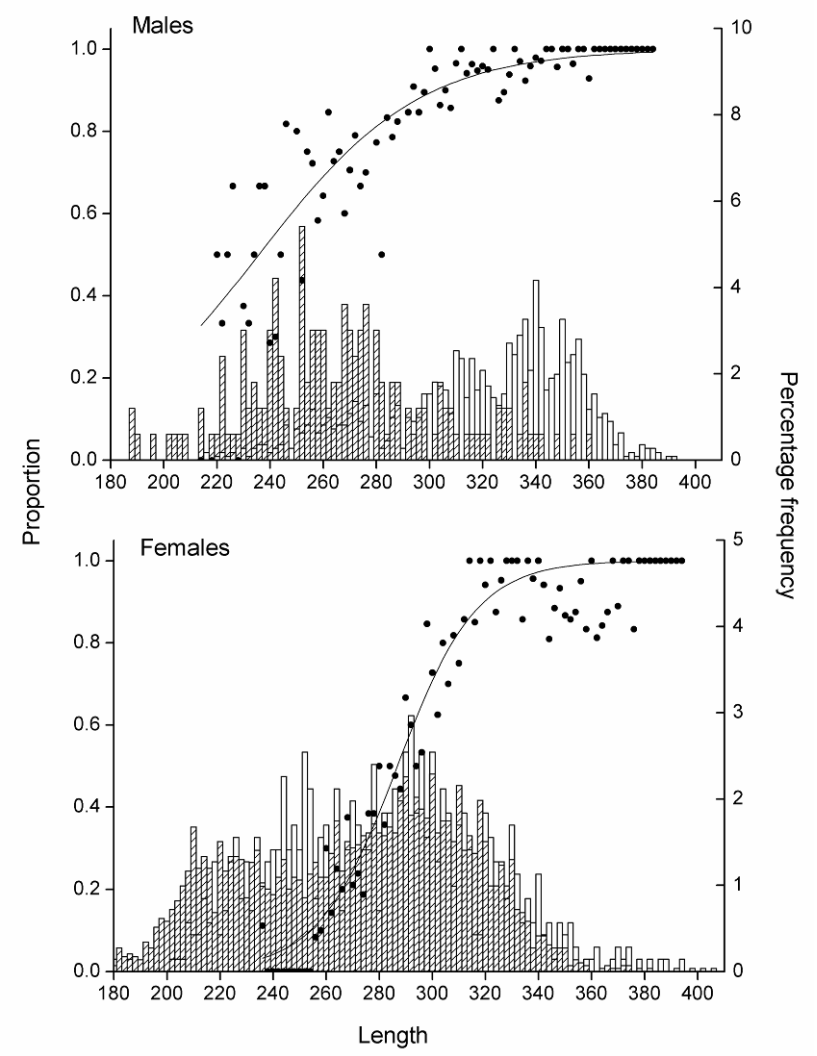

Figure 6.5. Length at maturity of *S. australasicus* in southern Australian waters. Percentage frequency of immature/mature fish in each length class is shown as hatched and non-hatched bars, respectively. Hatched bars in males represent length frequencies of fish with stage 1 (macroscopic) gonads and stage 1 and 2 gonads in females. Non-hatched bars represent length frequencies of mature fish (>1 males, >2 females).

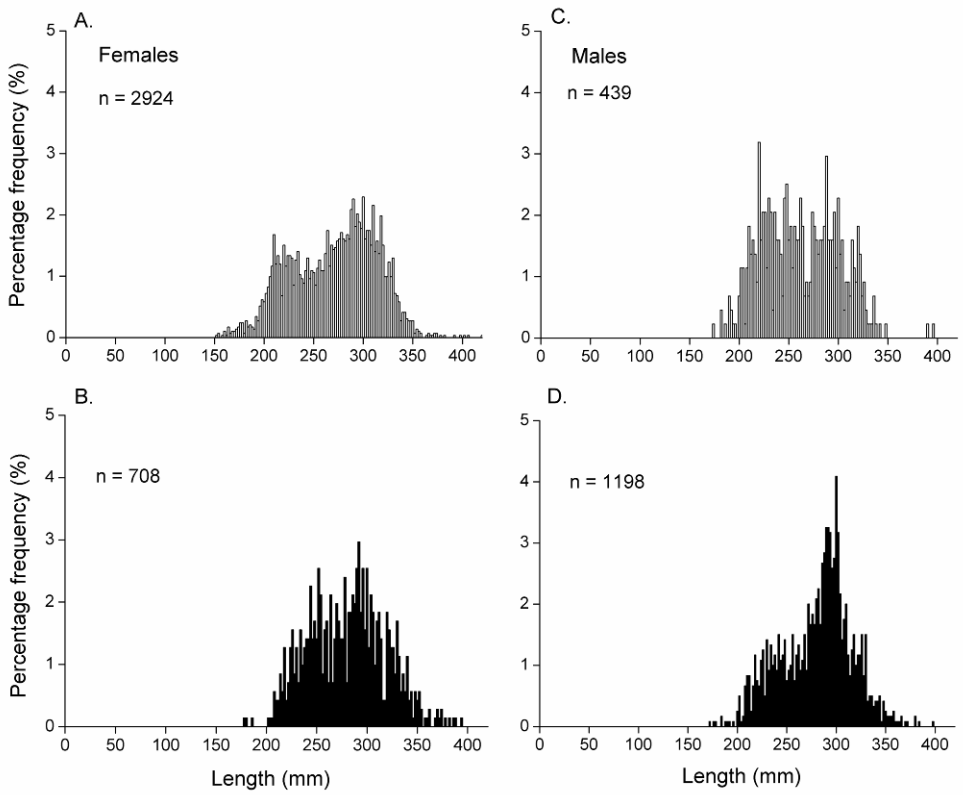

Figure 6.6. A. Percentage length frequencies of *S. australasicus* off eastern Australia for females with: A. immature and maturing (stage 1–2) ovaries and B. mature (3–5) ovaries and males; C. immature testes (stage1) and D. mature testes (stage 2 and 3).

6.3.4 Spawning frequency

Of the 702 mature females collected in southern Australia waters, 61 had hydrated oocytes, 153 had day 0 POFs and 49 had day 1+POFs. Mean spawning frequency estimates ranged between one spawning event per 6 days (when only day 0 POFs and hydrated oocytes were used), one event per 7 days (when only day 1+ POFs were used) and one event per 8 days (when day 0, hydrated oocytes and day 1+ POFs were used) (Table 6.3). Individual seasonal estimates of spawning frequency ranged between one event per 2 to 11 days. Fish with the highest spawning frequencies of one spawning event per 2–5 days were sampled at water depths between 22 and 42 m, and typically had average sizes of 258–354 mm, FL and average weights of 224–573 g. There were no significant relationships (regressions, $P>0.05$, N = 46) between mean sample estimates of spawning frequency, mean female weight, mean fish length, location, depth, mean sea-surface temperature during the spawning season (Fig. 6.7).

Table 6.3. Estimates of mean spawning frequency of *S. australasicus* collected in southern Australian shelf waters between 2001 and 2006. # denotes total number of female fish collected, (a) denotes weighted mean value.

Location/region	Sample size	Weighting	n Day 0 POF's	n Day 1 POF's	n hydrated	Sp freq Day 0 & hydrated	Sp freq Day 1+ only	Sp freq (Day 0, hydrated & +1)
Corny Point (SG)	20	1.00	0	7	0	0	3.8	5.7
	20#		**0#**	**7#**	**0#**	**0a**	**3.8a**	**5.7a**
Clarry's wreck (GSV)	5	0.48	0	1	0	0	1.7	10.0
Corny Point (SG)	20	1.93	1	3	1	20.0	8.9	10.0
Clarry's wreck (GSV)	10	0.96	0	0	0	0.0	0	0.0
7-Mile Reef (EB)	7	0.67	0	0	0	0.0	0	0.0
7-Mile Reef (EB)	6	0.58	0	0	0	0.0	0	0.0
Clarry's wreck (GSV)	3	0.29	0	0	0	0.0	0	0.0
Corny Point (SG)	7	0.67	0	0	0	0.0	0	0.0
Corny Point (SG)	25	2.41	0	3	0	0.0	13.9	16.7
	83#		**1#**	**7#**	**1#**	**4.8a**	**3.1a**	**8.0a**
Clarry's wreck (GSV)	11	0.61	0	0	0	0.0	0	0.0
Ulonga (GSV)	8	0.45	1	0	1	8.0	0	16.0
Clarry's wreck (GSV)	32	1.79	1	1	0	32.0	68.6	32.0
Ulonga (GSV)	17	0.95	6	0	2	2.8	0	5.7
Clarry's wreck (GSV)	30	1.67	2	4	0	15.0	15.1	10.0
Corny Point (SG)	41	2.29	11	7	6	3.7	16.1	4.6
Ulonga (GSV)	25	1.39	8	2	0	3.1	20.9	5.0
Clarry's wreck (GSV)	12	0.67	2	0	1	6.0	0	12.0
Corny Point (SG)	23	1.28	4	0	3	5.8	0	11.5
Greenly Island (GAB)	30	1.67	6	3	0	5.0	20.1	6.7
Clarry's wreck (GSV)	26	1.45	4	2	3	6.5	22.6	8.7
Ulonga (GSV)	9	0.50	3	0	0	3.0	0	6.0
7-Mile Reef (EB)	14	0.78	0	0	0	0.0	0	0.0
Ulonga (GSV)	6	0.33	2	1	2	3.0	2.4	4.0
Clarry's wreck (GSV)	3	0.17	1	0	0	3.0	0	6.0
Corny Point (SG)	24	1.34	15	0	14	1.6	0	3.2
Greenly Island (GAB)	47	2.62	12	2	0	3.9	73.9	6.7
Ulonga (GSV)	3	0.17	1	0	0	3.0	0	6.0
Ulonga (GSV)	2	0.11	0	1	0	0.0	0.3	4.0
Corny Point (SG)	33	1.84	16	4	0	2.1	18.2	3.3
Greenly Island (GAB)	4	0.22	0	0	0	0.0	0	0.0
Clarry's wreck (GSV)	2	0.11	0	0	0	0.0	0	0.0
Corny Point (SG)	14	0.78	12	0	8	1.2	0	2.3
Corny Point (SG)	16	0.89	8	0	6	2.0	0	4.0
Corny Point (SG)	30	1.67	2	3	1	15.0	20.1	12.0
Ulonga (GSV)	4	0.22	1	1	1	4.0	1.1	4.0
	466#		**118#**	**31#**	**48#**	**6.9a**	**10.8a**	**8.1a**
Clarry's wreck (GSV)	27	2.44	3	0	0	9.0	0	18.0
Ulonga (GSV)	4	0.27	1	2	0	4.0	0.5	2.7
Clarry's wreck (GSV)	17	1.14	4	0	2	4.3	0	8.5
Corny Point (SG)	19	1.27	8	1	4	2.4	24.2	4.2
Clarry's wreck (GSV)	4	0.27	0	0	0	0.0	0	0.0
Ulonga (GSV)	3	0.20	1	0	1	3.0	0	6.0
Corny Point (SG)	17	1.14	8	0	3	2.1	0	4.3
Ulonga (GSV)	4	0.27	0	0	0	0.0	0	0.0
Corny Point (SG)	3	0.20	1	1	0	0.0	0.6	6.0
Corny Point (SG)	28	1.87	6	0	1	4.7	0	9.3
Ulonga (GSV)	2	0.13	1	0	0	2.0	0	4.0
Corny Point (SG)	5	0.33	2	0	1	2.5	0	5.0
	133#		**34#**	**4#**	**12#**	**3.6a**	**2.1a**	**7.2a**
Grand Total/Mean	**702#**		**153#**	**49#**	**61#**	**6.0a**	**7.1a**	**8.1a**

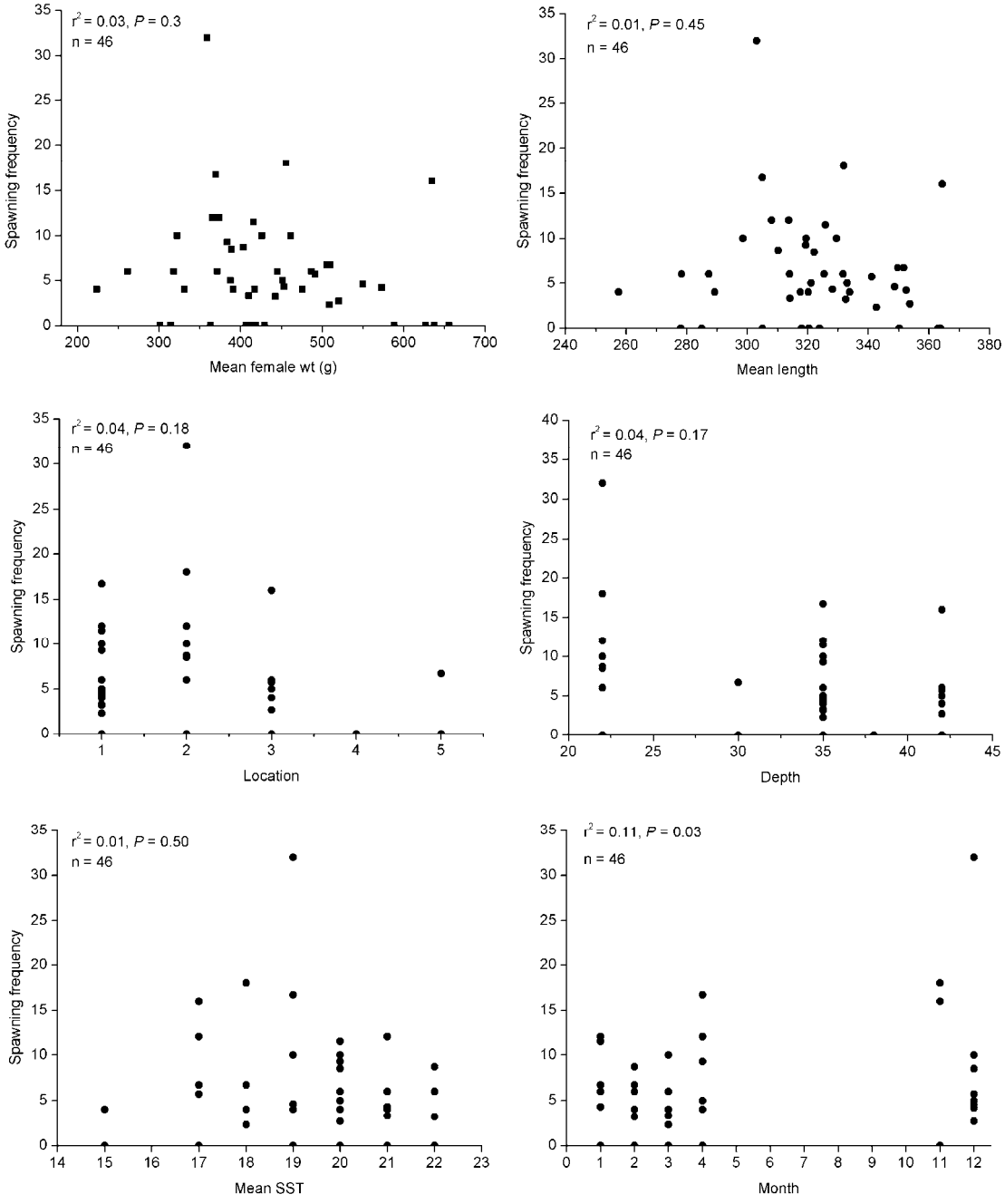

Figure 6.7. Relationships between sample estimates of mean spawning frequency, mean female weight, length location, depth, mean sea-surface temperature (over 3-days) at sampling location and month of sampling during the spawning season

6.3.5 Batch fecundity

Mean batch fecundity was 69,894 ±4,361 oocytes (±SE) per batch and 134 ±5.7 oocytes per g of ovary-free fish weight. Individual batch fecundity estimates ranged between 14,349 and 174,852 oocytes per batch and estimates of oocytes per g of ovary-free body weight ranged between 56.6 and 213.5 oocytes per g. Tables 6.4a and b show estimates of batch fecundity, ovary free weight and length of *S. australasicus* sampled at each location in southern Australia between 2002 and 2005. Females with hydrated oocytes ranged between 252 and 398 mm FL and had gonad-free fish weights ranging between 207.7 and 831.3 g. Exponential relationships between batch fecundity, ovary-free fish weight and length were best described using the allometric function when all data collected between 2002 and 2005 was included in the fits (Fig. 6.8). Fish length and weight explained 71% and 68% of the variability in batch fecundity, respectively.

Table 6.4a. Batch fecundity estimates for samples of *S. australasicus* collected in southern Australian shelf and gulf waters between 2002 and 2004.

Date	Location/region	Ovary wt (g)	FL (mm)	Gonad free fish wt (g)	Batch fecundity per g of body wt	Batch fecundity per female
3/12/03	Ulonga	94.3	349	493.3	205.9	101568.8
3/12/03	Ulonga	60.9	346	454.5	130.58	59350.2
14/12/03	Corny Point	43.8	345	501.1	73.95	37055.9
14/12/03	Corny Point	72.9	373	686.9	102.93	70699.8
14/12/03	Corny Point	84.2	377	744.6	108.95	81122.3
14/12/03	Corny Point	72	359	563.5	124.21	69990.5
14/12/03	Corny Point	82.7	336	483.6	168.79	81628.9
14/12/03	Corny Point	69.5	325	413.5	168.87	69829.6
13/01/04	Corny Point	60.4	329	441.5	117.79	52002.1
13/01/04	Corny Point	84.8	357	537.8	161.52	86867.5
4/02/04	Clarry's	32	298	369.6	83.63	30909.8
4/02/04	Clarry's	19.3	294	319.2	57.67	18406.7
4/02/04	Clarry's	11.1	263	234.9	61.09	14348.9
6/02/04	Ulonga	53.3	321	400.8	140.49	56309.7
6/02/04	Ulonga	35.3	324	436.6	107.45	46913.9
19/02/04	Corny Point	58.3	373	608.1	113.08	68764.6
19/02/04	Corny Point	38.7	304	351.2	125.31	44008.6
19/02/04	Corny Point	83.3	367	588.5	169.4	99690.9
19/02/04	Corny Point	39.7	320	409.1	93.28	38160.5
19/02/04	Corny Point	99	349	551.6	182.95	100914
19/02/04	Corny Point	59.8	324	395.5	160.54	63491.7
19/02/04	Corny Point	72.4	371	599.8	170.83	102462.3
19/02/04	Corny Point	64.6	356	529.5	121.28	64220.2
19/02/04	Corny Point	85.9	375	607.4	173.19	105193.2
19/02/04	Corny Point	45	337	417.2	141.7	59116.9
19/02/04	Corny Point	55.4	335	408.2	136.05	55533.7
19/02/04	Corny Point	72.5	336	442.2	194.47	85996.2
19/02/04	Corny Point	24.7	321	371.4	68.93	25599.9
19/02/04	Corny Point	63.5	327	397.5	157.4	62566.6

Table 6.4b. Batch fecundity estimates for samples of *S. australasicus* collected in southern Australian shelf and gulf waters between 2004 and 2005.

Date	Location/region	Ovary wt (g)	FL (mm)	Gonad free fish wt (g)	Batch fecundity per g of body wt	Batch fecundity per female
24/03/04	Corny Point	29.9	332	494.9	56.57	27997.1
24/03/04	Corny Point	52.6	354	549	138.57	76077.2
24/03/04	Corny Point	12.4	283	274	61.56	16867.8
24/03/04	Corny Point	60.8	335	509.6	124.35	63369.8
24/03/04	Corny Point	16.6	311	395.72	69.69	27577.9
24/03/04	Corny Point	60.4	349	489.76	141.95	69523.8
24/03/04	Corny Point	77.6	380	686.6	137.29	94266.6
24/03/04	Corny Point	59.1	393	709.6	100.09	71024.2
25/03/04	Corny Point	120.6	356	575.3	207.76	119521.5
25/03/04	Corny Point	32.4	335	462.8	68.01	31474.2
25/03/04	Corny Point	40.3	340	473	79.78	37737.4
25/03/04	Corny Point	89.3	345	528.6	180.05	95176.8
25/03/04	Corny Point	22.8	272	261.7	98.19	25695.7
25/03/04	Corny Point	106.5	352	594.6	184.47	109687.2
27/04/04	Ulonga wreck	34.1	307	355.2	97.49	34628.4
5/12/04	St Francis Is.	101.3	384	805.5	139.53	112392.4
5/12/04	St Francis Is.	181.4	397	831.3	210.34	174852.3
5/12/04	St Francis Is.	89.2	385	749.2	119.2	89303.5
5/12/04	St Francis Is.	91.9	360	580.5	157.72	91558.2
15/12/04	Clarry's wreck	67.6	360	528.3	161.69	85418.6
15/12/04	Clarry's wreck	72.6	340	424.6	203.03	86208.2
17/12/04	Corny Point	102.7	382	718.2	122.95	88300.2
17/12/04	Corny Point	114.8	398	754.2	162.8	122781.1
17/12/04	Corny Point	142	372	667.6	213.52	142547.3
17/12/04	Corny Point	45.1	319	371.1	138.19	51282.7
10/01/05	Ulonga wreck	85.4	339	495.4	175.08	86734.7
13/01/05	Corny Point	69	333	475.6	156.65	74504.5
13/01/05	Corny Point	68	349	605.2	125.64	76038.5
13/01/05	Corny Point	17.1	252	207.7	89.53	18596.4

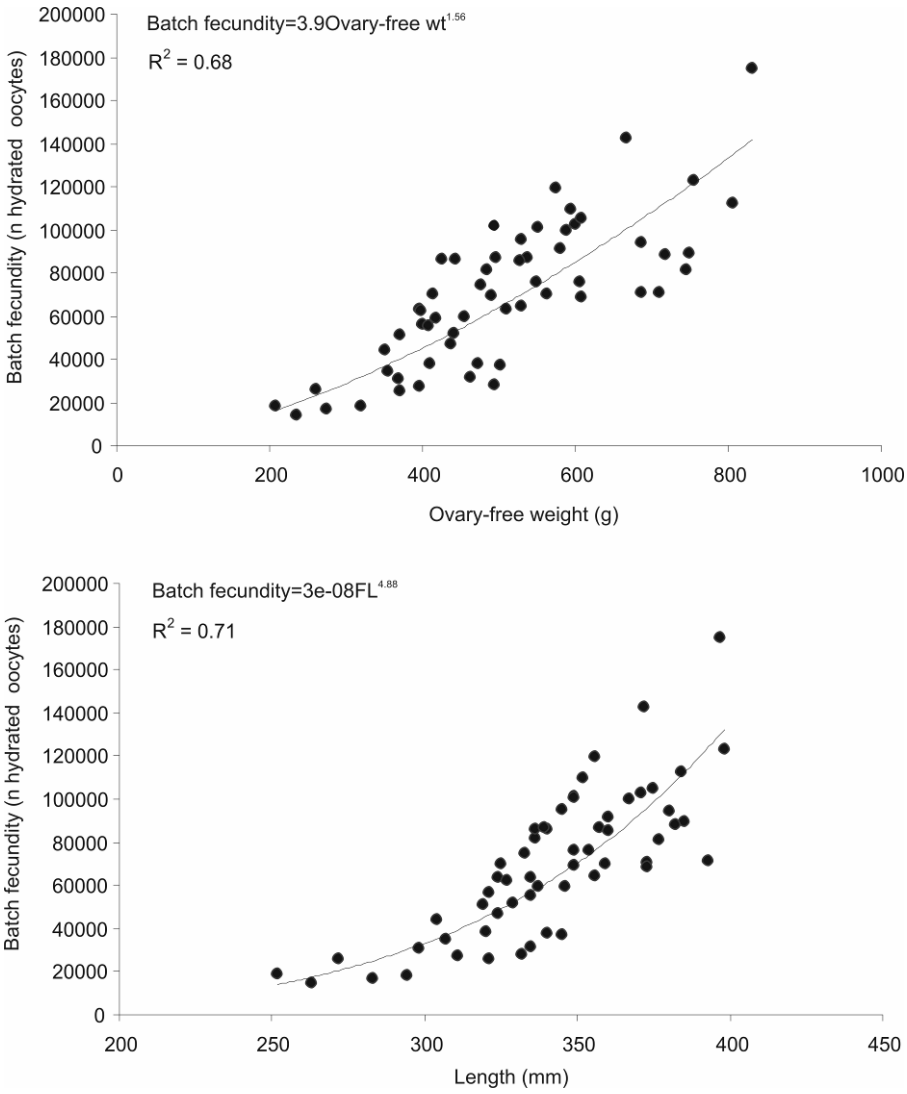

Figure 6.8. Relationship between (top) ovary-free body weight and (bottom) fork length and batch fecundity for *S. australasicus* sampled in southern Australia between 2002 and 2005.

6.4 Discussion

Microscopic analysis of ovarian sections and analysis of progressions in oocyte size frequencies suggested that *S. australasicus* has indeterminate fecundity. Similar conclusions were drawn for *S. japonicus*, based on a comprehensive examination of the gonads of this species off California (Dickerson *et al.* 1992). A review of the histological characteristics of *S. japonicus* throughout the Atlantic and Pacific Oceans (Hernández and Ortega 2000) also indicate that this species has indeterminate fecundity.

Collecting representative samples of spawning adults has impeded the application of the DEPM for several pelagic fishes, including sardine *Sardinops sagax* (Hunter and Lo 1997; Lo and Macewicz 2004) and anchovy *Engraulis encrasicolus* (Somarakis and Tsimenides 1997). Multi-panelled gill nets have been used in Australia to address this issue for several species, including *S. sagax* (Ward *et al.* 2001), Australian anchovy *E. australis* (Dimmlich and Ward 2006), and blue sprat *Spratelloides robustus* (Rogers *et al.* 2003). In the current study, gillnets were shown to be relatively ineffective for this purpose. Samples were obtained from commercial vessels and several fishery-independent methods (especially hook and line) and were used successfully. *Scomber* feed while reproductively active and there is no reason to suggest that samples taken by line are biased (Walsh and Johnstone 1992). Nonetheless, sampling methods that are more efficient and effective over a wide range of environmental conditions may be needed if the DEPM is to be used for ongoing assessment of this species.

Samples collected from southern Australia included fish over a wide range of sizes (109–422 mm FL), had similar mean sizes ($\overline{X}_{mature}$ = 318 mm FL) to fish collected during similar studies of *S. japonicus* off California ($\overline{X}_{mature}$ = 322 mm FL) (Dickerson *et al.* 1992) and Japan ($\overline{X}_{mature}$ = 352 mm FL) (Watanabe *et al.* 1999), and appear to be representative of the adult population. In contrast, samples of *S. australasicus* from eastern Australia mostly contained small fish ($\overline{X}_{mature}$ = 280 mm FL, >90% <350 mm FL) and did not include the large fish known to occur in this region. Hence, we consider that reproductive data for southern Australia are more robust than the data for eastern Australia. Future studies of *S. australasicus* should focus on the collection of samples of spawning fish from eastern Australia as commercial and recreational fishers operating in shelf waters have reported taking large spawning fish in these locations (Dennis Brown, Dr James Findlay, SPF RAG, pers. comm.).

Analysis of the macroscopic and microscopic features of gonads from fish collected from southern Australia indicated they were reproductively active for a longer duration (six months, November to April) than the smaller fish sampled off eastern Australia (four months, July to October). It is unclear whether this difference reflects variation in the length of the spawning season between the regions, which may be related to ecological and oceanographic variations, (Hernández and Ortega 2000), or the limitations of the adult sampling program off eastern Australia. The six month spawning season recorded for *S. australasicus* off southern Australia is comparable to the protracted spring to autumn spawning season recorded for similar sized (273–379 mm FL) *S. japonicus* off California (MacGregor 1976). Furthermore, a comprehensive summary of the spawning seasonality data for 57 separate studies of *S. japonicus* in eight separate regions concluded that spawning generally occurred between spring and autumn, occurred all year round near the equator and was related to localized variability in oceanographic conditions (Hernández and Ortega 2000).

Macroscopic staging of ovaries provided a useful indication of the timing and duration of the spawning season of *S. australasicus*. However, considerable error may result from macroscopic staging alone. For example, the interpretation of the macroscopic data for fish classified as 'spent' off eastern Australian should be treated with some caution as measurements of gonad weight for these samples were lower than would be expected for spent fish (<1.5 g) in 33% of samples. In addition, 28% of gonads assigned this stage had FL $<L_{50}$. Furthermore, no hydrated ovaries were collected in this region yet apparently spent ovaries were recorded during all months, including those outside the period when high abundances of eggs and larvae were collected in surveys. This suggests that an unknown proportion of fish with ovaries classified as stage V may have been stage II.

In southern Australia, the mean GSI was high (>4%) for males and females between November and March, indicating there was a protracted spawning season of 5–6 months, which contrasted with the situation in eastern Australia where GSI for females was only >2 % in September. GSI in both sexes declined in a synchronous manner between March and June in southern Australia. Peaks in male GSI were higher than for females in both regions, and male GSI was highest at the beginning of the spawning season, which concurs with findings for *S. japonicus* in previous studies (Perrotta and Christiansen 1993; Hernández and Ortega 2000). Estimates of GSI off southern Australia were similar to those recorded for *S. japonicus* off the Canary Islands (4–5%) (Lorenzo and Pajuelo 1996). Other studies of *S. japonicus* have shown that GSI can range up to 7.5 in

females and 9.7 in males (Hernández and Ortega 2000) which supports our findings that male investment of energy into sperm production may be substantial.

In southern Australia, the smallest male and female *S. australasicus* with mature gonads were in the 216 and 236 mm size classes and ~50% of males and females reached sexual maturity at 237 and 287 mm, respectively. These estimates were similar to those for *S. australasicus* sampled in the GAB during a previous study (Stevens *et al.* 1984) (50% maturity at 300 mm FL) and for *S. japonicus* sampled off Portugal (310 mm FL) and Peru (315–345 mm FL)(Hernández and Ortega 2000). Our estimates of size at maturity by sex showed that male *S. australasicus* mature earlier in their life history than females, which concurred with findings for Pacific Ocean populations of *S. japonicus* (Knaggs and Parrish 1973). The lack of large fish in samples collected off eastern Australia prevented the estimation of L_{50} using the logistic model; however mature females ranged in size between 178–394 mm FL and mature males ranged between 171–398 mm FL. The findings that females as small as 178 mm FL had maturing ovaries was surprising when compared to samples from southern Australia, yet comparable to estimates of size at first maturity for *S. japonicus* from several other regions of the world, including North-west Africa and South America (Hernández and Ortega 2000). Size at first maturity in southern Australia was similar to estimates for *S. japonicus* sampled off Baja California (218–223 mm FL) (Hernández and Ortega 2000). This information suggests that aggregations of *S. australasicus* that are >280 mm FL need to be sampled in both the eastern and southern regions of Australia during future DEPM surveys to facilitate routine estimation of key adult reproductive parameters.

Our classifications of POFs used to estimate spawning frequency were based on the assumption that degeneration rates of these structures were similar to those identified by Dickerson *et al.* (1992) for *S. japonicus*. These authors found that in waters ~20° C, POFs exhibited substantial shrinkage and degeneration of the granulosa at up to 24 hours old and were mostly degenerated and easily confused with atresic oocytes after 48 hours (day 2). Rates of degeneration of POFs need to be quantified for *S. australasicus* if the DEPM is to be used for ongoing stock assessment of this species. As rates of POF degeneration vary with temperature and between species (Fitzhugh and Hettler 1995), we calculated spawning frequency using three different methods that included: (i) using hydrated oocytes and day 0 POFs; (ii) using just day 1+ POFs and (iii) using hydrated oocytes , day 0 POFs and day 1+ POFs. Estimates of mean spawning frequency (all years combined) obtained using the three methods declined depending on the degree of inclusion of the data, i.e. 6 days (day 0 POFs and hydrated oocytes), 7 days (day 1+ POFs only)

and 8 days (day 0, hydrated oocytes and day 1+ POFs). This finding shows that subjective decisions to exclude POF stages (e.g. stages with higher levels of degeneration/older POFs) have the potential to introduce bias in estimates of spawning frequency. This has a flow-on effect when these estimates are used to calculate spawning biomass using the DEPM. Given the intrinsic uncertainties involved in estimating this parameter, the most appropriate estimates of spawning frequency for stock assessment purposes were those that used method (iii) (inclusion of hydrated oocytes, day 0 and day 1+POF stages).

Estimates of mean spawning frequency for individual seasons ranged between 2 and 11 days in southern Australia, which are similar to the estimates for *S. japonicus* off California in (12 days) (Dickerson *et al.* 1992) and Japan (2–11 days) (Watanabe *et al.* 1999). There was no relationship between fish size and spawning frequency off southern Australia. However, Dickerson *et al.* (1992) suggested there was evidence that larger, older (4 year old age class) females spawn more often than smaller and younger (2 year old) females (10 days cf. 26 days). Additional research is required to determine the spatial and temporal patterns in the spawning frequency of *S. australasicus* in southern and eastern Australia, as this has implications for the application of the DEPM for stock assessment of this species. Further, previous studies of other small pelagic species that focused on applying the DEPM have emphasised the importance of collecting samples from areas where fish have a range of spawning frequencies (Hewitt 1985).

Mean batch fecundity for *S. australasicus* in southern Australia was 69,894 oocytes per batch and 134 oocytes per g of body weight, which was higher than estimates for *S. japonicus* off Japan (Watanabe *et al.* 1999), similar to estimates off California (68,356 oocytes, 168 oocytes per g of body weight)(Dickerson *et al.* 1992) and lower than estimates of Peru (278 oocytes per g of body weight)(Peña *et al.* 1986; Dickerson *et al.* 1992). Quantification of the variance in batch fecundity estimate between years is important when estimates and regressions with fish weight are used to calculate the average fecundity of females in the sampled population (Hunter *et al.* 1985). The degree of variation we observed between individual estimates (14,349–174,852 oocytes per batch) was relatively high and shows that variability in the weight of individuals sampled has the potential to impact on the accuracy of estimates of average fecundity and spawning biomass. Regardless of these considerations, we are confident our estimates of batch fecundity provide suitably robust starting points for evaluating use of the DEPM for estimating the spawning biomass of *S. australasicus* off southern Australia.

6.5 Conclusions

S. australasicus is a serial spawner with asynchronous oocyte development and indeterminate fecundity. Off southern Australia, this species reaches sexual maturity at 237–287 mm, FL (~2 yrs of age) and spawns batches of eggs that contain between 14,349 and 174,852 oocytes per batch approximately once per 4–8 days during a protracted spawning season of up to six months. The spawning season off southern Australia extends from autumn to spring, whereas spawning occurs during winter and spring off eastern Australia. Batch fecundity varies with fish length and weight, but these variables may not affect spawning frequency. Our estimates of adult reproductive parameters for *S. australasicus* off southern Australia are suitable for use in the application of the DEPM, but estimates obtained for eastern Australia may not be suitable for this purpose. There is a need to collect representative samples of adult *S. australasicus* off eastern Australia before the DEPM is used for ongoing stock assessment in this region. If the DEPM is used for future stock assessment of *S. australasicus* it is also important that the degeneration rates of POFs are quantified to ensure that estimates of spawning fraction are robust.

6.6 Acknowledgments

Mr David Fleer, Mr Richard Saunders, Mr Wetjens Dimmlich, Mr Alex Ivey and Mr Paul Van Ruth (SARDI Aquatic Sciences) collected samples, assisted during surveys, entered data and dissected fish samples. We thank the master of the *RV* Ngerin, Neil Chigwidden and crew Mr Dave Kerr, Mr Chris Small, and Mr Ralph Putz, for their efforts during SARDI research surveys between 2001 and 2005. Ms Sandra Leigh (SARDI Aquatic Sciences) and Mr Chris Leigh (SOMA, Adelaide University) conducted the histological analyses. Mr Wetjens Dimmlich designed the Blue mackerel Access database. Samples were also collected by Dr Francisco Neira and Mr John Keene during egg surveys on the *RV* Bluefin. Thanks to Dr Scoresby Shepherd (SARDI) and Dr Adrian Linnane (SARDI) for comments on drafts of this chapter.

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7. Methods and criteria for identifying and staging the eggs of blue mackerel *Scomber australasicus*.

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Objective: To establish methods and criteria for identifying and staging the eggs of *S. australasicus*.

Summary: This chapter describes the pelagic eggs of *Scomber australasicus*, and a developmental series from fertilization to hatching. Eggs of *S. australasicus* are transparent, spherical and 1.05-1.30 mm in diameter and are characterised by a smooth chorion, and a prominent, unsegmented yolk with a single, 0.26-0.31 mm diameter oil globule. The oil globule is located off-centre from the animal axis early in development and posteriorly in the yolk of middle- to late-stage eggs, and becomes pigmented after the blastopore closure. Eggs of *S. australasicus* are morphologically similar to those of the *S. japonicus*, and the 7-stage series we established for *S. australasicus* eggs is similar to the 15-stage series described for *S. japonicus*. Molecular analyses show that middle and late stage eggs of *S. australasicus* can be identified with a high degree of confidence using standard morphological techniques. However, significant uncertainty exists regarding the morphological identification of early stage eggs. Only early stage eggs with a high probability of being *S. australasicus* were included in the datasets used in other chapters of this report. Hence, the egg counts used in these chapters may be negatively biased (conservative). There is a clear need to develop reliable, cost-effective molecular techniques for identifying the early-stage eggs of *S. australasicus*. These methods must overcome technical difficulties associated with the small amount of genetic material present in early-stage eggs. An egg development-temperature model is also needed to support the application of the DEPM to this species. Future surveys to support application of the DEPM to *S. australasicus* should involve the preservation of one (bongo net) sample from each haul in a formaldehyde solution and the other in an ethanol solution.

7.1 Introduction

Accurate identification of eggs to species level is a prerequisite for application of the Daily Egg Production Method (DEPM) to estimate spawning biomass of pelagic fishes (Picquelle and Stauffer, 1985; Stratoudakis *et al.*, 2006). Field-caught eggs can be identified in several ways. The most commonly used method is to match target eggs against morphological descriptions in the literature. A more advance method involves rearing eggs spawned from adults, and comparing these with the field-caught eggs. The most accurate method involves the use of molecular techniques (e.g. sequencing of mitochondrial DNA) to match the egg gene sequence to that of the adult. Molecular techniques are increasingly being used to confirm the identity of field-caught fish eggs (e.g. Shao *et al.*, 2001; Fox *et al.*, 2005), and have the advantage of being applicable to the full spectrum of developmental stages, i.e. early and late-stage eggs. The application of the DEPM also requires eggs to be staged and aged, which is usually done using an egg development-temperature key (Smith and Hewitt, 1980; Lo *et al.* 1996).

Information on the early life history of blue mackerel *S. australasicus* is sparse. The pelagic eggs of this species have not been described previously, although eggs of the closely related *S. japonicus* are well known (Watanabe, 1970; Berrien, 1975; Fritzsche, 1978; Kramer, 1960; Lancot, 1980; Mendiola *et al.*, 2007). This chapter describes methods and criteria for identifying and staging *S. australasicus* based on rearing experiments and eggs collected during ichthyoplankton surveys in southern and eastern Australia during 2002 to 2005.

7.2 Materials and methods

7.2.1 Artificial rearing

Adult *S. australasicus* (n = 40; 250-350mm CFL) were caught on 21 April 2005 at the 'north-west lump', approximately 7 nm off Corny Point in southern Spencer Gulf, South Australia (see Chapter 5). Fish were captured using baited lines in water 32-35 m deep. Sea surface temperature (SST) was 19.7°C.

Each fish was externally examined after capture for signs of sperm or eggs. At 16:45 pm, a female with hydrated oocytes (350mm CFL) was captured and eggs immediately stripped into a glass beaker. Eggs were carefully mixed with sperm in the presence of a small quantity of seawater to activate fertilization, and then left in the shade for 30 minutes. Eggs and sperm were subsequently transferred to a container with a 350µm mesh bottom to facilitate water flow, and yolked oocytes expelled during the stripping process were removed from samples of fertilised

eggs. The holding container was fitted with a battery-operated aerator, and held inside a bin full of seawater to allow continued circulation. Temperature of the seawater in the bin was maintained at 18.0-21.0°C. Sub-samples of eggs were removed every hour after the initial activation of the fertilisation process and fixed in a 5% formaldehyde solution. For each sub-sample, time since capture and fertilization of eggs, number of hours since fertilization and temperature of the water bath (Table 1).

Fertilized eggs were transported to the aquaculture facilities of SARDI Aquatic Sciences, and monitored overnight. Sub-samples continued to be removed hourly, and the eggs photographed under both transmitted and reflected light using image analysis software, and fixed for later analysis. A series of measurements were taken from the sub-sampled eggs, including diameter of the chorion, yolk and oil-droplet, and size of perivitelline space. Diameter and size ranges (to 0.01μm), as well as means and standard errors, are provided for a total of 47 eggs that were successfully reared to 10 hours. The initial developmental stages of *S. australasicus* eggs described in this report (Stages 1 and 2 of 8) are based on artificially-reared material.

Table 7.1. Time since capture and fertilization, hours since fertilization and water temperature at time of sub-sampling of artificially-reared eggs of *S. australasicus* stripped from a 350mm CFL mature female caught in Spencer Gulf, South Australia, in April 2005.

Time	Hours	Temp water bath (°C)
17:45	1	19.4
18:45	2	18.8
19:45	3	18.4
20:45	4	18.6
21:45	5	18.7
22:45	6	18.7
23:45	7	18.8
00:55	8	18.5
02:05	9	18.0
03:00	10	21.0
04:02	11	20.0
05:15	12	19.0
06:15	13	18.5
07:15	14	18.2
08:15	15	19.0
09:15	16	19.0
10:15	17	19.0
11:15	18	19.5

7.2.2 Field-collected eggs

Pelagic eggs of *S. australasicus* were collected from shelf waters of southern and eastern Australia as described in Chapter 8 of the present report.

7.2.3 Morphological identification of eggs and larvae

The initial identification of field-caught eggs of *S. australasicus* was based on the morphological characters described for eggs of two *Scomber* species, namely *S. japonicus* and *S. scombrus* (Watanabe, 1970; Berrien, 1975; Fritzsche, 1978; Kramer, 1960; Lancot, 1980; Mendiola *et al.*, 2000). The accuracy of the morphological identifications was verified using the molecular techniques described below.

7.2.4 Molecular techniques

Verification of the identity of eggs using DNA barcoding methodology was carried out at the CSIRO Genetics Division (Hobart) and Genetics Laboratory of the University of Tasmania (School of Zoology). The analyses were conducted in two stages. The first set of tests was conducted on 90 early-stage to late-stage eggs with *Scomber*-like features, as well as five late-stage eggs positively identified as *S. australasicus*. The second set of tests, however, predominantly targeted blue mackerel eggs following results from the initial tests, and eggs suspected belonging to other teleosts. Of the 149 eggs tested, 96 were early stage (i.e. no embryo), 13 were mid stage and 40 late stage. The technique comprised DNA extraction from individual eggs, followed by amplification using Polymerase Chain Reaction (PCR) and the sequencing of four different mtDNA gene fragments, namely *Cytochrome B* (*CytB*), 12s and 16s rRNA, and the 655 base-pair region of the protein-coding cytochrome oxidase subunit 1 gene (*cox1*). The *cox1* gene was chosen for this study since it constitutes the marker currently used in the Fish Barcode of Life (Fish-BOL) database being developed to barcode all fish species worldwide (Herbert *et al.*, 2003; Ward *et al.*, 2005; Pegg *et al.*, 2006). Primers used included FishF1-R1 and FishF2-R2 (*cox1*), and arL and BRH (16s). All sequences were compared against those of *S. australasicus*/*S. japonicus* archived in the Genbank public database (National Centre for Biotechnology Information - NCBI). The *cox1* sequence was also compared to those in Fish-BOL.

7.3 Results

7.3.1 Reared eggs

Eggs were artificially reared for up to 10-11 hours, i.e. stage 2. Water temperature during the trial was maintained at 18.0-21.0°C. The reared, early-stage eggs are characterised by a small perivitelline space, a blastodermal cap, which is golden/orange in colour, and a relatively large oil globule, which at this stage lacks melanophores. The diameter of eggs and single oil globule averaged 1.153 and 0.299mm, respectively (Table 7.2).

Table 7.2. Standard morphometric features (after fixation in 10% formalin) of live *S. australasicus* eggs (n = 47) reared from mature adults caught in Spencer Gulf, South Australia in April 2005.

Feature	**Mean (µm)**	**±SE (µm)**	**Range (µm)**	**n**
Diameter egg (µm)	1152.66	6.97	1046.17 - 1339.71	47
Diameter oil globule (µm)	299.57	4.34	261.59 - 444.85	45
Diameter yolk (µm)	1073.48	14.37	903.55 - 1194.06	18
Perivitelline space (µm)	63.03	11.49	7.11 - 182.91	18
Oil droplet diameter as % of egg diameter	26.00	0.27	22.91 - 33.20	45
Yolk diameter as % of egg diameter	92.45	0.94	85.68 - 99.06	18
PVS as % of egg diameter	5.43	1.01	0.63 - 15.58	18

7.3.2 Molecular tests

Of the 149 eggs tested, PCR products were successfully obtained for 44 early-stage, 8 mid-stage and 27 late-stage eggs (n = 79). The initial molecular tests were carried out on 57 eggs (Table 7.3). Five late-stage eggs tested positive for *S. australasicus/japonicus* in the NCBI database using *Cytochrome B* (n=4) and *12s* (n=1) fragments (Table 4; Appendix 1). Morphological identifications of *S. australasicus* were also confirmed for 100% of mid-stage (4) and late-stage (17) eggs. However, only 44.5% of early-stage eggs (16 of 36) returned a positive match with *S. australasicus* (Table 7.3), i.e. 55.5% of early stage eggs were not *S. australasicus*.

In the additional tests, 100% of mid-stage (1) and late-stage (8) eggs were confirmed to be *S. australasicus*. However, one of the four early stage eggs identified as *S. australasicus* on the basis of morphology was genetically determined to belong to another species (Table 7.3). In addition,

three out of nine eggs identified as other species on the basis of their morphology were found to be *S. australasicus* using the genetic technique (Table 7.4). Pelagic eggs that were either misidentified as *S. australasicus* or correctly identified as belonging to other species belonged to eight teleosts, including *Lepidotrigla* spp., *Optivus agrammus*, *Saurida undosquamis* and *Chelidonichthys kumu* (Table 7.5).

Table 7.3. Summary of results of identification of known and suspected *S. australasicus* eggs using molecular (mtDNA) techniques (see text for details on sequenced gene fragments). Note that PCR products were not successfully obtained for an additional 70 eggs, which could not be identified morphologically.

Purpose of molecular tests and results	**Developmental stage**			
Initial tests – verify *S. australasicus* identifications	**Early**	**Mid**	**Late**	**Total (%)**
S. australasicus – morphological identification confirmed	16	4	17	37 (64.9)
S. australasicus – morphological identification rejected	20	0	0	20 (35.1)
Total	**36**	**4**	**17**	**57**
Second tests – verify identifications of both *S. australasicus* and other species	**Early**	**Mid**	**Late**	**Total (%)**
S. australasicus - morphological identification confirmed	3	1	8	12 (54.5)
S. australasicus - morphological identification rejected	1	0	0	1 (4.5)
Other species - morphological identification confirmed	3	1	2	6 (27.3)
Other species - morphological identification rejected	1	2	0	3 (13.6)
Total	**8**	**4**	**10**	**22**
Grand Total tested	**44**	**8**	**27**	**79**

Table 7.4. Percentage species match of mtDNA gene fragments amplified from five positively-identified eggs of *S. australasicus* following BLAST submissions via the National Centre for Biotechnology Information database.

Egg number	**Amplified mtDNA fragment**	**BLAST**	
		S. australasicus	***S. japonicus***
1	*Cyt B*	99%	
3	*12s*	98%	99%
4	*Cyt B*	98%	98%
8	*Cyt B*	99%	98%
10	*Cyt B*	98%	99%

Table 7.5. Summary of identifications of known and suspected *S. australasicus* eggs using molecular (mtDNA) techniques (see text for details on sequenced gene fragments). Note that eggs of some taxa were matched to species using more than one gene.

Taxa	***cox1***	***16s***	***12s***	***Cyt B***
Argentina sp.	1			
Auxis rochei	1			
Chelidonichthys kumu	1			
Cyttopsis sp.	1			
Lepidotrigla spp	15	4		
Optivus sp.	2			
Pseudopentaceros pectoralis	1			
Saurida undosquamis	1			
Scomber australasicus	37	10	1	4
No good match		1		

7.3.3 General description of eggs

Eggs of *Scomber australasicus* can be identified by the following combination of characters: (a) round shape, 1.05-1.30 mm in diameter; (b) smooth chorion; (c) small perivitelline space; (d) prominent, unsegmented yolk (e) single, 0.26-0.31mm diameter oil globule, located off-*centre* of animal pole axis in early-stage eggs and posteriorly in yolk of mid- to late embryos; globule is initially unpigmented but develops pigment by late stage 5; (f) pigment pattern of mid- to late-stage embryos consisting of a paired row of melanophores along dorsal surface from head to tail, pigment anterior to eyes, and no pigment over the mid nape region (Fig. 7.1).

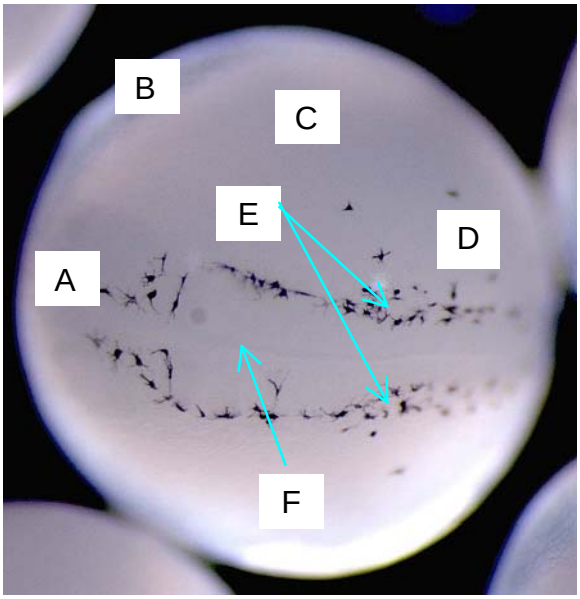


Figure 7.1. Photograph of a 1.20mm diameter Stage 5 egg of *S. australasicus* . A, head; B, small to medium perivitelline space; C, homogeneous yolk, with single, pigmented, 0.26-0.31 mm oil globule located posteriorly (not visible in photograph); D, scattered pigment over yolk, at level of pectoral fin primordium; E, paired row of melanophores along dorso-lateral surface of body of embryo, continuing across head/trunk junction and towards developing eyes; F, unpigmented nape region. Egg from Transect A5 Stn 3, northern New South Wales, October 2003. Photo by F.J. Neira (TAFI). Fixative: 98% ethanol.

7.3.4 Development and staging of eggs

Detailed examination of a series of field-collected and laboratory-reared eggs of *S. australasicus* made possible the assemblage of a developmental sequence comprising seven main stages. The descriptions have been assembled to represent sequential stages of development but are mostly based on field-collected material from different seasons and areas and should be used with some caution. A glossary of the terms used in the descriptions is provided in Appendix 7.1.

7.3.4.1 Stage 1: Fertilization to early blastoderm

Small blastodermal cap (early embryonic tissue) at animal pole starts to develop towards vegetal pole and covers up to 1/4 of yolk (Fig. 7.2). Single oil globule at the vegetative pole is unpigmented at this stage, and located slightly off centre of polar axis. Eggs to Stage 1 were reared at SARDI Aquatic Science at 18.4-19.4°C, to about 2-5h post-fertilization. Mean diameter eggs = 1.15mm (range = 1.05-1.19mm); mean diameter oil globule = 0.29mm (range = 0.27-0.31mm).

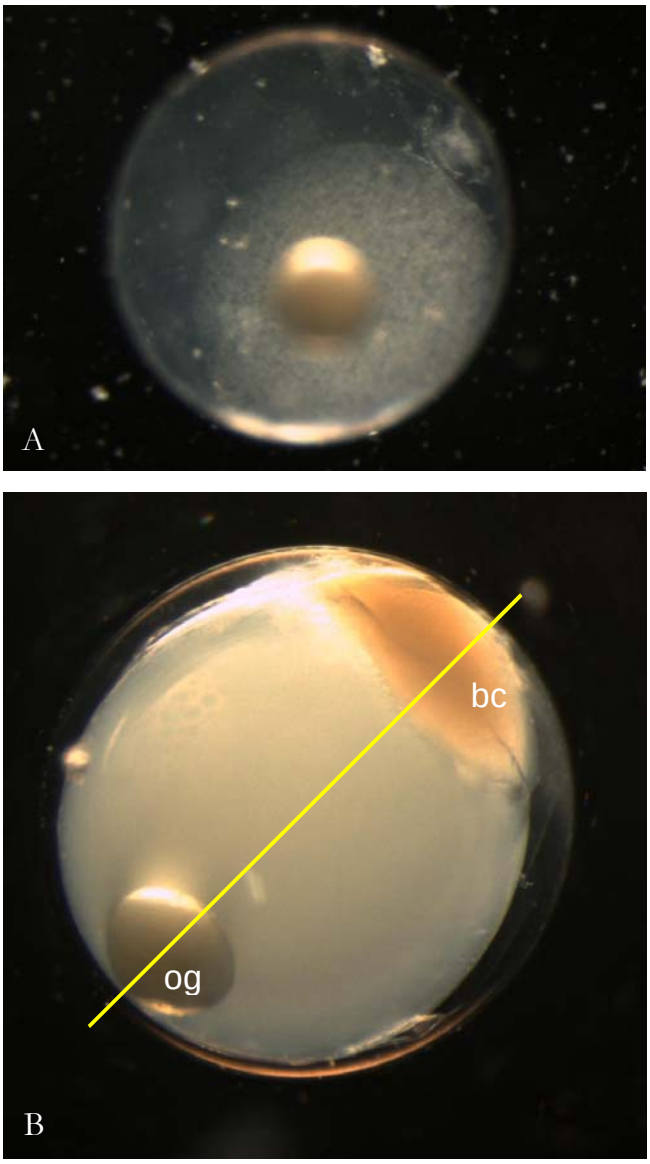


Figure 7.2. Laboratory-reared Stage 1 eggs of *S. australasicus* showing blastodermal cap (bc) opposite to single, unpigmented oil globule (og). Yellow line in B indicates polar axis. Photos by P. Rogers (SARDI). Fixative: 10% formalin.

7.3.4.2 Stage 2: Early blastoderm to blastula formation

Blastodermal cap continues developing towards vegetative pole, with epiboly covering >1/2-<3/4 of yolk (Fig. 7.3). Marginal blastoderm cells thicken to form the germ ring. Blastoderm becomes distinctly thicker on side of axial portion of developing embryo; blastocoele is also visible. Oil globule at vegetative pole is unpigmented, and is located slightly off *centre* of polar axis.

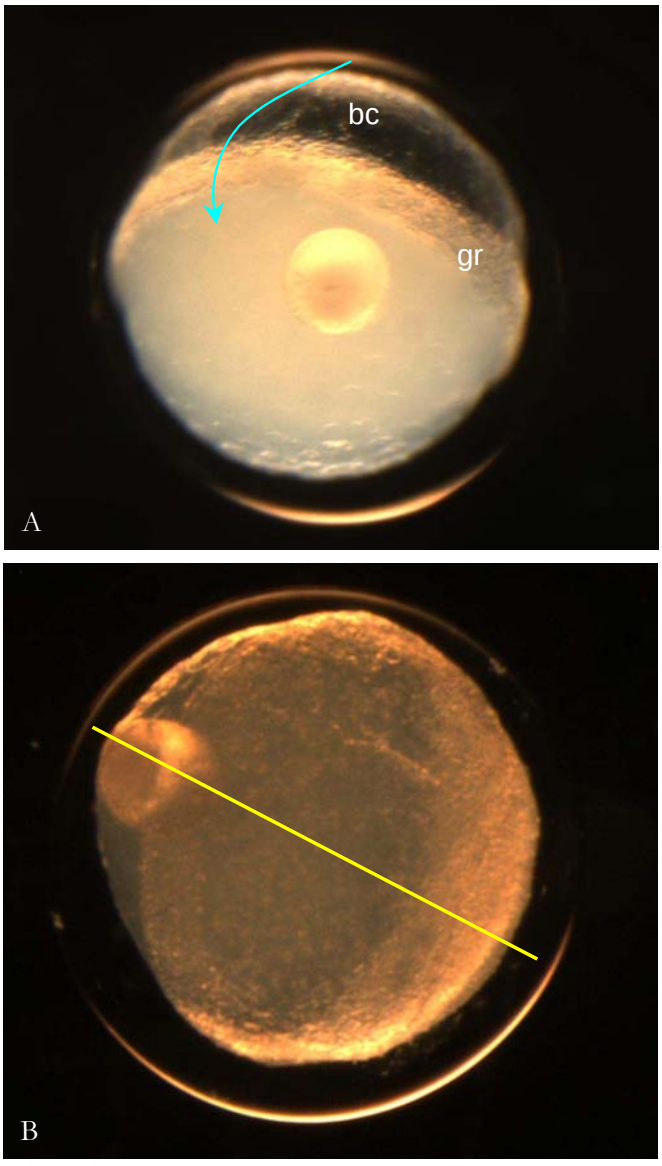


Figure 7.3. Field-collected Stage 2 eggs of *S. australasicus* showing blastodermal cap (bc) covering >1/2 of yolk and germ ring (gr). Blue arrow in A shows direction of epiboly; yellow line in B indicates polar axis. Eggs from Stn F8, South Australia, March 2004. Photos by L. McLeay (SARDI). Fixative: 10% formalin

7.3.4.3 Stage 3: Embryonic shield to completion of epiboly

Embryonic shield is visible on animal pole, with developing embryo clearly distinguishable by end of stage (Fig 7.4). Epiboly 3/4 to 4/5 complete, i.e. germ ring reaches about 3/4 to 4/5 of yolk, leaving opening (blastopore) and eventually closing (closure signs completion of epiboly). Eyes start to differentiate, and optic cups become visible. No embryo pigment is distinguishable at this stage.

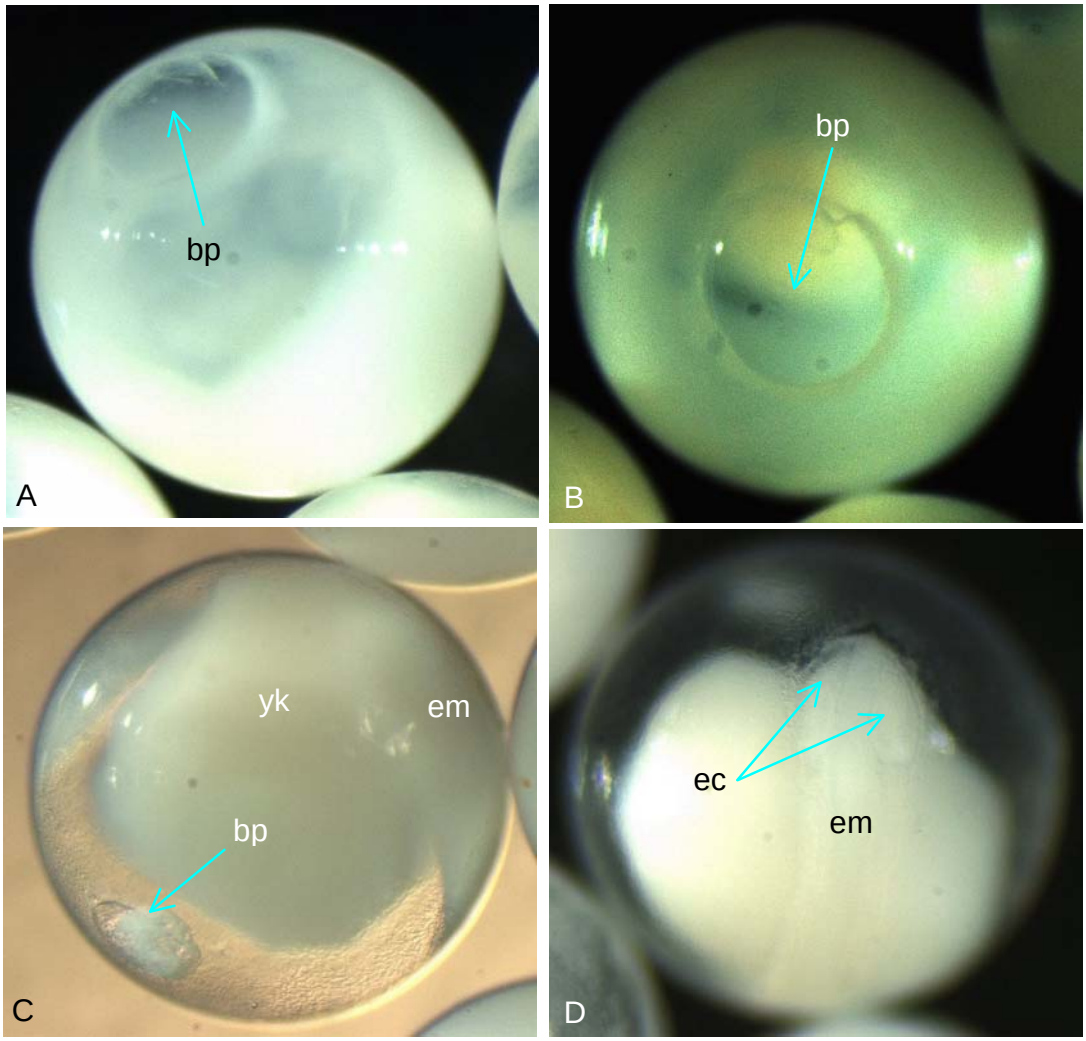


Figure 7.4. Field-collected Stage 3 eggs of *S. australasicus* showing blastopore (bp), developing embryo (em), yolk (yk) and developing eye cups (ec). Note blastopore still closing in C. Egg in A, B (1.12mm diameter) from Transect 3 Stn 3, southern Queensland, July 2004; egg in C, D (1.07mm diameter) from Transect 18 Stn 1, southern New South Wales, October 2002. Photos by F.J. Neira (TAFI). Fixative: 98% ethanol.

7.3.4.4 Stage 4: 1/2 circle embryo

Embryo extends to around 1/2 of yolk, and blastopore has closed (Fig. 7.5). First body somites (= myomeres) visible along posterior region of tail. Fine melanophores appear along dorsal surface of trunk and tail of embryo. Eyes start to differentiate, with the unpigmented optic cups (lenses) becoming more defined. Single oil globule still unpigmented.

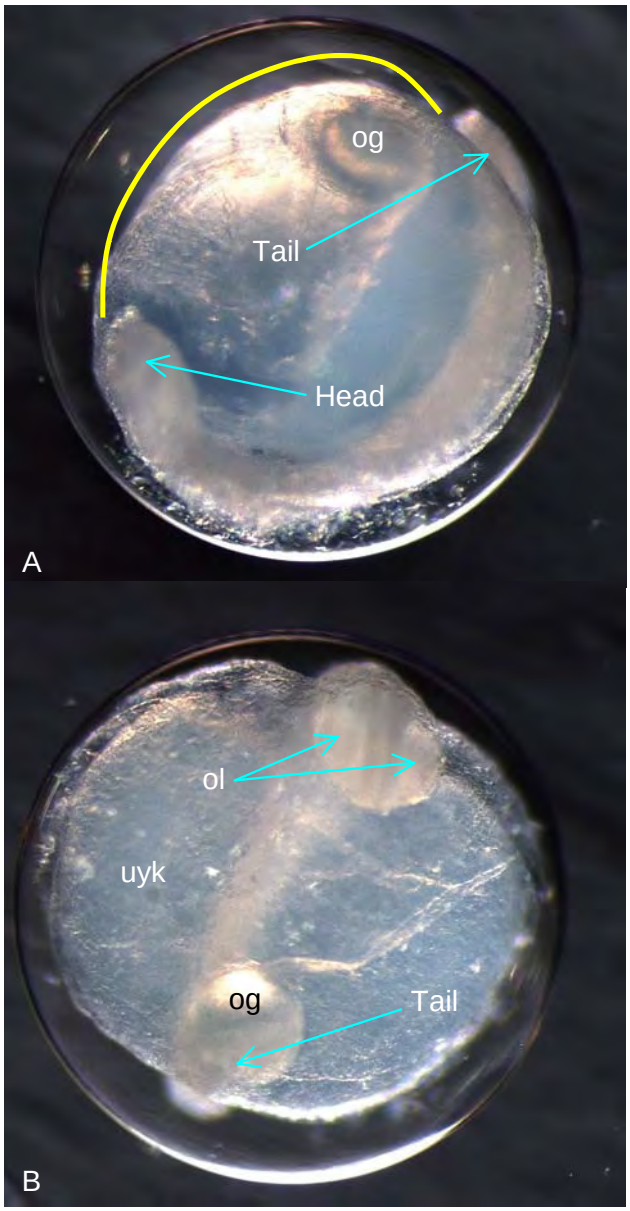


Figure 7.5. Field-collected Stage 4 egg of *S. australasicus* (1.17mm diameter) showing embryo extending to around 1/2 of yolk (indicated by yellow curve in A, unpigmented eyes with defined optic lenses (ol), single, unpigmented oil globule (og) and unsegmented yolk (uyk). Note tail almost reaching level of oil globule in B. Egg from Stn N7, South Australia, March 2004. Photos by F.J. Neira (TAFI). Fixative: 10% formalin.

7.3.4.5 Stage 5: 2/3 – 3/4 circle embryo

Embryo extends to around 2/3 – 3/4 of yolk, with tail reaching level of and passing oil globule (Fig. 7.6). Head starts to become wider than rest of body, as well as dorsally depressed. Myomeres clearly visible along posterior region of tail. Pigment continues to develop along dorsal surface of embryo, including posterior of head; pigment dorsally along trunk and tail is divided into two distinct melanophore rows, leaving nape region just behind head unpigmented. Developing eyes still not pigmented. A few stellate melanophores develop over yolk and around single oil globule in late Stage 5 eggs.

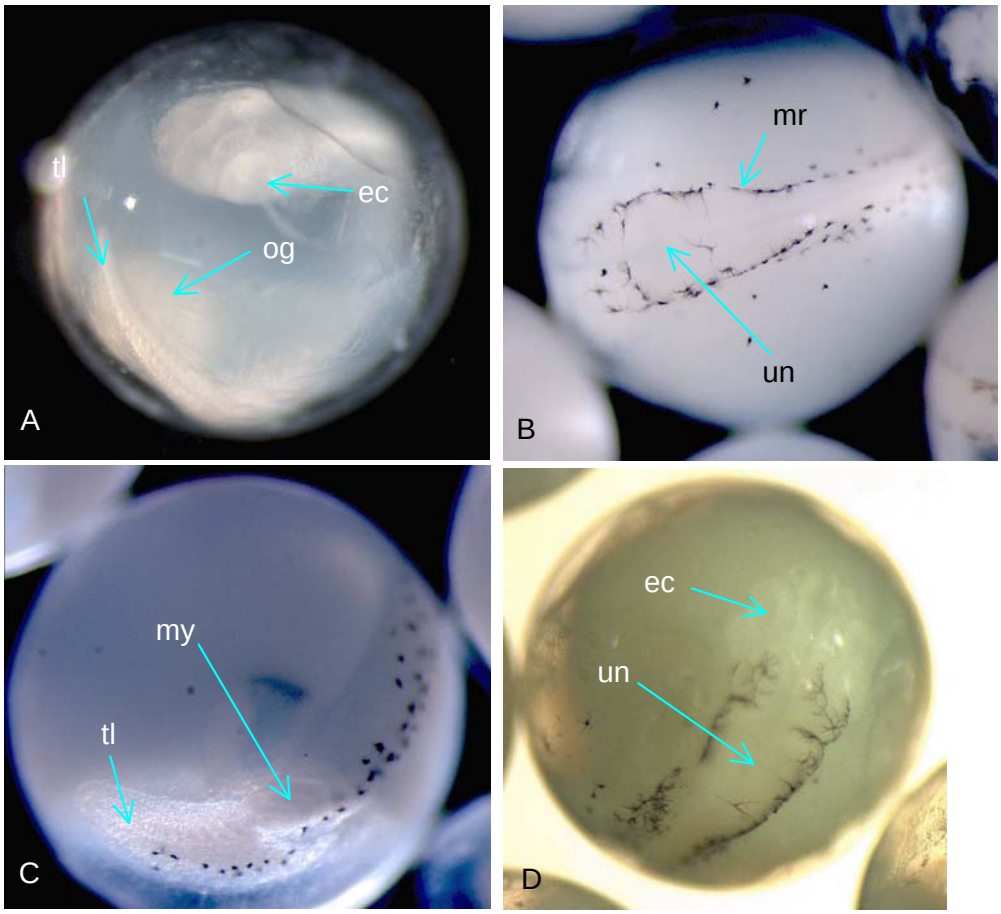


Figure 7.6. Field-collected Stage 5 eggs of *S. australasicus* showing embryo extending to around 2/3-3/4 of yolk, and tail (tl) passing level of oil globule (og). Also note eye cups (ec), still unpigmented at this stage, tail myomeres (my), paired melanophore row along dorsal surface of trunk and tail (mr), and unpigmented triangular nape region (un). Early-stage 5 egg in A (1.16mm diameter) from Stn O15, South Australia, February 2005; late-stage 5 egg in B, C (1.20mm diameter) from Transect A5 Stn 3, northern New South Wales, October 2003; late-stage 5 egg in D (1.19mm diameter) from Transect 21 Stn 7, central New South Wales, July 2004. Photos by F.J. Neira (TAFI). Fixative: 10% formalin (A); 98% ethanol (B, C, D).

7.3.4.6 Stage 6: Full circle embryo

Embryo extends to around entire yolk (Fig. 7.7). Head and nape area are noticeabley wider laterally than rest of body; main brain divisions well defined. Tail is still attached to yolk, with caudal fanfold clearly visible around tail region. Fine stellate melanophores develop on head in some embryos; eyes remain unpigmented until after hatching. Nape region that continues unpigmented. Paired melanophore rows along dorsal surface of trunk and tail extend almost to end of tail; few melanophores start to develop on surface of yolk. Single oil globule is located posteriorly, towards tip of tail, and is now about 3/4 pigmented.

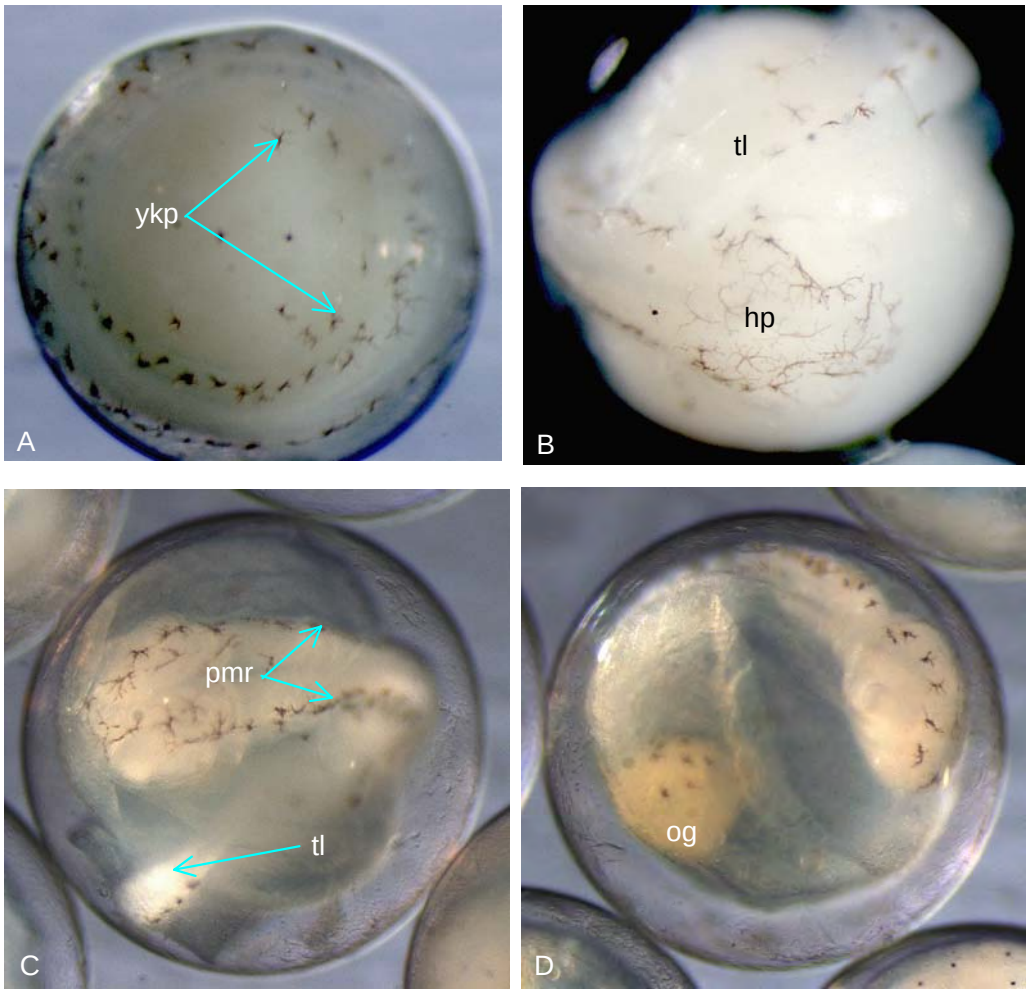


Figure 7.7. Field-collected Stage 6 egg of *S. australasicus* showing full circle embryo. Other features include tail (tl) reaching past oil globule (og) which is now pigmented, paired melanophore row along dorsal surface of trunk and tail (pmr), and head pigment (hp). Eyes still unpigmented (ue). Eggs in A, B (1.10mm diameter) from Transect A5 Stn 1, northern New South Wales, October 2002; egg in C, D (1.09mm diameter) from Stn 10 Esperance, Western Australia, February 2006. Photos by F.J. Neira (TAFI). Fixative: 98% ethanol (A, B); 10% formalin (C, D).

7.3.4.7 Stage 7: Pre-hatching

Embryo fully developed, prior to egg hatching (Fig. 7.8). Tail is twisted off the embryonic axis and has clearly separated from yolk, with the tip ending very close to either side of head. Yolk is becoming increasingly smaller. Single, pigmented oil globule is positioned next to anus, towards posterior region of yolk, and remains so in early preflexion, yolk-sac larvae. Embryo with similar pigment pattern to that of Stage 6, including melanophores over yolk sac, and over snout region ahead of eyes; nape region continues without pigment.

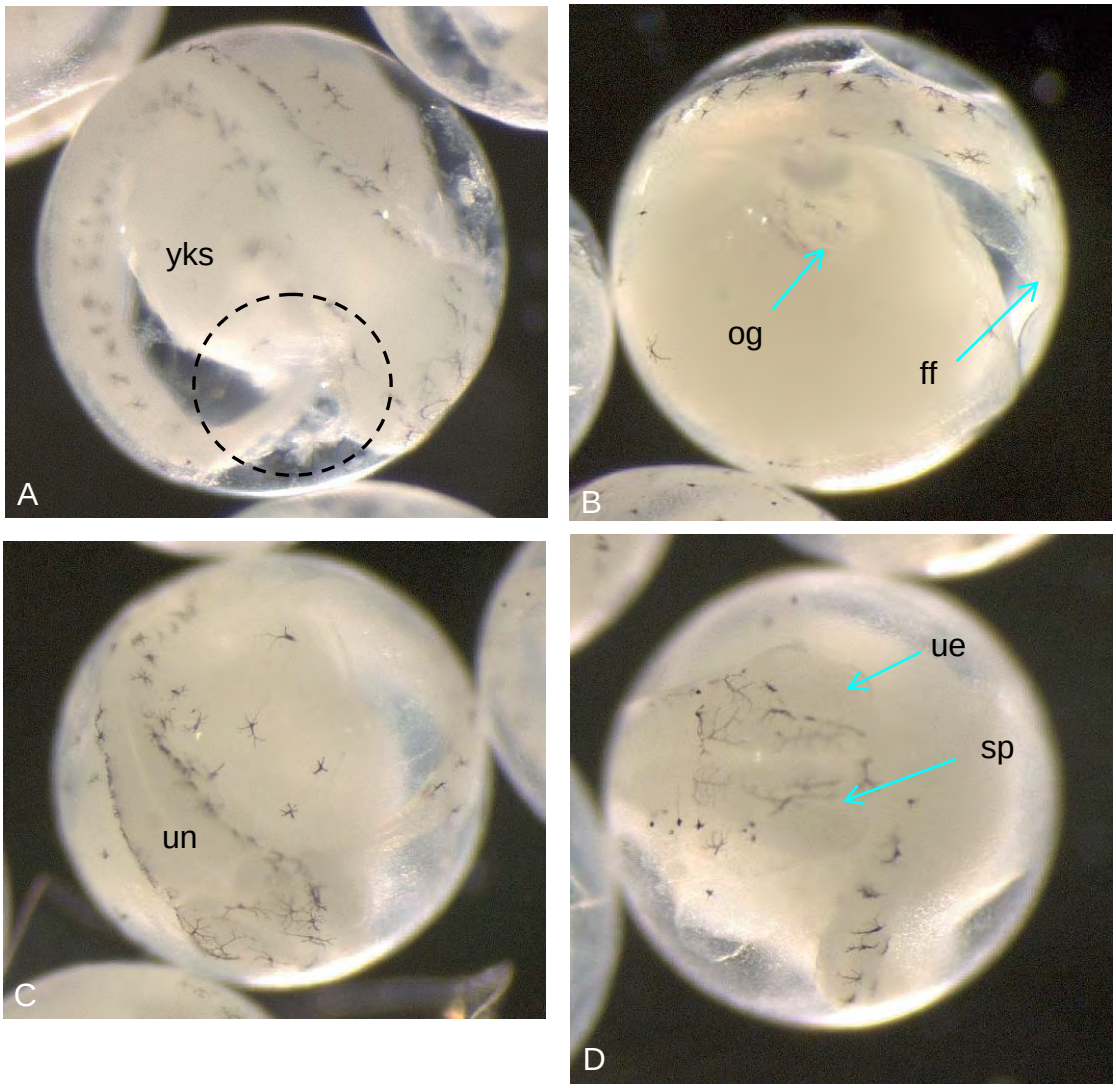


Figure 7.8. Early pre-hatching Stage 7 egg of *S. australasicus* (1.25mm diameter) showing tail of embryo twisted and fully separated from yolk (dashed line circle). Other features include pigmented oil globule (og) towards posterior region of yolk sac (yks), distinct caudal fin fold (ff), snout pigment (sp), unpigmented eyes (ue), and unpigmented nape region (un), a diagnostic character of mid to late-stage *S. australasicus* embryos. Eggs Transect 6 Stn 1 northern New South Wales, October 2002. Photos by J.P. Keane (TAFI). Fixative: 98% ethanol.

7.3.5 Similar eggs

The pelagic eggs of *S. australasicus* are likely to be confused with those belonging to a number of species which also release pelagic eggs and spawn at similar times in the same region to *S. australasicus*, particularly during the early stages. Depending on developmental stage, similarities may comprise features such as a diameter of ~1.0-1.3mm, embryo's shape and pigment, and presence of a single, pigmented oil globule. Groups whose eggs could be confused with those of *S. australasicus* include gurnards (*Lepidotrigla* – Triglidae), roughy (*Optivus* sp. – Trachichthyidae) and saury (*Saurida* – Synodontidae). Gurnard eggs are particularly susceptible to misidentification during late stages of development due to similarities in the morphology and pigmentation pattern of the embryos (Fig. 7.9). However, eggs of these genera can be distinguished from those of *S. australasicus* using characters which are unique to *S. australasicus* eggs, such as the posteriorly-located, pigmented oil globule, the shape and pigment of the embryo, and the unsegmented (= clear) yolk which is sprinkled with a few, sparsely-distributed stellate melanophores.

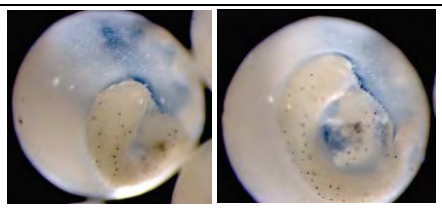
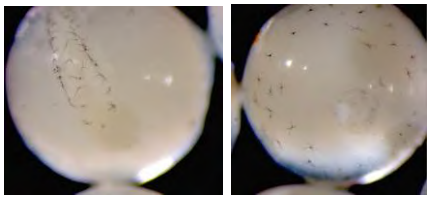
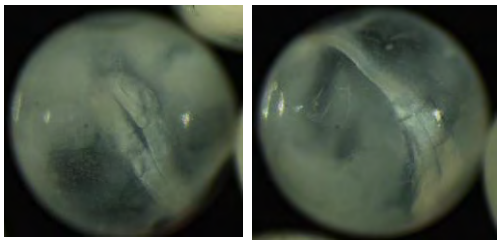
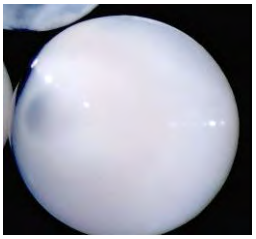
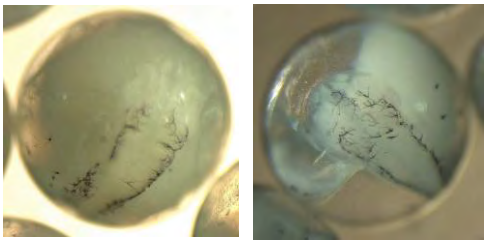
Egg(s)	Genus/species	Survey information	mtDNA barcoding method(s)
	*Lepidotrigla spinosa* (early stage) 1.05mm	July 2004 Transect 6 Station 2	*cox1*: BOLD (90%) NCBI (89%) 16S rRNA: NCBI (98%)
	*Lepidotrigla spinosa* (mid stage) 1.00mm	July 2004 Transect 6 Station 2	16s: NCBI (98%)
	*Lepidotrigla spinosa* (late stage) 1.00mm	July 2004 Transect 6 Station 2	16s: NCBI (98%)
	*Saurida undosquamis* (mid stage) 1.12mm	July 2004 Transect 6 Station 1	*cox1*: BOLD (100%) NCBI (99%)
	*Pseudopentaceros pectoralis* (early stage) 1.00mm	October 2002 Transect A8 Station 1	16s: NCBI (96%)
	*Scomber australasicus* (late stage) [L] 1.100mm [R] 1.17mm	[L] July 2004 Transect 21 Station 7 [R] October 2002 Transect 6 Station 3	(L) cox1: BOLD (100%) NCBI (98%) 16s: NCBI (99%) (R) cox1 BOLD (100%) NCBI (99%) 16s:

Figure. 7.9. Selected examples of pelagic eggs likely to be confused with those of *S. australasicus* . Photographed eggs were collected simultaneously with those of *S. australasicus* during the 2002-2004 surveys, and identified to genus/species using molecular methods (see Section 7.2.4 for details and abbreviations). Photographs of a 1.10mm diameter (left) and a 1.17mm diameter (right) mid-stage egg of *S. australasicus* have been included for comparison.

7.4 Discussion

This study provides the first detailed description of the pelagic eggs of *Scomber australasicus*. The pelagic eggs of *S. australasicus* are almost indistinguishable from those of *S. japonicus*. Eggs of both scombrids are transparent and spherical, and measure 0.80-1.35mm in diameter. Both possess a smooth chorion and a prominent, unsegmented yolk with a single, 0.22-0.38mm diameter oil globule located off-centre from the animal axis early in development and posteriorly in the yolk of mid- to late-stage eggs. In both species, the oil globule becomes pigmented after the blastopore closure (Watanabe, 1970; Kramer, 1960; Berrien, 1975; Fritzsche, 1978; Crossland, 1981). The morphological similarities also extend to the shape and pigment pattern of late-stage embryos, particularly the flat, enlarged nape region, and the paired row of melanophores along the dorsal surface of the embryo.

Our results (Table 7.3) show that the mid and late stage eggs of *S. australasicus* can be identified with a high degree of confidence using standard morphological techniques. In contrast, significant uncertainty exists regarding the morphological identification of early stage eggs. The morphological identification and staging of early and mid stage eggs is enhanced by preservation in formaldehyde solution. However, estimating the accuracy with which the young eggs of *S. australasicus* preserved in formaldehyde can be identified is precluded by the damage caused to the DNA by preservation in this medium. If the DEPM is used for future stock assessment of *S. australasicus* it is important that for each bongo net sample, the contents of one cod-end are stored in ethanol solution (to facilitate genetic identification) and the contents of the other cod-end are stored in formaldehyde solution (to facilitate morphological identification and staging).

Egg identifications made using the techniques outlined in this chapter were used in the descriptions of the distribution and abundance of *S. australasicus* eggs in southern and eastern Australia (Chapter 8) and the development and evaluation of the application of the DEPM to this species (Chapter 10). Only early stage eggs that were considered highly likely to be *S. australasicus* were included in the datasets used in these analyses. Hence, it is likely that the egg counts used in Chapters 8 and 10 are negatively biased (conservative). The findings of this study highlight the need to develop reliable, cost-effective techniques for the molecular identification of the early-stage eggs of *S. australasicus*. It is critical that these methods overcome the difficulties associated with the small amount genetic material present in early-stage eggs. These techniques should be developed before the DEPM is used for ongoing stock assessment of this species.

The molecular analyses conducted in this study provided useful information on the taxa with pelagic eggs that are similar to those of *S. australasicus*. Gurnards (*Lepidotrigla* spp.) are the group with eggs most similar to those of *S. australasicus*. Even the late stage eggs of gurnards could be potentially confused with those of *S. australasicus* because of the strong similarities in both morphology and pigment patterns. Other taxa with early stage eggs that can be confused with those of *S. australasicus* include *Optivus*, *Auxis and Saurida* spp. For these taxa, late stage eggs are unlikely to be confused with those of *S. australasicus*.

In this study, we established a development series comprising seven main stages from fertilization through to hatching. Since artificially-reared fertilized eggs could only be maintained for up to 11 hours, all stages except 1 and 2 were described from field-collected material. As the eggs that were used to establish the developmental series came from waters with different temperature regimes the morphological split between each stage is somewhat subjective. Until an egg development-temperature model is developed from laboratory-reared material, the developmental stages described here for the eggs of *S. australasicus* should be used with caution.

The seven stages described here for *S. australasicus* egg are comparable to the 15-stages described for *S. japonicus* eggs reared at 16.4-20.5°C (Watanabe, 1970). The greater number of stages described for *S. japonicus* reflects the identification of seven stages during the first 20 hours of development, whereas the last six (to almost 42 hours) were defined by the degree of growth of the embryo (Watanabe, 1970). We consider that a 7-stage egg series is sufficient to encompass the main morphological changes between fertilization and hatching in *S. australasicus*. The 7-stage *S. australasicus* egg series that we developed is comparable to six stage series described for *S. scombrus* (Lockwood *et al.*, 1981), and the 13 stage series described for this species by Mendiola *et al.* (2007).

7.5 Conclusions

The pelagic eggs of *S. australasicus* from southern and eastern Australia are morphologically similar to those of the closely-related *S. japonicus*. Molecular analyses show that mid and late stage eggs of *S. australasicus* can be identified with a high degree of confidence using standard morphological techniques. However, significant uncertainty exists regarding the morphological identification of early stage eggs. Hence, only early stage eggs with a high probability of being *S. australasicus* were included in the datasets used in other chapters of this report (i.e. 8 and 10). We consider that the egg counts used in these chapters are negatively biased (conservative). There

is a clear need to develop reliable, cost-effective molecular techniques for identifying the early-stage eggs of *S. australasicus*. These methods must overcome technical difficulties associated with the small amount genetic material present in early-stage eggs. An egg development-temperature model is also needed for this species. Future surveys to support application of the DEPM to *S. australasicus* should include the preservation of one sample from each haul in a formaldehyde solution and the other in an ethanol solution.

7.6 Acknowledgements

We acknowledge Sharon Appleyard (CSIRO Marine, Hobart) for her initial work on the molecular identification of eggs. We are grateful to Sandra Davidson and Adam Smolenski (Central Science Laboratory, University of Tasmania) for establishing the methodology and sequencing gene fragments to identify fish eggs, including *S. australasicus*. Lachlan McLeay, Paul Rogers, Alex Ivey and Richard Saunders (SARDI Aquatic Sciences) conducted the at-sea egg rearing trails in Spencer Gulf, South Australia and took photographs of reared eggs. Dr Stephen Mayfield (SARDI) and Thor Saunders (SARDI) reviewed the chapter.

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7.8 Appendices

7.8.1 Fish egg development glossary

Blastocoele: cavity of blastula; segmentation cavity.

Blastoderm: early embryonic tissue composed of blastomeres; generally refers to embryonic tissue prior to formation of embryonic axis. Usually referred to as blastoderm cap, it has the shape of an upside down bowl.

Blastodisc: embryo-forming area in egg prior to cleavage; also early embryo comprising a disc of cells on the yolk.

Blastopore: opening formed by and bordered by germ ring as it extends over yolk; also circular area over yolk of egg not covered by advancing germ ring during epiboly.

Blastula: stage in embryonic development which represents final product of cleavage stages; characterized by formation of blastocoele.

Early embryo: stage in embryonic development characterized by formation of embryonic axes.

Egg development: egg development after fertilization until hatching. Roughly subdivided into eight stages: early cleavage (1-64 cells), morula, blastula, gastrula, early embryo, tail-bud stage, tail-free stage and late embryo.

Epiboly: movement of embryonic cell mass over yolk surface; germ ring marks boundary of advancing sheet of cells.

Gastrula: stage in embryonic development between blastula and embryonic axes.

Germ ring: thickened rim of blastoderm, evident during late blastula and gastrula stages.

Germinal disc: blastodisc.

Incubation period: time taken for development from time of fertilization to egg hatching; varies according to temperature, egg diameter and amount of yolk it contains; can reach days to months.

Yolk sac: bag-like ventral extension of gut containing nutritive materials; first appears in fish embryo and is later absorbed by larva during stage after hatching and before feeding.

7.8.2 Genetic identification of *S. australasicus* eggs via molecular (mtDNA) methodology.

By Dr Sharon Appleyard (Molecular Geneticist, CSIRO Marine Research)

Fourteen pelagic eggs suspended in ethanol were received from the AMC (labelled AMC, *S. australasicus* , *S. australasicus*, Tr5 st2, 14/10/02) and stored in the genetics laboratory at -20^{0}C. Ten of these eggs were then used in the identification experiment.

Individual eggs were isolated in petri dishes and ethanol was evaporated off. Each egg was then rinsed in several drops of ddH_20. Eggs were either used directly in PCR reactions (eggs had been placed in a small amount of ddH_2O and were frozen and thawed at least twice, toothpicks were used to manually grind the eggs in the PCR tubes) or in a modified CTAB DNA extraction protocol (Table 1). As the results will later indicate, there was no discernible difference in the sequences of the eggs irrespective of DNA extraction method.

Table 1. Summary of DNA extractions methods undertaken on alcohol stored pelagic eggs.

Egg number	DNA Extraction Method	Amplified mtDNA fragment
1	Freeze & thaw in 6ul water	*Cyt B*
2	Freeze & thaw in 6ul water	*16S*
3	Freeze & thaw in 10ul water	*12S*
4	Modified CTAB	*Cyt B*
5	Modified CTAB	*16S*
6	Modified CTAB	*12S*
7	Freeze & thaw in 15ul water	*Cyt B*
8	Freeze & thaw in 15ul water	*Cyt B*
9	Freeze & thaw in 15ul water	*Cyt B*
10	Freeze & thaw in 15ul water	*Cyt B*

While the supernatant of the frozen eggs was used directly in PCR, 1/5 gDNA dilutions were made for eggs 4, 5 & 6 and this was used in subsequent amplifications. Three mtDNA fragments were amplified (Cytochrome B, 16s RNA, 12s RNA) using standard mtDNA primer concentrations, PCR conditions and cycling parameters. Resultant double stranded PCR products were purified using the Wizard™ PCR Preps DNA Purification System (according to manufacturer's instructions). The sequence of each individual egg was then determined with an ABI Prism BigDye Terminator Cycle Sequencing Ready Reaction Kit (Applied Biosystems) according to manufacturer's instructions.Unincorporated dye terminators were

removed using an isopropanol precipitation method. Sequencing reactions were run a 5% denaturing polyacrylamide Long Ranger Singel (FMC) on an ABI Prism 377 DNA sequencer (Applied Biosystems).

Products were amplified and analysed in both directions, however only one sequence (either forward or reverse) per egg was used in subsequent BLAST submissions. Unambiguous alignment was not undertaken although primer sequences were removed from the ends of sequences before BLAST submission. Sequence lengths varied from 243 base pairs (12S) to 388 base pairs (Cytochrome B).

The Cytochrome B and 12S sequencing was the most successful, alhtough not all individuals were used for BLAST submissions due to variable sequence quality. The following table demonstrates the results from subsequent BLAST (NCBI) comparisons.

Table 2. Pelagic egg BLAST (National *Centre* for Biotechnology Information database) results.

Egg Number	Amplified mtDNA fragment	BLAST results
1	*CytB*	99% match to *S. australasicus* mtDNA Cyt B gene
3	*12s*	99% match to *S. japonicus* mtDNA 12s gene
		98% match to *S. australasicus* mtDNA 12s gene
4	*CytB*	98% match to *S. australasicus* mtDNA Cyt B gene
		98% match to *S. japonicus* mtDNA Cyt B gene
8	*CytB*	99% match to *S. australasicus* mtDNA Cyt B gene
		98% match to *S. japonicus* mtDNA Cyt B gene
10	*CytB*	99% match to *S. japonicus* mtDNA Cyt B gene
		98% match to *S. australasicus* mtDNA Cyt B gene

In all cases, the highest percentage match to sequences available on the public database were to either *S. australasicus* or *S. japonicus* (based on the limited number of base pairs as outlined above). Lower percentage matches (i.e. 85%) to other Scombridae species were observed (e.g. to *Thunnus thynnus thynnus*, Pacific Northern Bluefin tuna) however this is not surprising given the highly conserved nature of these mtDNA genes.

Overall, while PCR amplification and sequencing protocols may still require some optimisation, the utility of mtDNA sequencing analysis for pelagic egg identification has been demonstrated. Successful identification was obtained from eggs used directly in PCR or from genomic DNA preparations.

8. Distribution and abundance of eggs and larvae of blue mackerel *Scomber australasicus* off southern and eastern Australia

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Objectives: To describe the distribution and abundance of eggs and larvae of blue mackerel (*Scomber australasicus*) in south-eastern Australia

Summary: This chapter describes and compares the timing and location of spawning of blue mackerel *S. australasicus* in southern and eastern Australia, and examines the relationships between latitude, sea surface temperature, salinity and depth and the abundance of eggs and larvae. Advice is provided regarding the timing, location and logistical constraints of future daily egg production method (DEPM) surveys in the two regions. Data were obtained from 2,386 plankton samples collected during 12 research surveys conducted between 2001 and 2006 in waters between southern Queensland and the western Great Australian Bight (GAB). A total of 4,025 eggs and 938 larvae of *S. australasicus* was collected, including 1,057 eggs and 276 larvae from southern Australia and 2,968 eggs and 727 larvae from eastern Australia. The main spawning season of *S. australasicus* occurs during summer and early autumn off southern Australia and during late winter and early spring off eastern Australia. Most of the eggs collected off southern Australia were obtained from stations located over the mid-shelf. The location of spawning off southern Australia appears to vary substantially between years. Results of an exploratory survey suggest that the western GAB is an important spawning area, which was not sampled intensively during the present study. The main spawning ground of *S. australasicus* off eastern Australia is in shelf waters of southern Queensland and northern New South Wales. Most eggs were collected from shelf waters, however significant numbers of eggs were found at stations located over the shelf-break during one of the east coast surveys. Off both southern and eastern Australia, high egg and

larval densities were recorded at stations located in depths of 40–120 m with SSTs of 18–22°C. Future ichthyoplankton surveys to support application of the DEPM off southern Australia will be logistically challenging due to the large and variable area over which *S. australasicus* spawns in this region. In contrast, applications of the DEPM off eastern Australia may be more tractable due to the comparatively smaller size of the spawning area. Off southern Australia surveys would ideally be conducted during January-February between Encounter Bay, South Australia and Esperance, Western Australia. Off eastern Australia, high intensity surveys (i.e. many stations on closely spaced, parallel transects) could be conducted during August-September in shelf waters between Bundaberg, Queensland and Wollongong, NSW.

8.1 Introduction

Knowledge of the timing and location of spawning is a critical prerequisite for application of the daily egg production method (DEPM) to estimate the spawning biomass of small pelagic fishes (Lasker 1985; Stratoudakis *et al.* 2006). Information collected during ichthyoplankton surveys is commonly used to determine the location and timing of spawning. Microscopic and macroscopic information on gonad development is also used to determine the seasonal periodicity of spawning (see Chapter 6).

The patterns of distribution and abundance of blue mackerel, *Scomber australasicus* eggs and larvae in southern and eastern Australia may reflect differences in the bathymetric and oceanographic conditions in the two regions (see Rochford 1972; Rochford 1977; Gibbs *et al.* 1986; Oke and Middleton 2001; Kaempf *et al.* 2004; McClatchie *et al.* 2006; Ward *et al.* 2006a). The east-west coastline of southern Australia includes two large gulfs (Spencer Gulf and Gulf St Vincent) and the shelf is broad (up to 230 km), whereas the north-south coastline of eastern Australia has smaller bays and estuaries (e.g. Harvey Bay, Morton Bay, Sydney Harbour) and a much narrower continental shelf (generally <60 km). Southern Australia is part of the world's only northern boundary current system and the key oceanographic features include: shelf break and coastal upwelling that enhance productivity during summer and autumn; inverse estuaries (gulfs) which are separated from shelf waters during the upwelling period by temperature and salinity fronts (Bruce and Short 1990); and the Leeuwin Current which intrudes into the GAB during winter (Ward *et al.* 2006b). In contrast, eastern Australia is one of the world's four major western boundary current systems and the dominant oceanographic feature is the East Australia Current (EAC), which transports warm water from the Coral Sea into temperate waters in the south (e.g. Ward *et al.* 2003b). There are also localised upwellings along the east coast of Australia, including those triggered by the deflection of the EAC offshore north off Port Stephens in northern NSW during the austral spring-summer (Oke and Middleton 2001; Uehara *et al.* 2005) and those occurring in eastern Bass Strait during late summer and autumn (Rochford 1977; Gibbs *et al.* 1986; Neira 2005).

Prior to this study, few data were available on the distribution and abundance of *S. australasicus* eggs or larvae in Australian waters. This lack of data was due, at least in part, to the absence of protocols for identifying eggs (see Chapter 7). However, some information has been published on the factors affecting the distribution and abundance of *S. australasicus* eggs and larvae in New Zealand waters. For example, *S. australasicus* eggs and larvae were recorded in plankton surveys

conducted off the North Island (e.g. Hauraki Gulf, Bay of Plenty) during December to April in waters with SST ranging from ~15 to 23ºC (Crossland 1981; 1982; Jones 1983).

There are few published data on the distribution or abundance of *S. australasicus* larvae in waters off southern Australia. Scombrid larvae (no species identification provided) were recorded in samples collected off Sydney in August-September (Gray 1993) and in January and April (Smith and Suthers 1999). Grey and Miskiewicz (2000) collected a small number of *S. australasicus* larvae (n = 49) in 14 surveys (four summer, three autumn, three winter and four spring) off Sydney. Over 90% of larvae were obtained from depths of 60–80 m and over 95% were collected during August-September when SST ranged from 15 to 17ºC.

This chapter describes and compares the timing and location of spawning by *S. australasicus* in southern (Cape Otway, Victoria to Archipelago of the Recherche, Western Australia) and eastern Australia (Bundaberg, Queensland to St Helens, Tasmania), and investigates the relationships between egg and larval abundance and environmental parameters, including SST, salinity and depth, in these two regions. Information is used to provide advice regarding the future application of the DEPM for this species in southern and eastern Australia.

8.2 Methods

8.2.1 Timing and location of surveys

Between 2001 and 2005, 12 ichthyoplankton surveys were conducted between the western GAB and Wide Bay, southern Queensland (Table 8.1, Figs 8.1 and 8.2). Of the seven surveys off southern Australia, one survey included waters as far east as Cape Otway (February 2003), five surveys were located in gulf and shelf waters of South Australia (2001–2005) and one survey was located in the western GAB (Feb 2006). In eastern Australia three of the five surveys were conducted in the region between Bundaberg (Qld) and Cape Howe (NSW) (Oct 2002, Oct 2003 and Jul 2004). Two surveys were also conducted between Cape Howe (NSW) and Four Mile Creek (Tas), and between Kiama (NSW) and Cape Conran (Vic) in February 2003 and 2004 respectively. All 12 surveys were undertaken over shelf waters, and covered gulf waters in the case of southern Australia.

8.2.2 Survey design

The aim of this study was to identify the timing and location of spawning by *S. australasicus*. The timing and location of surveys varied among years as additional information became available from the adult reproductive studies (Chapter 6) and from the surveys. Details of all surveys are shown in Table 8.1. Off southern Australia, stations were located on east-west transects in the two SA gulfs, cross shelf transects approximately perpendicular to the coast and along shelf transects between Cape Otway and the Archipelago of the Recherche (western GAB, Fig. 8.1). Off eastern Australia, stations were located on cross shelf transects between 20 and 50 nm apart and on long-shelf transects which linked the cross shelf transects (Fig. 8.2). Survey designs off eastern Australia varied considerably between years.

Table 8.1. Details of ichthyoplankton surveys conducted off eastern and southern Australia between 2001 and 2006.

Survey date	Shelf region sampled (States)	Method	Range	n Transects	n stations sampled
Southern Australia					
1. 19 Feb–29 Mar. 01	Encounter Bay – Head of Bight (SA)	CalVET	130.5–138.5 °E	32	315
2. 1 Feb–18 Mar. 02	Encounter Bay – Head of Bight (SA)	CalVET	129.5–138.5 °E	33	328
3. 21 Feb–3 Apr. 03	Encounter Bay – Head of Bight (SA)	CalVET	130.5–138.5 °E	32	320
4. 3–15 Feb. 03	Cape Northumberland – Head of Bight (SA)	Bongo	130.7–141.0 °E	21	74
5. 14 Feb–26 Mar. 04	Encounter Bay – Head of Bight (SA)	CalVET	130.4–138.5 °E	28	284
		Bongo	130.7–138.5 °E	26	137
6. 5 Feb–19 Mar. 05	Encounter Bay – Head of Bight (SA)	CalVET	130.4–138.5 °E	31	334
		Bongo	130.4–138.5 °E	29	152
7. 2 Feb–7 Feb. 06	Archipelago of the Recherche (WA)	Bongo	122.3–124.4 °E	1	75
			Total	**233**	**2,019**
Eastern Australia					
1. 12–22 Oct. 02	Wide Bay – Cape Howe (Qld-NSW)	Bongo	25.8–37.5 °S	15	97
2. 5–11 Feb. 03	Cape Howe – Four Mile Creek (NSW-Tas)	Bongo	37.5 –41.7 °S	10	55
3. 1–8 Oct. 03	Wide Bay – Cape Howe (Qld-NSW)	Bongo	25.8–37.5 °S	15	74
4. 5–12 Feb. 04	Kiama – Cape Conran (NSW-Vic)	Bongo	34.7–38.2 °S	14	60
5. 19–28 July 04	Bundaberg – Newcastle (Qld-NSW)	Bongo	24.6–32.9 °S	21	81
			Total	**75**	**367**
			Grand Total	**208**	**2,386**

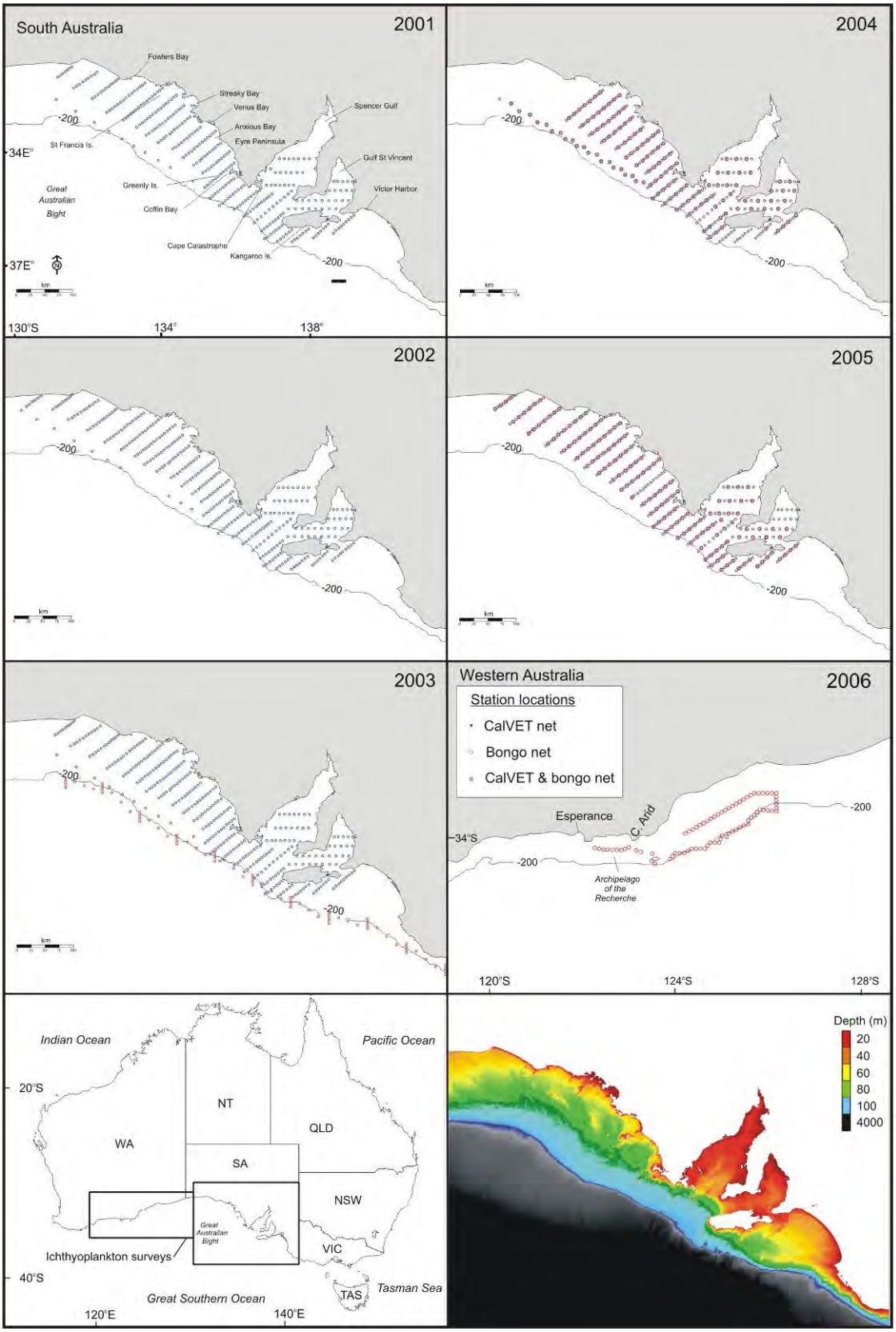

Figure 8.1. Locations of ichthyoplankton surveys conducted in southern Australia between 2001 and 2006. Inset shows study region. Figure at the bottom right shows the bathymetry of the region. (*GeoScience Australia*, 1 x 1 km bathymetric dataset).

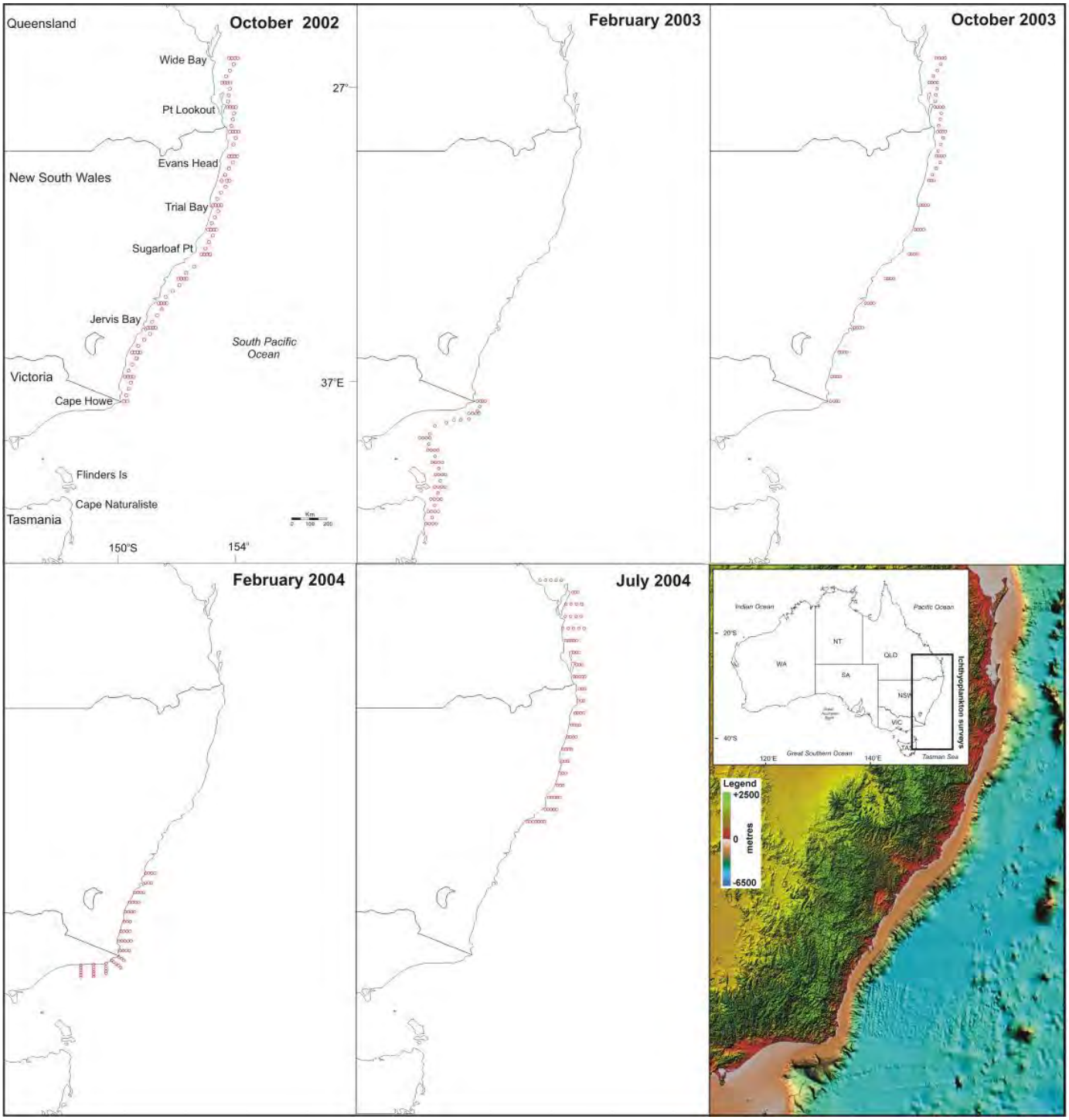

Figure 8.2. Locations of ichthyoplankton surveys conducted in eastern Australia between October 2002 and July 2004. Inset shows study region. Figure at the bottom right shows the bathymetry of the region (*GeoScience Australia*).

8.2.3 Sampling regime

Off southern Australia, bongo nets (0.57 m, 0.58 m, 0.67 m diameter; 330 and 500 μm mesh) and a Californian Vertical Egg Tow (CalVET, 0.3 m diameter, 330 μm mesh) net were used to collect plankton samples. CalVET nets were deployed to within 10 m of the seabed at depths <80 m or to a depth of 70 m at depths >80 m. Bongo nets were deployed to within 10 m of the seabed at depths <100 m or to a depth of 100 m at depths >110 m. To estimate volume filtered a General Oceanics™ flowmeter 2030 was attached to the mouth of each net for both sampler types. Factory calibrations were used to estimate volumes of water filtered by the two nets. Wire length was measured using a digital meter (2 d.p) during each deployment. After retrieval, both nets were washed thoroughly, and plankton samples from the two cod-ends were combined and stored in 5% buffered formalin and seawater solution.

Off eastern Australia, plankton samples were collected using a bongo net (0.6m diameter; 300 and 500μm mesh. A General Oceanics™ flowmeter 2030 was attached to the mouth of each net. The bongo net was fitted with a Scanmar depth sensor to regulate sampling depth. At each station the net was lowered vertically to within 5–10m of the seabed in waters <200 m or to a maximum of 200 m. After retrieval, both nets were washed thoroughly, and plankton samples from the two cod-ends were combined and fixed in 98% ethanol. Approximately 5-10 samples per survey were fixed in 5% formaldehyde-seawater solution.

8.2.4 Environmental Data

At each station in southern and eastern Australia (Fig. 8.1 and 8.2), data on the salinity (psu) and temperature (^{o}C) by depth were obtained at each station using a Seabird Electronics SBE19 Conductivity-Temperature-Depth instrument (CTD). Composite and single-pass sea-surface temperature (SST) images of southern and eastern Australia (NOAA AVHRR satellite) were obtained from the CSIRO Marine Research Remote Sensing Facility. Images were selected from 5-day and 9 day averages centred on the sampling dates, and processed for cloud cover. High resolution satellite images, showing direction and strength of surface-ocean currents (geostrophic velocities in $m.s^{-1}$ and knots) superimposed over sea-surface temperature (SST) were obtained from CSIRO Marine Research Remote Sensing Facility, and are provided for days coinciding with each survey. Current vectors were modelled using real-time radar altimetry data (sea level anomalies) and Surface Velocity Program (SPV) drifters (www.marine.csiro.au/remotesensing/oceancurrents).

8.2.5 Identification of eggs and larvae

Eggs of *S. australasicus* were identified using the morphological criteria identified in Chapter 7 of this report. Morphological identifications of some (49) eggs were confirmed using genetic techniques (Chapter 7). Due to the uncertainties associated with the identification of early stage eggs outlined in Chapter 7 of this report, we only included early stage eggs that could be identified as *S. australasicus* with a high degree of confidence.

The potential for bias in the estimates of egg abundance resulting from potential misidentification of young eggs was assessed by staging sub-samples of eggs from each location as being day-1 or day-2 to determine the proportion of early stage eggs in samples. Eggs were determined to be either day-1 or day-2 based on the criteria and stages of *S. japonicus* described by Watanabe (1974). Larvae of *S. australasicus* were identified using the descriptions provided by Neira *et al.* (1998).

8.2.6 Data analyses

The total numbers of eggs and larvae were counted and converted to abundance per unit surface area (numbers/m^{-2}), which was calculated from the sampling depth and the volume of water filtered by the plankton nets. Egg and larval abundances were plotted using SURFER® and MapInfo GIS software.

General Additive Models (GAM) in S-Plus © software were used to explore the relationships between egg and larval densities and environmental variable for each independent survey data set. GAMs were run for the samples collected using the bongo nets in both regions as per the general form: $y \sim s(\text{sst})+s(\text{sal})+s(\text{dep})+s(\text{lat})+s(\text{long})$ (Chambers and Hastie 1992). Smoothing spline functions (s) and back-fitting algorithms (local scoring) were used in each model as the regression fitting tools. Results of fits were displayed in rugplots showing the additive fits (± 2 s.e) of the response and explanatory variables, their residuals and jittered locations of observed values along the x-axis. Exploratory scatter plot matrices with Loess (lo) smoothing functions were fitted to each dataset for eastern and southern Australia to investigate distributions. Quasi-likelihood based methods were used to fit the GAMs due to the highly skewed data (i.e. the presence of many zero values and small numbers of large values). Regression trees were fitted to examine relationships and interactions between egg and larval density and environmental variables for each survey dataset (Crawley 2003).

8.3 Results

8.3.1 Identification of eggs

Approximately 65% of the eggs for which estimates of age (i.e. day-1 or day-2) are available were day-2 eggs, which were identified with a high degree of certainty (Table 8.2). The proportion of day-1 eggs in samples ranged from 10% for the survey conducted of eastern Australia in October 2004 to 65% for the survey conducted in the same location in October 2003. We consider it unlikely that the total egg abundance was significantly over-estimated in this study through the mis-identification of early stage eggs because day-1 eggs are typically more abundant than day-2 eggs in samples (due to the reduced potential for the effects of mortality).

8.3.2 Occurrence

Totals of 4,025 eggs and 1,003 larvae were collected during the 12 surveys, including 1,057 eggs and 276 larvae from southern Australia and 2,968 eggs and 727 larvae from eastern Australia (Table 8.2). *S. australasicus* eggs and larvae were collected in six of the seven surveys conducted in southern Australia and three of the five surveys in eastern Australia. Over 60% of both eggs and larvae collected in southern Australia were obtained in two surveys (Encounter Bay to the Head of the GAB, February-March 2005; Archipelago of the Recherche, February 2006) (Fig. 8.1, Table 8.2). Over 45% of the eggs and larvae collected in eastern Australia were obtained from the survey conducted between Wide Bay and Cape Howe in October 2003 (Fig. 8.2, Table 8.2).

8.3.3 Abundance

8.3.3.1 Eggs

In stations within surveys where eggs were collected, mean egg density ranged between 4.3 and 23.5 eggs.m^{-2} in southern Australia and 12.4 and 41.7 eggs.m^{-2} in eastern Australia (Table 8.2). The highest egg densities recorded in a single tow in southern and eastern Australia were 258.3 and 739.0 eggs.m^{-2}, respectively. In 2004 and 2005, many stations (>75%) contained no eggs; some stations (e.g. 10–20%) contained moderate numbers of eggs and a few stations contained a large number of eggs.

8.3.3.2 Larvae

Mean larval density for surveys where larvae were collected ranged between 4.7 and 14.7 larvae.m^{-2} in southern Australia and between 4.8 and 14.2 larvae.m^{-2} in eastern Australia (Table 8.2). The highest larval densities recorded in a single tow in southern and eastern Australia were 104.2 and 117.2 larvae.m^{-2}, respectively.

Table 8.2. Summary of total number of eggs and larvae of *S. australasicus* collected in surveys conducted off southern and eastern Australia between 2001 and 2006. (NI = Not identified).

Survey	Net	n eggs	n larvae	% eggs	% larvae	Day-1 eggs # (%)	Day-2eggs # (%)	% Stations containing eggs	% Stations containing larvae	Mean egg density (eggs.m^{-2} Range)	Mean larval density (larvae.m^{-2} Range)
Southern Australia											
1. Encounter Bay – Head of Bight (Feb - Mar 2001)	CalVET	23	NI	2.2	NI	NI	NI	4.8	NI	16.5 (7.6–87.8)	NI
2. Encounter Bay – Head of Bight (Feb - Mar 2002)	CalVET	19	3	1.8	1.1	1.1	1.1	4.3	0.6	13.7 (8.7–43.3)	14.7 (10.6–18.8)
3. Encounter Bay – Head of Bight (Feb - Apr 2003)	CalVET	15	8	1.4	2.9	2.9	2.9	3.7	2.8	12.2 (7.9–46.9)	8.6 (7.3–9.6)
4. Cape Northumberland – Head of Bight (Feb 2003)	Bongo	0	0	0.0	0.0	0.0	0.0	0	0	0	0
5. Encounter Bay – Head of Bight (Feb - Mar 2004)	CalVET	77	16	7.3	5.8	9 (14)	54 (86)	10.2	3.9	16.1 (4.5–103.7)	8.4 (5.8–15.1)
	Bongo	72	49	6.8	17.8	27 (37)	46 (63)	23.4	13.1	4.3 (1.2–31.8)	4.7 (1.4–20.9)
6. Encounter Bay – Head of Bight (Feb - Mar 2005)	CalVET	127	51	12.0	18.5	34 (59)	24 (41)	10.5	7.2	23.5 (4.1–196.1)	14.2 (5.4–104.2)
	Bongo	512	67	48.4	24.3	240 (58)	177(42)	35.5	13.2	17.7 (1.2–258.3)	6.1 (1.2–42.4)
7. Archipelago of the Recherche (Feb 2006)	Bongo	212	82	20.1	29.7	100 (55)	82 (45)	37.3	22.7	11.5 (0.9–104.6)	6.7 (1.4–44.7)
	Total	**1,057**	**276**			410 (52)	383 (48)				
Eastern Australia											
1. Wide Bay – Cape Howe (Oct 2002)	Bongo	492	197	16.6	27.1	266 (65)	124 (30)	25.8	23.7	13.0 (0.3–121.4)	4.8 (0.19–43.7)
2 Cape Howe – Four Mile Creek (Feb 2003)	Bongo	0	0	0	0	0	0	0	0	0	0
3. Wide Bay – Cape Howe (Oct 2003)	Bongo	1,639	342	55.2	47.0	164 (10)	1320 (87)	39.2	29.7	41.7 (0.5–739.0)	14.2 (0.3–117.2)
4. Kiama – Cape Conran (Feb 2004)	Bongo	0	0	0	0	0	0	0	0	0	0
5. Bundaberg – Newcastle (July 2004)	Bongo	837	188	28.2	25.9	268 (42)	369 (57)	52.9	30.6	12.4 (0.6–177.5)	6.1 (0.5–46.1)
	Total	**2,968**	**727**			698 (28)	1813 (72)				
Grand total		**4,025**	**1,003**			1108 (34)	2196 (66)				

8.3.4 Distribution

8.3.4.1 Eggs

Eggs occurred at <5% of stations sampled between Encounter Bay and the Head of Bight in 2001, 2002 and 2003, but were collected in >10% of CalVET net samples and >23% of bongo net samples collected in this area in 2004 and 2005 (Table 8.2). In 2004 and 2005, eggs were collected from stations located in the southern parts of the two gulfs, in Investigator Strait and over the shelf (Fig. 8.3). No eggs were collected over the shelf-break (200 m depth contour) survey in February 2003. In 2004 and 2005, the stations with the highest egg densities were located in shelf waters between the Coffin Bay Peninsula and Streaky Bay in the eastern GAB. Eggs were also present in 37.3% of samples collected from the western GAB (Archipelago of the Recherche) during 2006.

Eggs were abundant in samples collected from shelf waters of southern Queensland and northern NSW during surveys conducted in October 2002 (25.8% of samples), October 2003 (39.2% of samples) and July 2004 (52.9% of samples) (Table 8.2). Eggs were distributed most widely in this region in July 2004 when samples were collected from stations between Indian Head (Fraser Island) and Newcastle (Fig. 8.4). Most stations containing eggs were located on the shelf. Fewer eggs were collected from stations located on the western end of transects near the continental shelf-break (see July 2004). The highest egg density (over 739 eggs. m^{-2}) was recorded between Evans Head (31.7ºS) and north of Trial Bay (32.9ºS) during October 2003.

8.3.4.2 Larvae

The distribution patterns of *S. australasicus* larvae in southern Australia were similar to those of the eggs. Larvae were collected from <3% of stations sampled between Encounter Bay and the Head of Bight in 2001, 2002 and 2003 and 3.9 to 13.2% of stations sampled in this region during 2004 and 2005. Larvae were present in 32.7% of samples collected from the western GAB (Archipelago of the Recherche) during 2006 (Table 8.2). Relatively few larvae were collected from stations in the southern gulfs and Investigator Strait (Fig. 8.5). Most larvae were collected from stations on the mid to outer shelf in the eastern GAB. No larvae were collected from stations at or beyond the shelf-break (Figures 8.1 and 8.5).

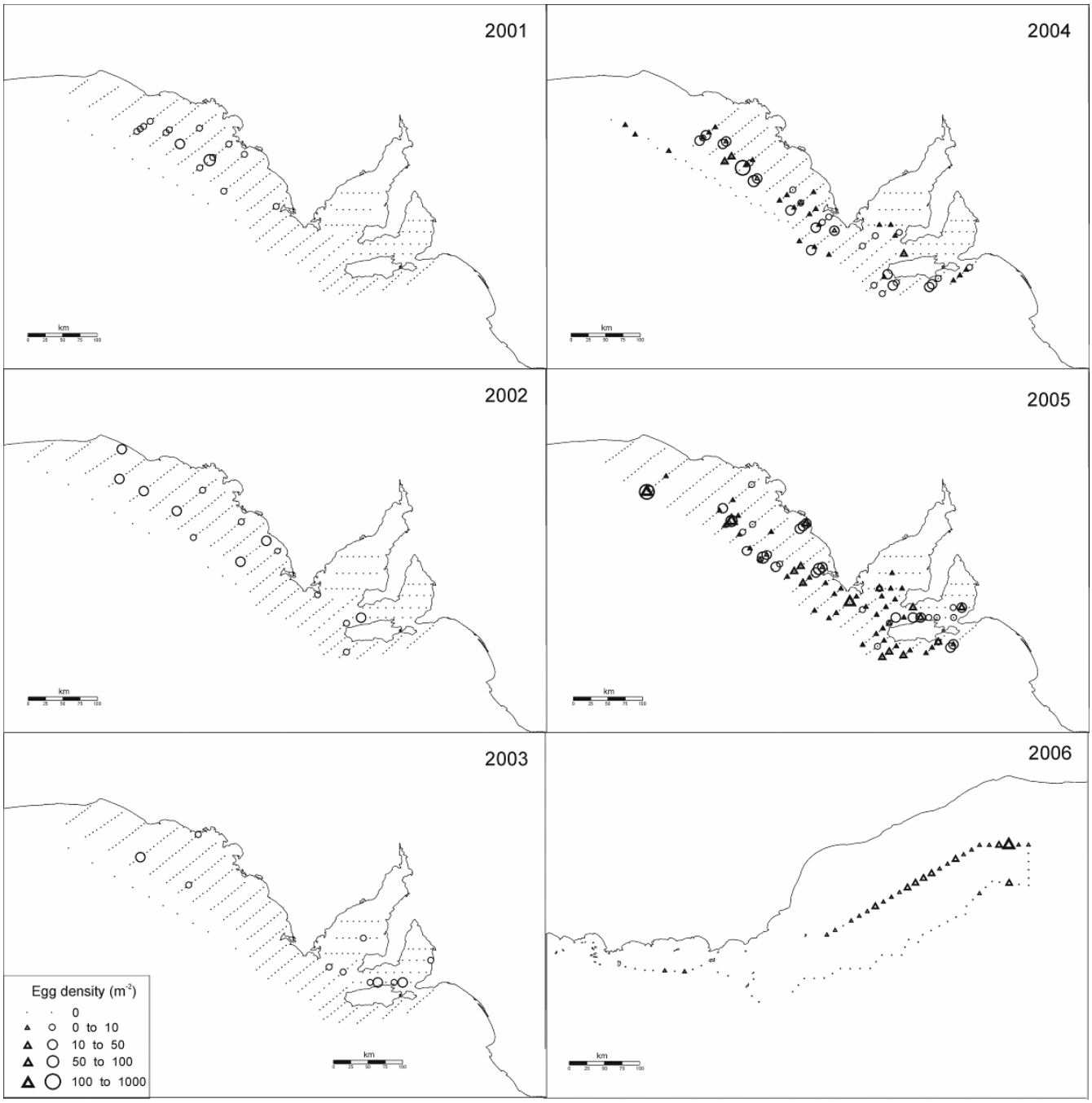

Figure 8.3. Distribution and abundance of *S. australasicus* eggs in samples taken from southern Australia between 2001 and 2005 and the western GAB in 2006. Circles and triangles represent samples collected with CalVET and Bongo net, respectively.

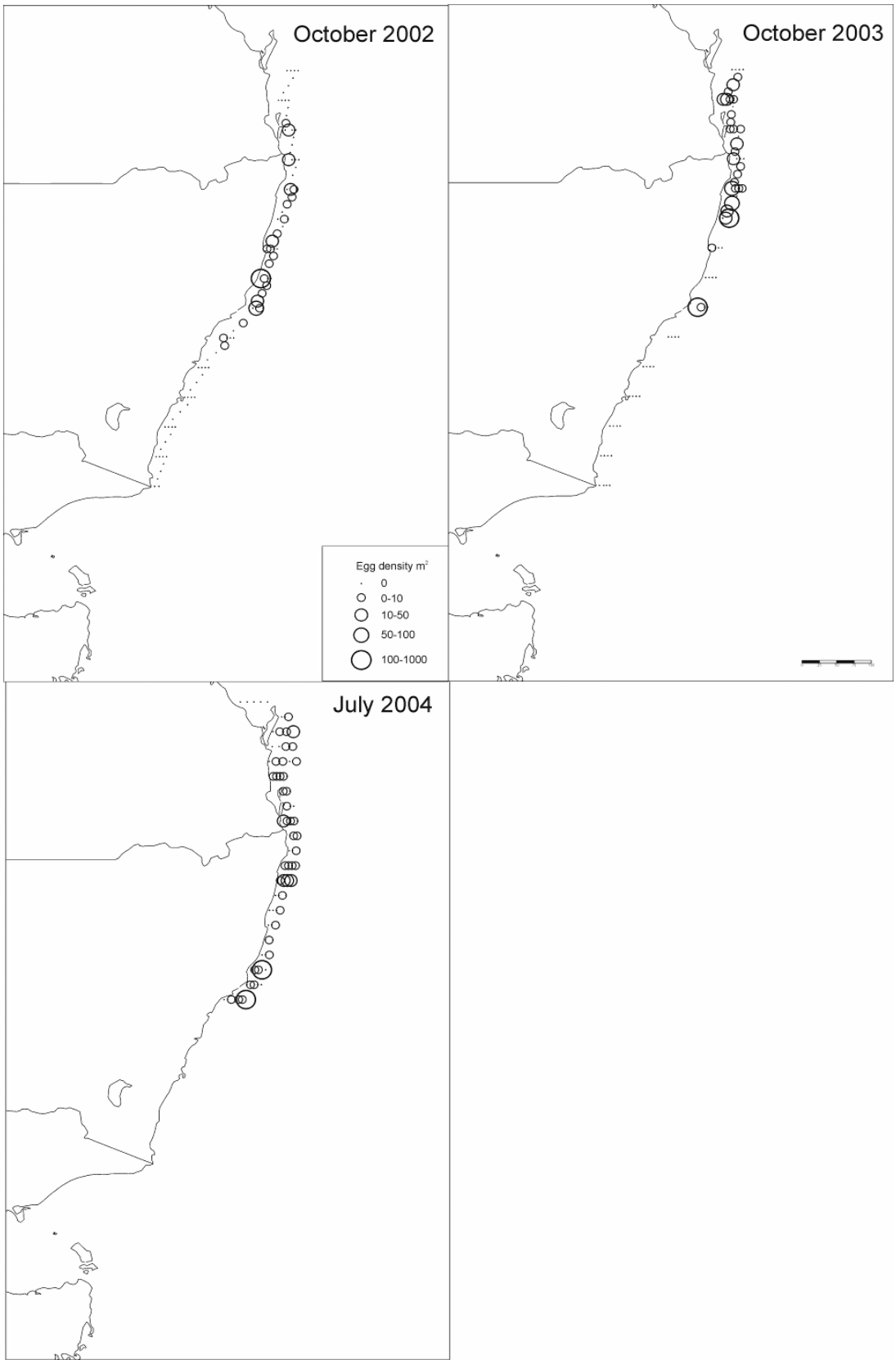

Figure 8.4. Distribution and abundance of *S. australasicus* eggs in samples taken from eastern Australia between October 2002 and July 2004.

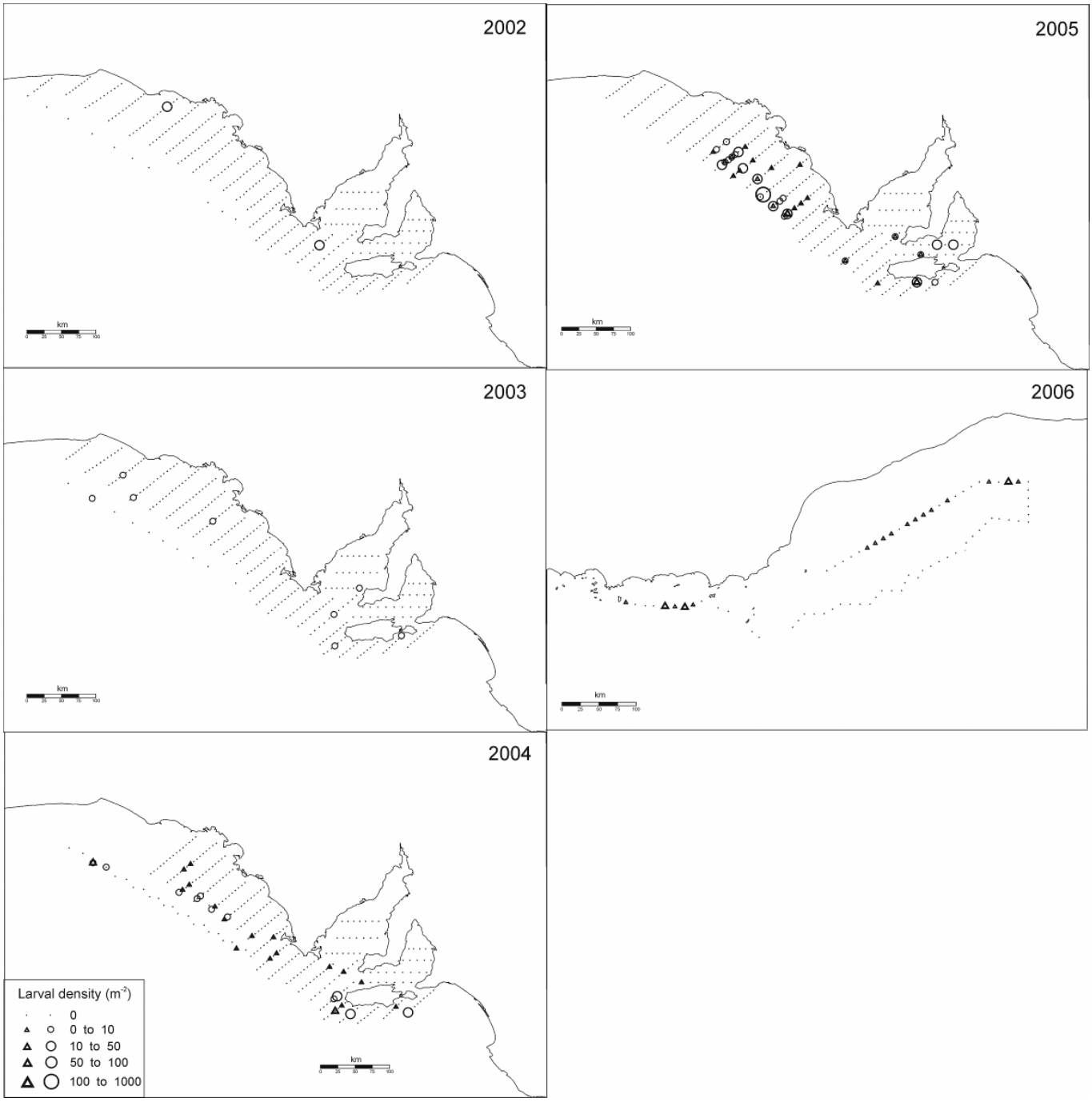

Figure 8.5. Distribution and abundance of *S. australasicus* larvae in samples taken from southern Australia between 2001 and 2005 and the western GAB in 2006. Circles and triangles represent samples collected with CalVET and Bongo net, respectively.

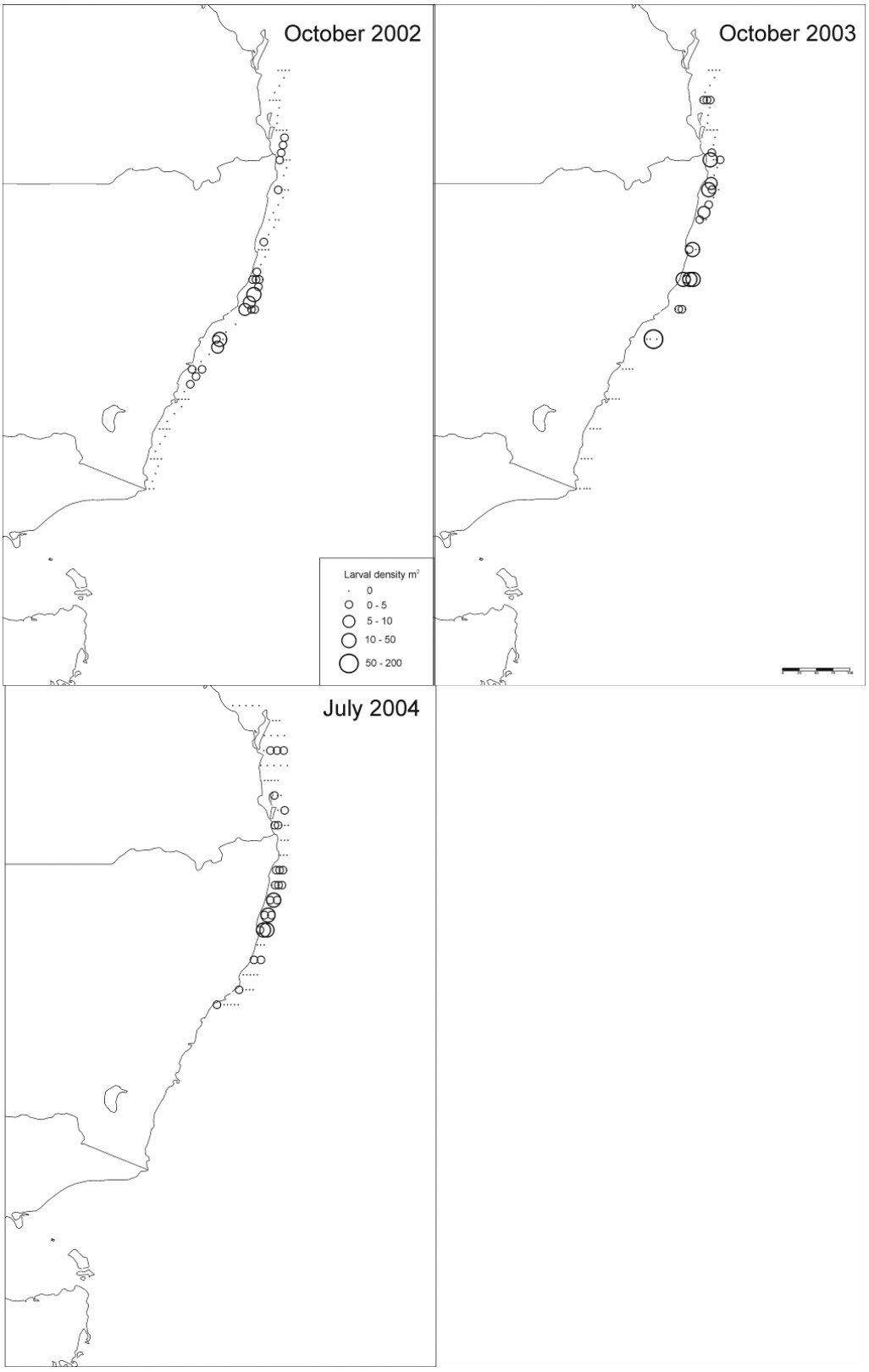

Figure 8.6. Distribution and abundance of *S. australasicus* larvae in samples taken from eastern Australia between October 2002 and July 2004.

Larvae were collected from 23.7 to 30.6% of stations sampled off eastern Australia during October 2002, October 2003 and July 2004 (Table 8.2). In these surveys, *S. australasicus* larvae were located further south than the eggs (Figs. 8.4 and 8.6). In all surveys where *S. australasicus* larvae were collected, the highest densities were recorded at shelf stations between Smoky Cape (30.8°S) and Tuggerah Lakes (33.3°S). The distribution of larval density data analysed from key surveys off southern Australia (2004, 2005) and eastern Australian (October 2002, October 2003, July 2004) was "over-dispersed".

8.3.5 Environmental Conditions

8.3.5.1 Sea surface temperatures

During research cruises in southern Australia between 2001 and 2005, SST over the mid-outer shelf ranged from 20 to 23°C and cooler water was present on the inner shelf in the eastern GAB (Fig. 8.7). In 2001, 2004 and 2005 a warmer pool of water (≥22°C) was present on the shelf in the western part of the study area. SST on the inner shelf and around Coffin Bay Peninsula varied between years from 17–21°C, apparently in response to inter-annual differences in upwelling strength. For example, during 2003 and 2004, large patches of cool (<17°C) surface water were present in inshore waters along the southern Eyre Peninsula, whereas during 2001, 2002 and 2005, SSTs in this region were higher. There were distinct thermal fronts at the mouth of Spencer Gulf in most years (with the exceptions of in 2002 and 2003) where temperatures were 18–20°C at the outer margin of the front and 23–24°C inside the gulf mouth. SST in the two gulfs were consistent between years ranging from 19 to 25°C. In the western GAB, SST during 2006 ranged from 19 to 21°C, and was coolest nearer Esperance (SARDI unpublished data).

Off eastern Australia the warm tropical water of the EAC extended from southern Queensland as far south as the Tasman front in eastern Bass Strait during the February 2003 and 2004 surveys (Fig. 8.8). The warm EAC front was visible on the mid-outer shelf around 30–35°S during October 2002, 2003 and July 2004. The warm EAC front pushed further south in October 2002 compared to October 2003 and July 2004. This front was typically comprised of 18–20°C water at the shoreward margin and 22–24°C water at the offshore margin. EAC associated water masses with SST of 22–24°C covered the entire shelf of southern Queensland in October 2002, 2003 and July 2004. Cooler surface water ranging between 16 and 22 °C occurred in Moreton Bay and inshore waters of northern NSW during these periods. Cooler water (~16 °C) was evident near Sugarloaf Point in central NSW where the main EAC stream separates from the coast and deflects offshore in an anticlockwise eddy (Figures 8.2 and 8.8).

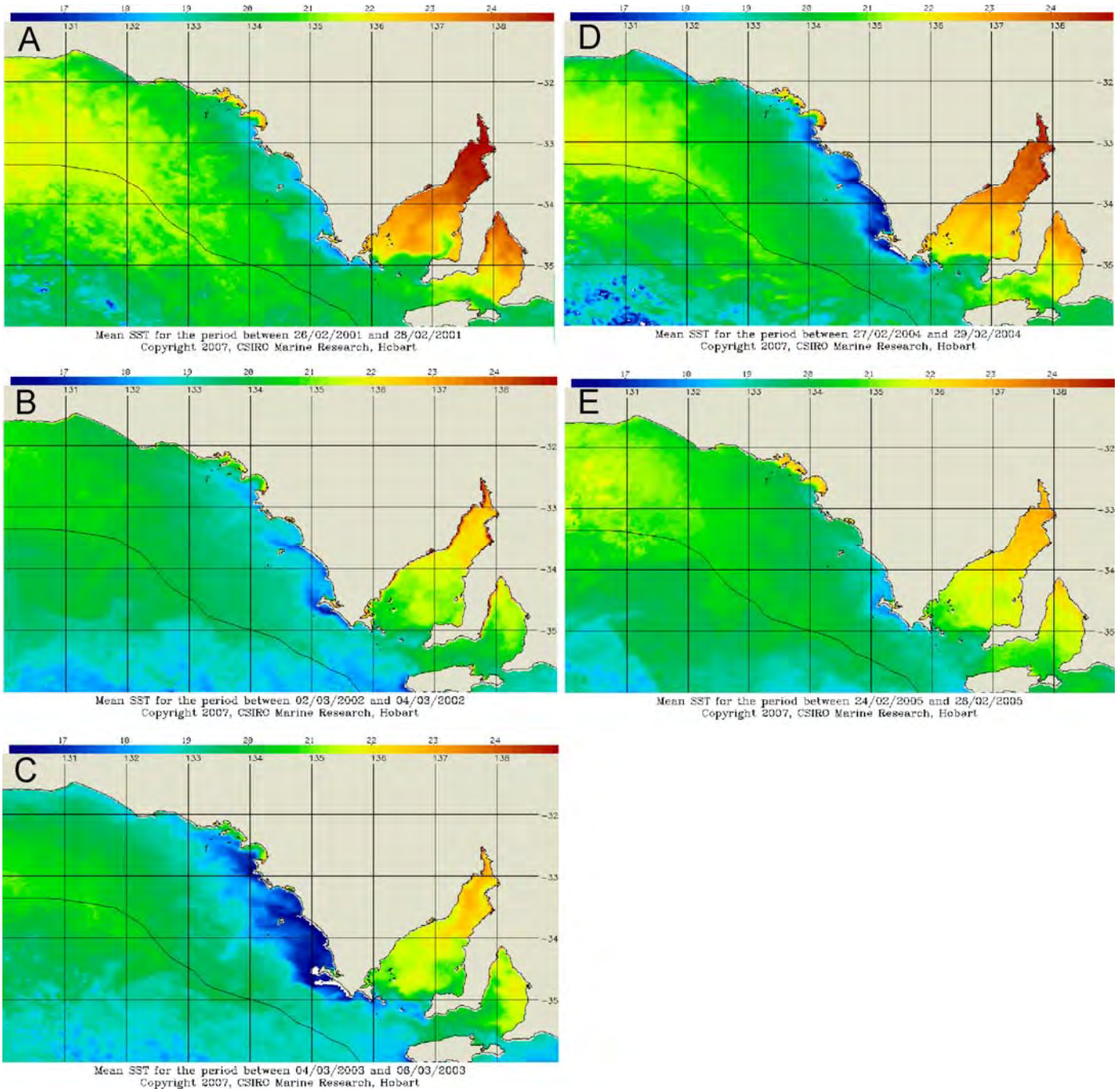

Figure 8.7. Satellite images showing sea surface temperature during ichthyoplankton surveys in southern Australia in 2001 (A), 2002 (B), 2003 (C), 2004 (D) and 2005 (E). Images courtesy of CSIRO Marine Atmospheric Research, Hobart.

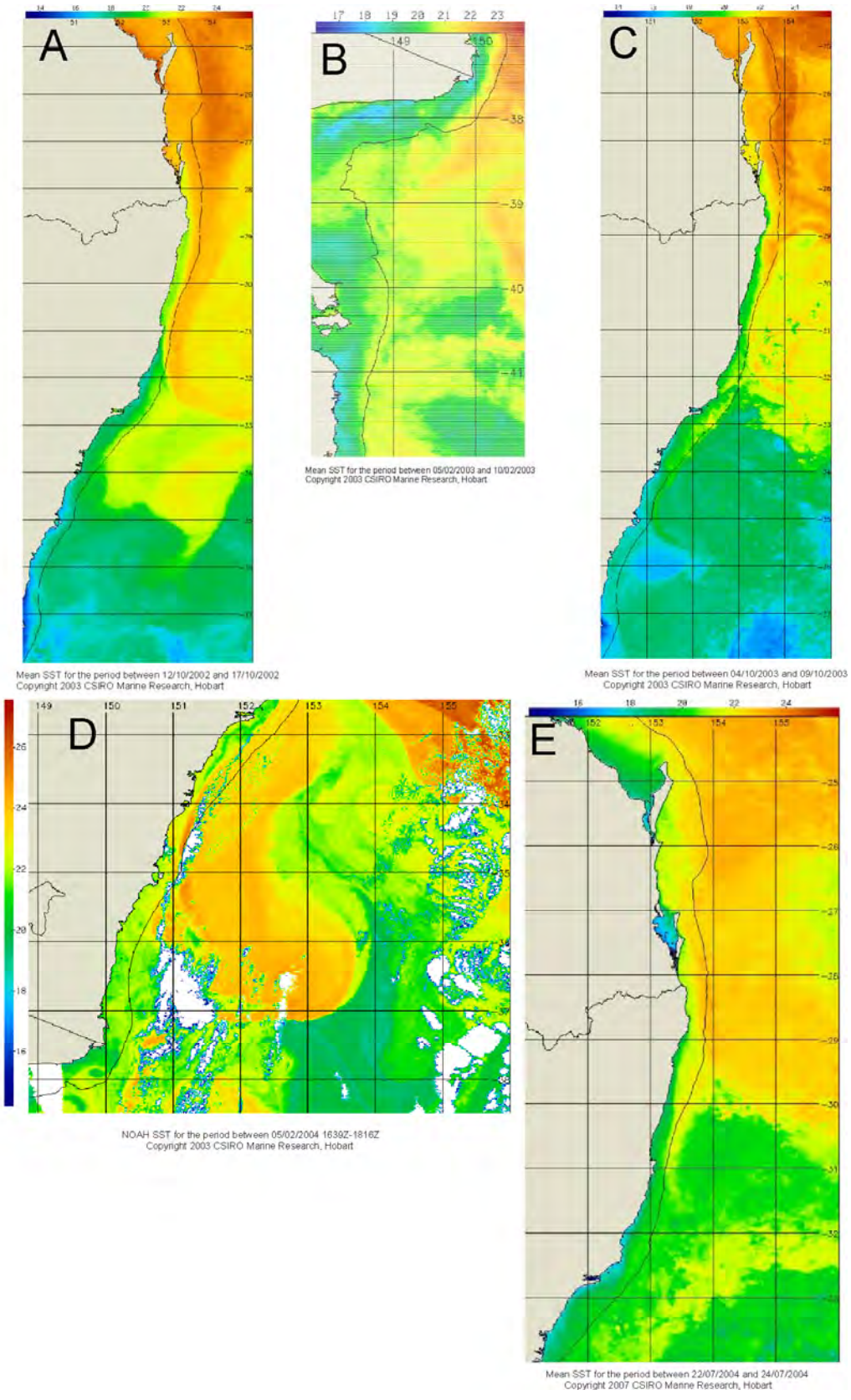

Figure 8.8. Satellite images showing sea surface temperature during ichthyoplankton surveys in eastern Australia in Oct 2002 (A), Feb 2003 (B), Oct 2003 (C), Feb 2004 (D) and July 2005 (E). Images courtesy of CSIRO Marine Atmospheric Research, Hobart.

8.3.5.2 Current Data

Surface current images show that current velocities off southern Australia were predominantly slower (0.2–0.4m.s^{-1}) than those off eastern Australia (Figs. 8.9 and 8.10). The flow direction in the GAB is mostly north-westward on the shelf and this was strongest during early February 2003 surveys that coincided with strong upwelling off Coffin Bay. The north-westward flow was also relatively strong during early February 2006. Surface circulation in the southern gulfs was clockwise from west to east during most surveys.

Surface current images show the fast (0.6–0.8m.s^{-1}), south-flowing EAC during all five surveys, and a large, fast (0.6–0.8 m.s^{-1}) anticlockwise eddy separating from the coast near Smoky Cape (Fig. 8.10). Weaker surface currents were evident in inshore waters south of Sugarloaf Point. These mainly flowed southwards except in southern NSW during February 2004 and northern NSW in July 2004, when the flow was mainly northwards at ~0.2 m.s^{-1}. Current velocities in inshore waters off the mid-NSW coast in October 2002 and October 2003 were 0.2–0.3m.s^{-1}, whereas in July 2004 they were 0.4–0.6 m.s^{-1}. Surface currents off the eastern Bass Strait and eastern Tasmania during February 2003 were weak (<0.2 m.s^{-1}) except for the south-flowing EAC at the Vic-NSW border.

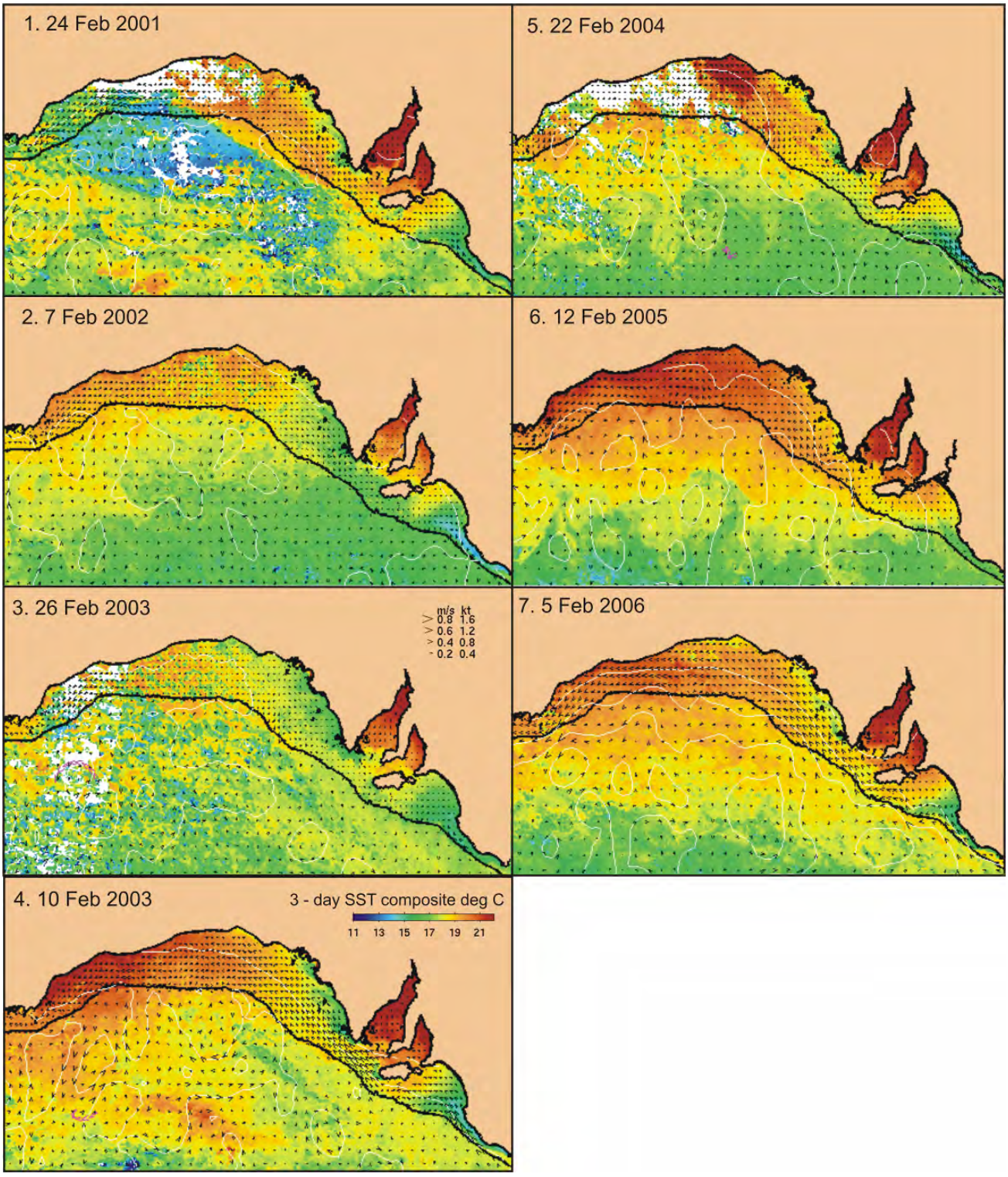

Figure 8.9. Direction and strength of surface ocean currents during surveys conducted off southern Australia (courtesy of CSIRO Marine Research, Hobart).

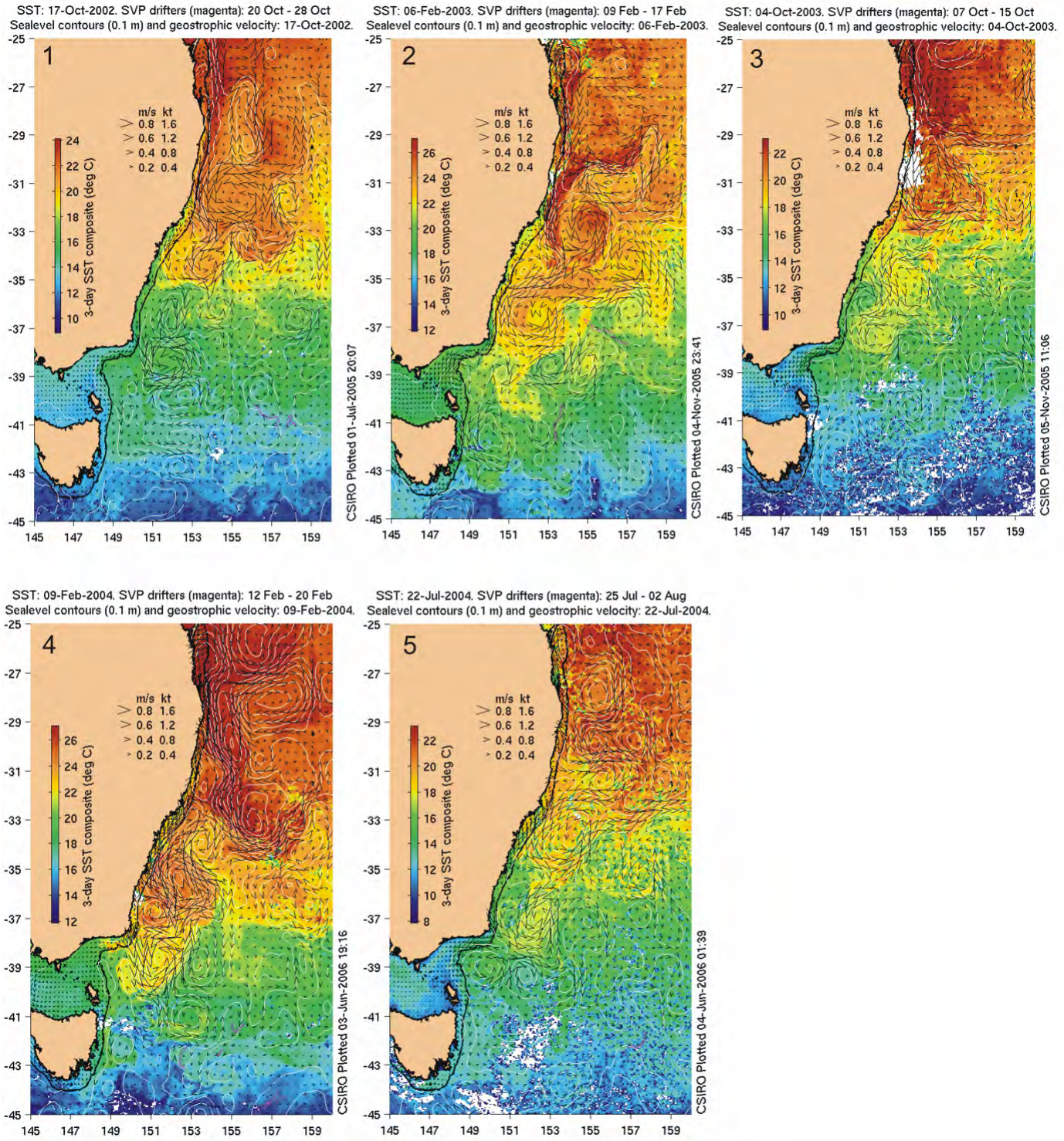

Figure 8.10. Direction and strength of surface ocean currents and SST during surveys 1 to 5 conducted off eastern Australia (refer to Table 1 for dates of surveys) courtesy of CSIRO Marine Research, Hobart).

8.3.6 Factors affecting distribution and abundance

8.3.6.1 Eggs

Off southern Australia, egg abundance was relatively high at stations located in depths of 40 to 120 m, with SST of 18–22ºC, salinities of 35.5–36.5, longitude of 132.0-137.0ºE and latitude of 33.5-36.0ºS (Fig. 8.11). Scatter plots show that eggs were collected across almost the entire range of values of environmental variables recorded during the surveys (Fig. 8.11). The GAMs suggest that the abundance of *S. australasicus* eggs off southern Australia in 2004 or 2005 were not significantly related to the environmental variables (Fig. 8.12, Table 8.3). Regression trees suggest that in 2004 the highest mean egg densities were recorded at longitudes >132.96 ºE SSTs >18.66 ºC and depths 42.0-50.5 m (Fig. 8.14). In 2005 the highest mean eggs densities were recorded in depths between 77.5 and 91.5 m (Fig. 8.14).

Off eastern Australia, stations located in depths of 50 to 100 m, SST of 18–22ºC, salinities of 34.5–35.8 ppm, longitude of 132.0-137.0 ºE and latitude of 28.0-33.0ºS recorded relatively high egg abundance (Figs 8.15-8.17). The GAMs showed that the factors with the strongest relationships with egg abundance off eastern Australia were latitude ($p < 0.0001$) in October 2002 and SST in October 2003 ($p = 0.044$) (Figs. 8.16-8.17, Table 8.4). Regression trees suggest that stations with salinities <35.42 and latitudes >28.4ºS were important for spawning in 2002 (Fig 8.18). Similarly, stations with salinities <35.27 and depths <85.76 m were important in 2003, as were stations with SSTs >19.01ºC in 2004 (Fig. 8.18). In 2004, high mean egg densities were recorded at stations with latitudes >31.8°S and SSTs >19.07ºC (Fig. 8.18).

8.3.6.2 Larvae

Off southern Australia, relatively high larval abundances were recorded at stations located in depths of 50 to 200 m, with SST of 18–22ºC, salinities of 35.4–35.8 ppm, and latitude of 28.0-34.0ºS (Fig. 8.11). The GAMs suggest that off southern Australia there was a significant relationship between larval abundance and SST ($p = 0.004$), latitude ($p = 0.019$), longitude ($p = 0.04$) and depth ($p = 0.024$) during 2004 (Table 8.3). Regression trees suggested that high mean egg densities occurred at latitudes >36.0°S in 2004 and latitudes >29.7°S and SSTs >19.88°C in 2005 (Fig. 8.14).

The GAMs indicated that the abundance of *S. australasicus* larvae off eastern Australia was related to SST ($p<0.007$) and latitude ($p<0.026$) during 2002, SST during 2003 ($p=0.005$), and SST ($p<0.009$) and latitude ($p=0.009$) during 2004. (Fig 8.17, Table 8.4). Regression trees suggested

high mean larval densities occurred at stations with: SST <19.6°C and latitude <33.7° in 2002; SST of 19.54-20.36°C and salinities<35.38 in 2003 and latitudes >29.8°S and SST >19.88°C in 2004 (Fig. 8.18).

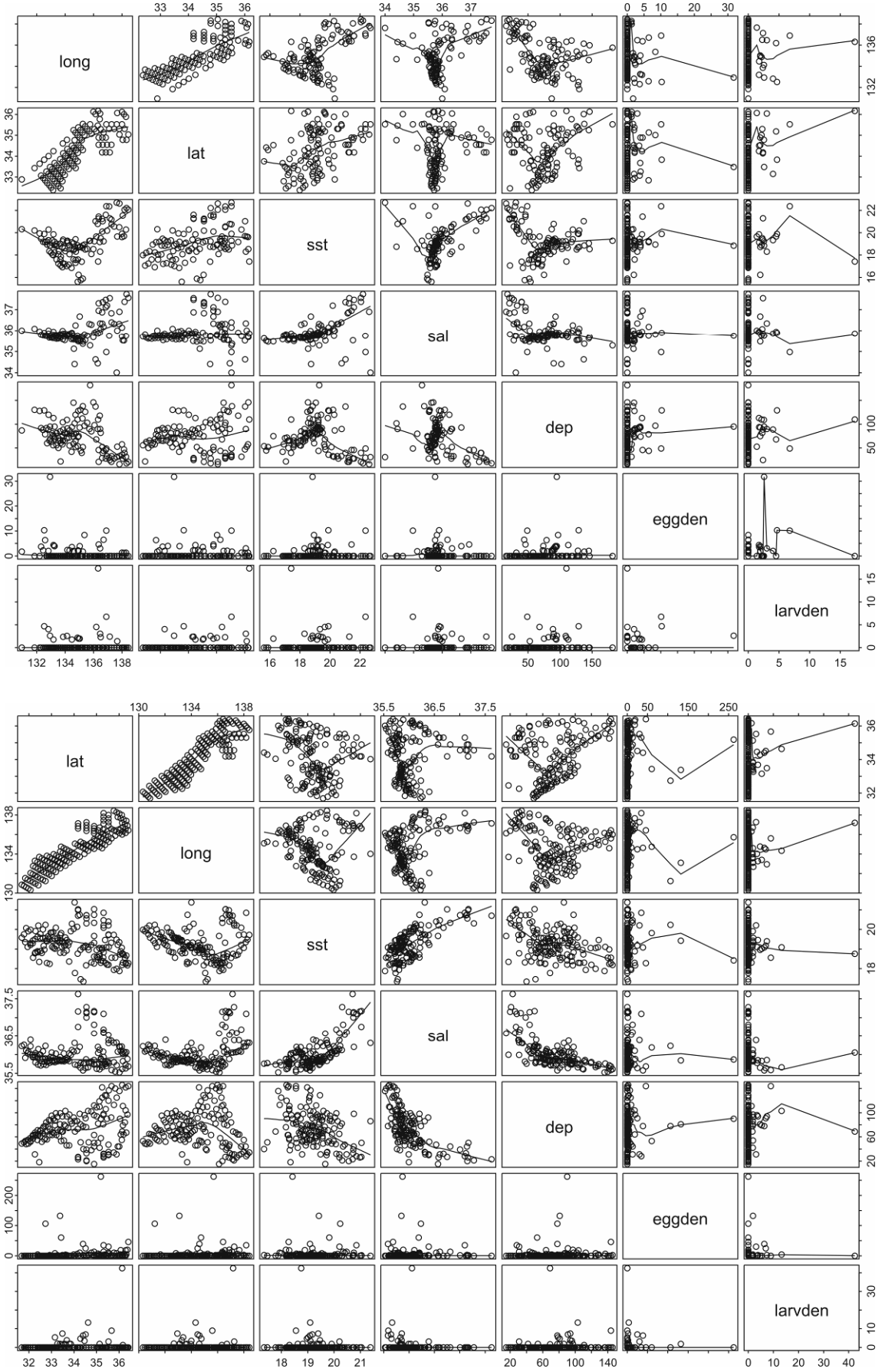

Figure 8.11. Scatter plot matrix with loess smoother fitted to egg and larval densities and environmental variables for southern Australia in 2004 and 2005.

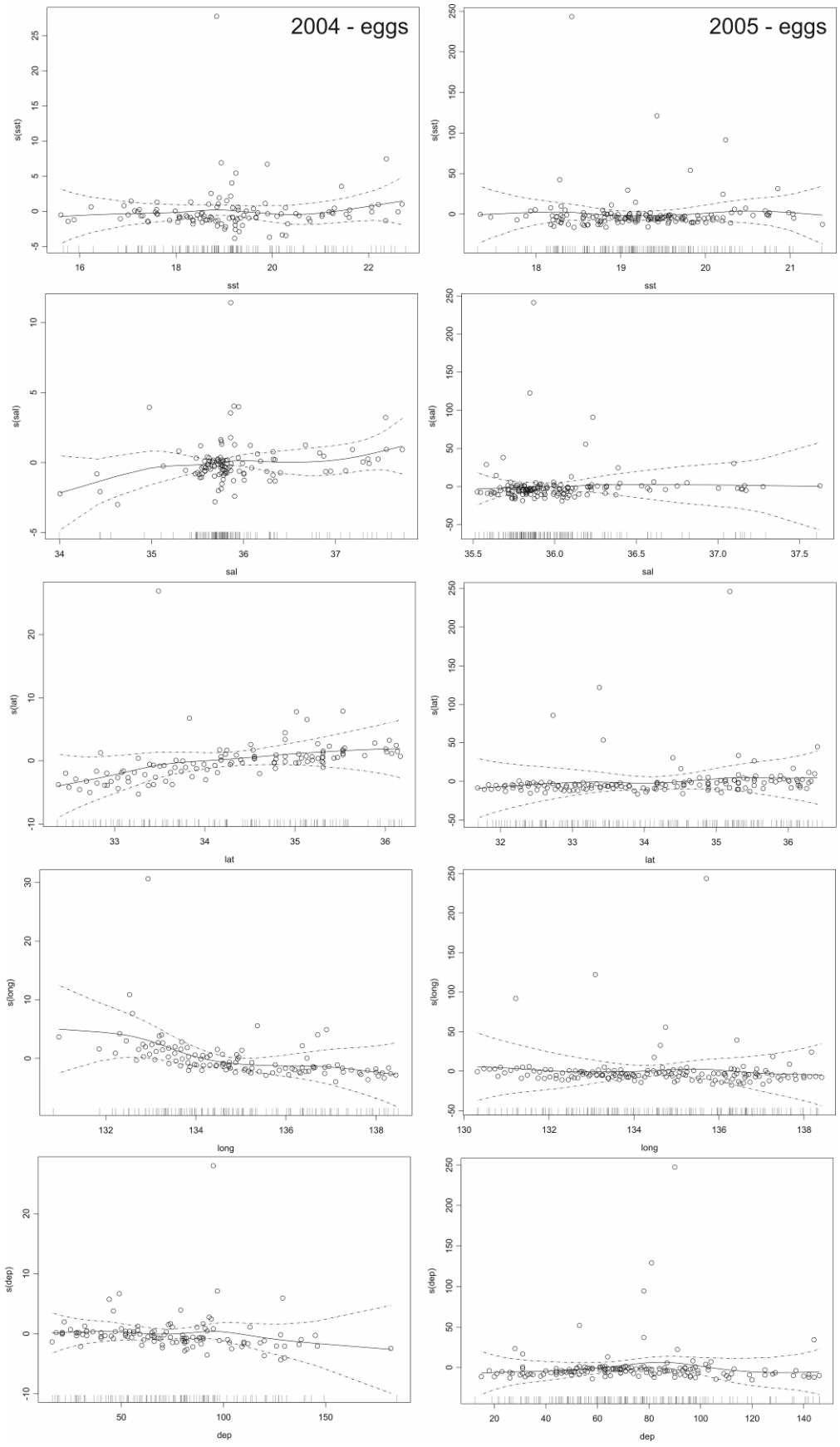

Figure 8.12. Generalised additive model fits to egg density and environmental explanatory variables for southern Australian surveys in 2004 and 2005. Plots include partial residuals (dots), 2 s.e. and rug-plot of explanatory data (along x-axis).

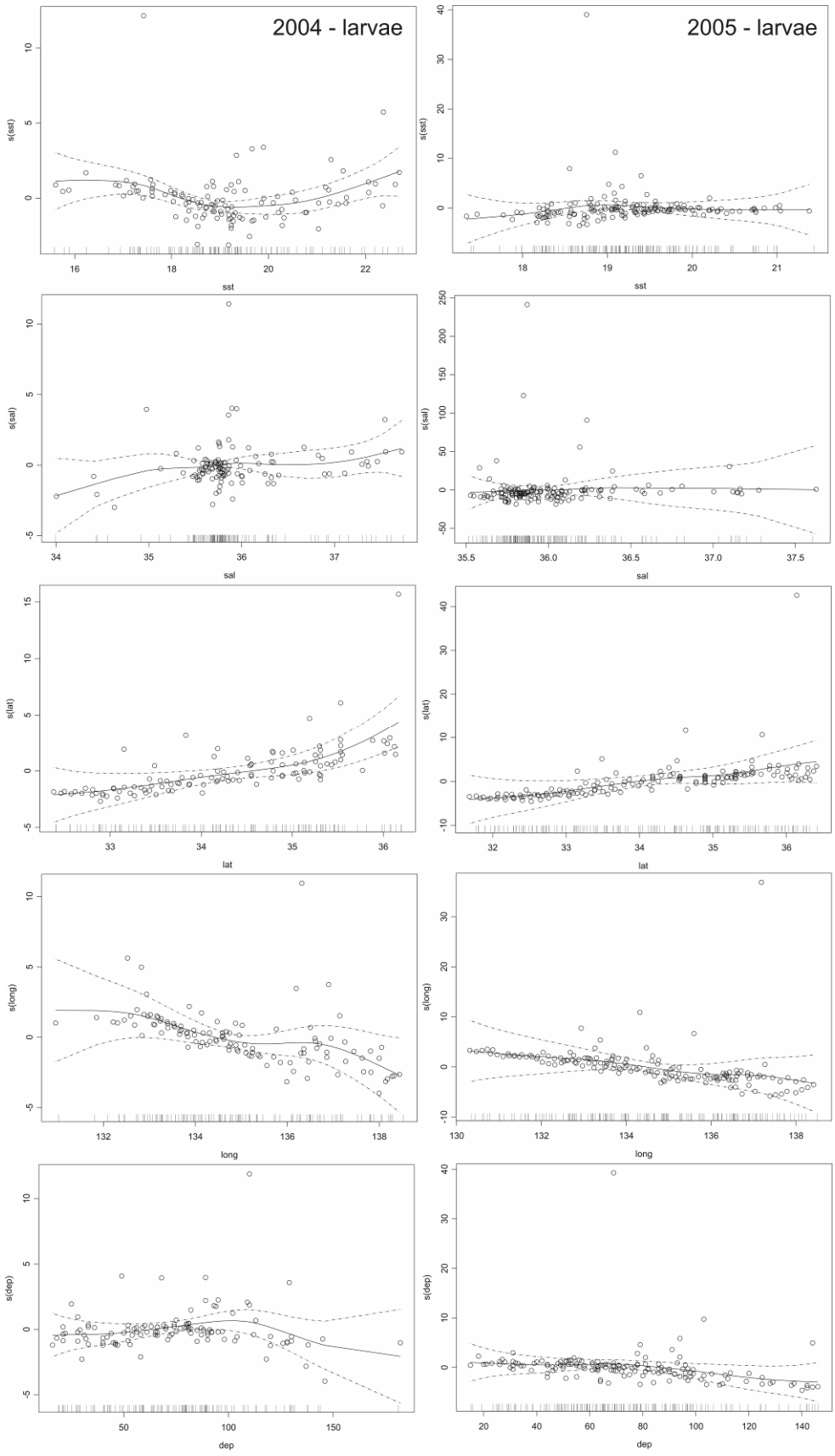

Figure 8.13. Generalised additive model fits to larval density and environmental variables for southern Australian surveys in 2004 and 2005. Plots include partial residuals (dots), 2 s.e. and rug-plot of explanatory data (along x-axis).

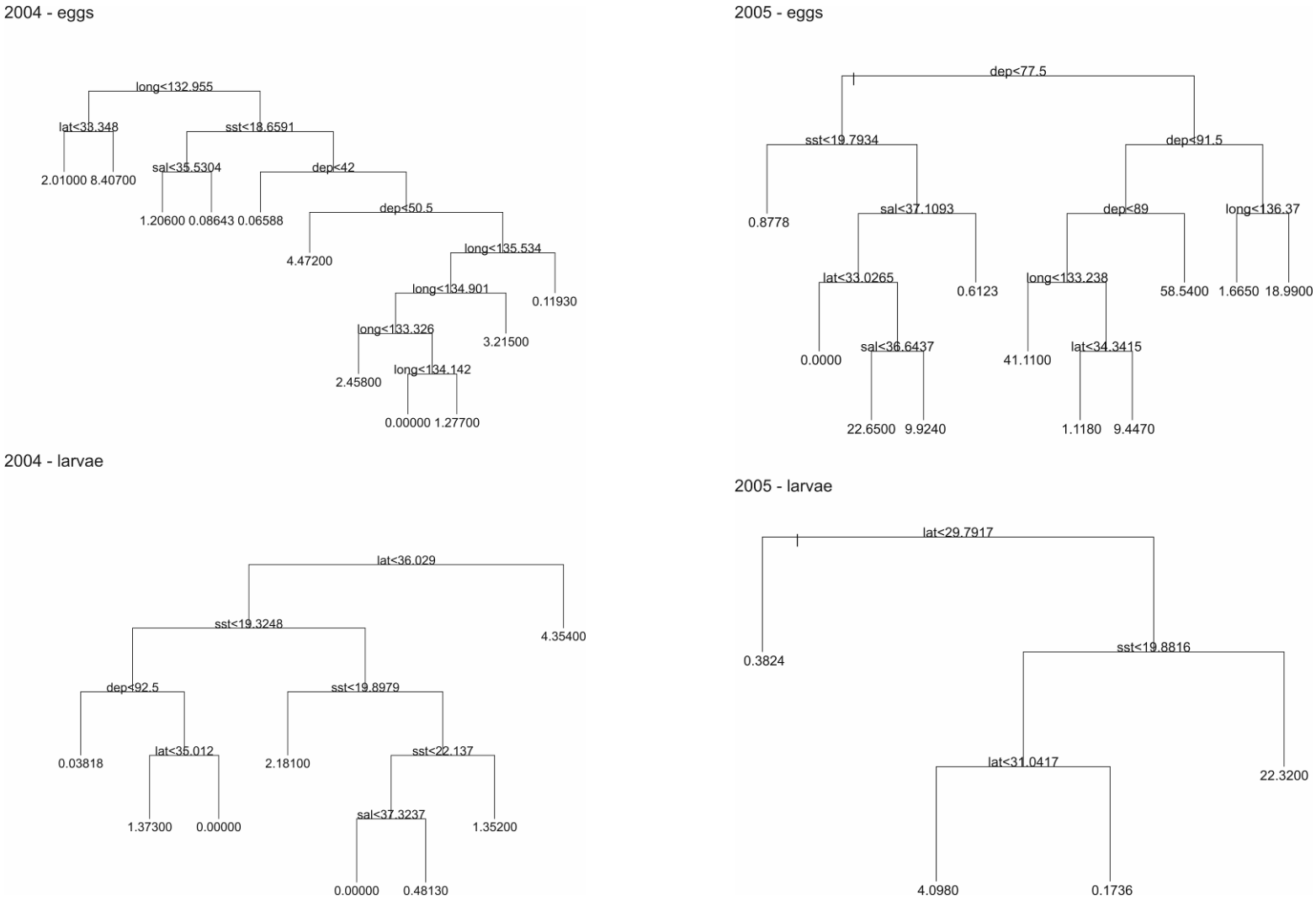

Figure 8.14. Regression trees showing the relationships between egg and larval density and environmental variables for the southern Australian in 2004 and 2005.

Table 8.3. Results of General Additive Model fits to *S. australasicus* eggs and larvae, SST, salinity, latitude and depth by station in southern Australian waters in 2004 and 2005. Significant *p*-values are shown in bold italics.

Eggs		**Df**	**Npar Df**	**Npar F**	***p*(F)**	**Larvae**		**Df**	**Npar Df**	**Npar F**	***p*(F)**
2004	**Intercept**	**1**				**2004**	**Intercept**	**1**			
	s(sst)	1	3	0.6975	0.5561		s(sst)	1		34.7086	***0.0042***
	s(sal)	1	3	0.8261	0.4828		s(sal)	1		30.9527	0.4186
	s(lat)	1	3	0.7527	0.5235		s(lat)	1		33.4693	***0.0193***
	s(long)	1	3	2.1332	0.1014		s(long)	1		32.8853	***0.0399***
	s(dep)	1	3	1.0572	0.3713		s(dep)	1		33.2831	***0.0244***
2005	**Intercept**	**1**				**2005**	**Intercept**	1			
	s(sst)	1	3	0.5479	0.6504		s(sst)	1		31.1905	0.3160
	s(sal)	1	3	0.2316	0.8741		s(sal)	1		30.9035	0.4414
	s(lat)	1	3	0.4939	0.6871		s(lat)	1		30.5414	0.6547
	s(long)	1	3	0.4985	0.6840		s(long)	1		30.7002	0.5536
	s(dep)	1	3	1.7331	0.1633		s(dep)	1		30.8445	0.4720

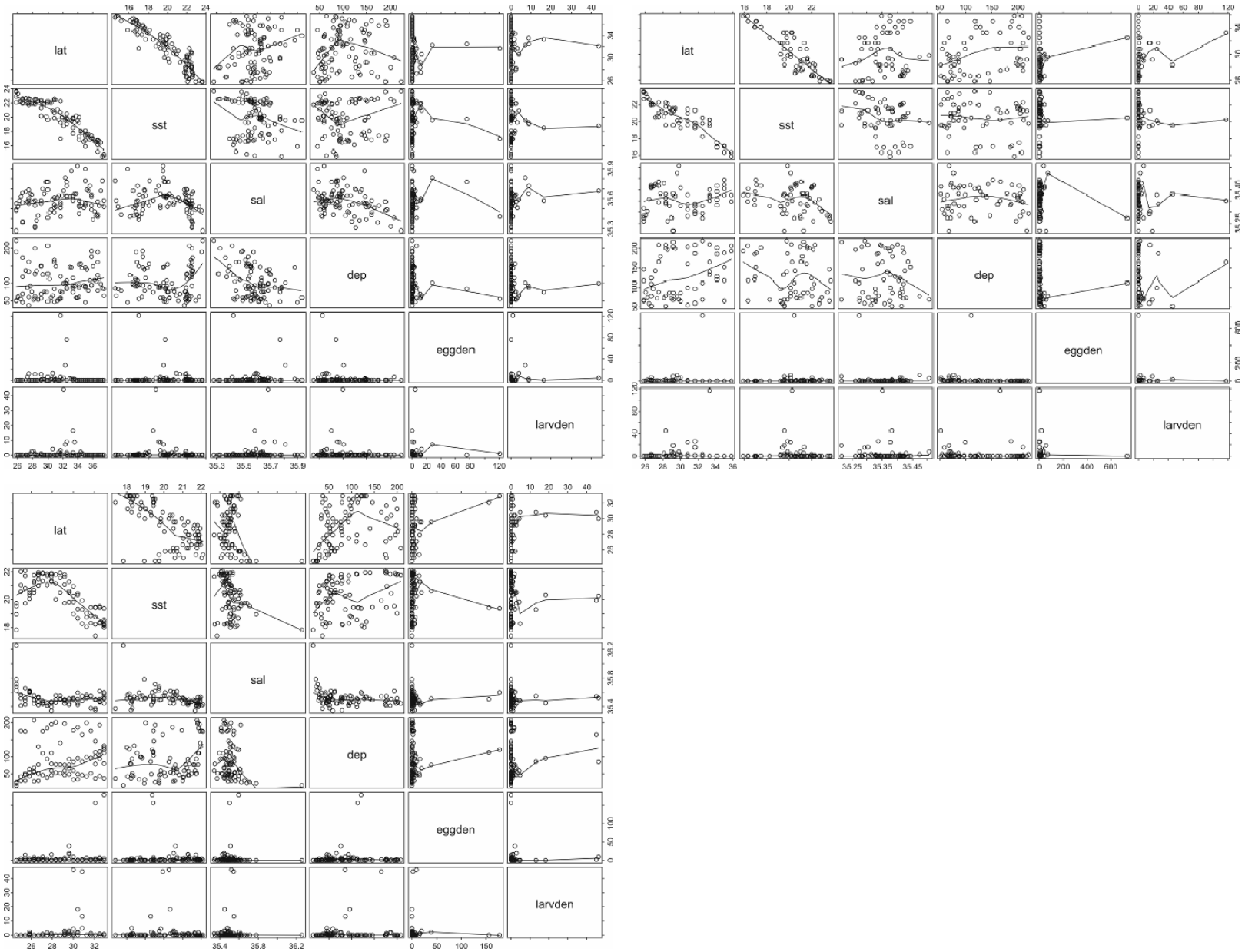

Figure 8.15. Scatter plot matrix with Loess smooth fitted to egg and larval densities and environmental variables for eastern Australian in October 2002, October 2003 and July 2004.

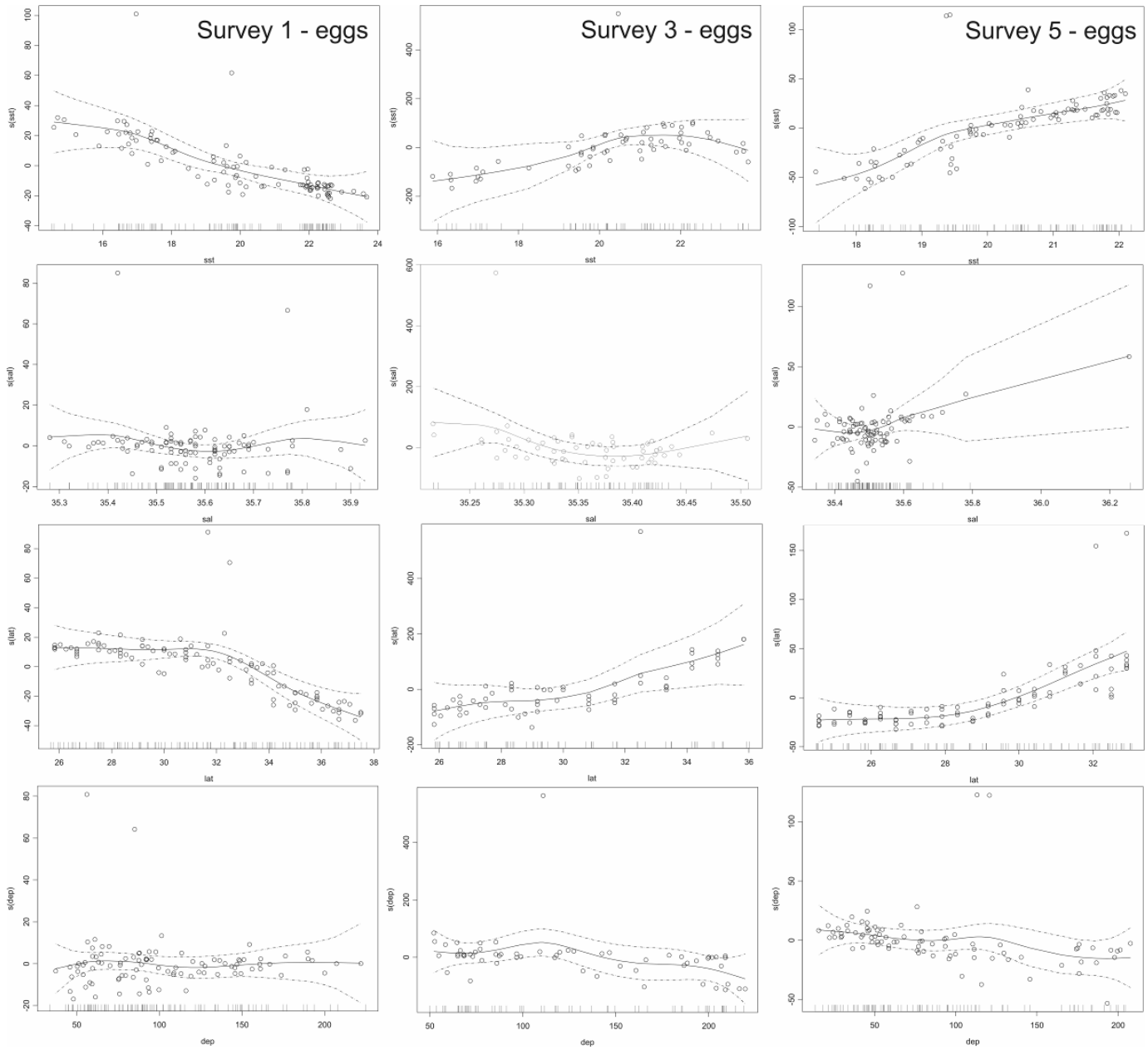

Figure 8.16. Generalised additive model fits to egg density and environmental variables for eastern Australian surveys in October 2002, October 2003 and July 2004. Plots include partial residuals (dots), 2 s.e. and rug-plot of explanatory data (along x-axis).

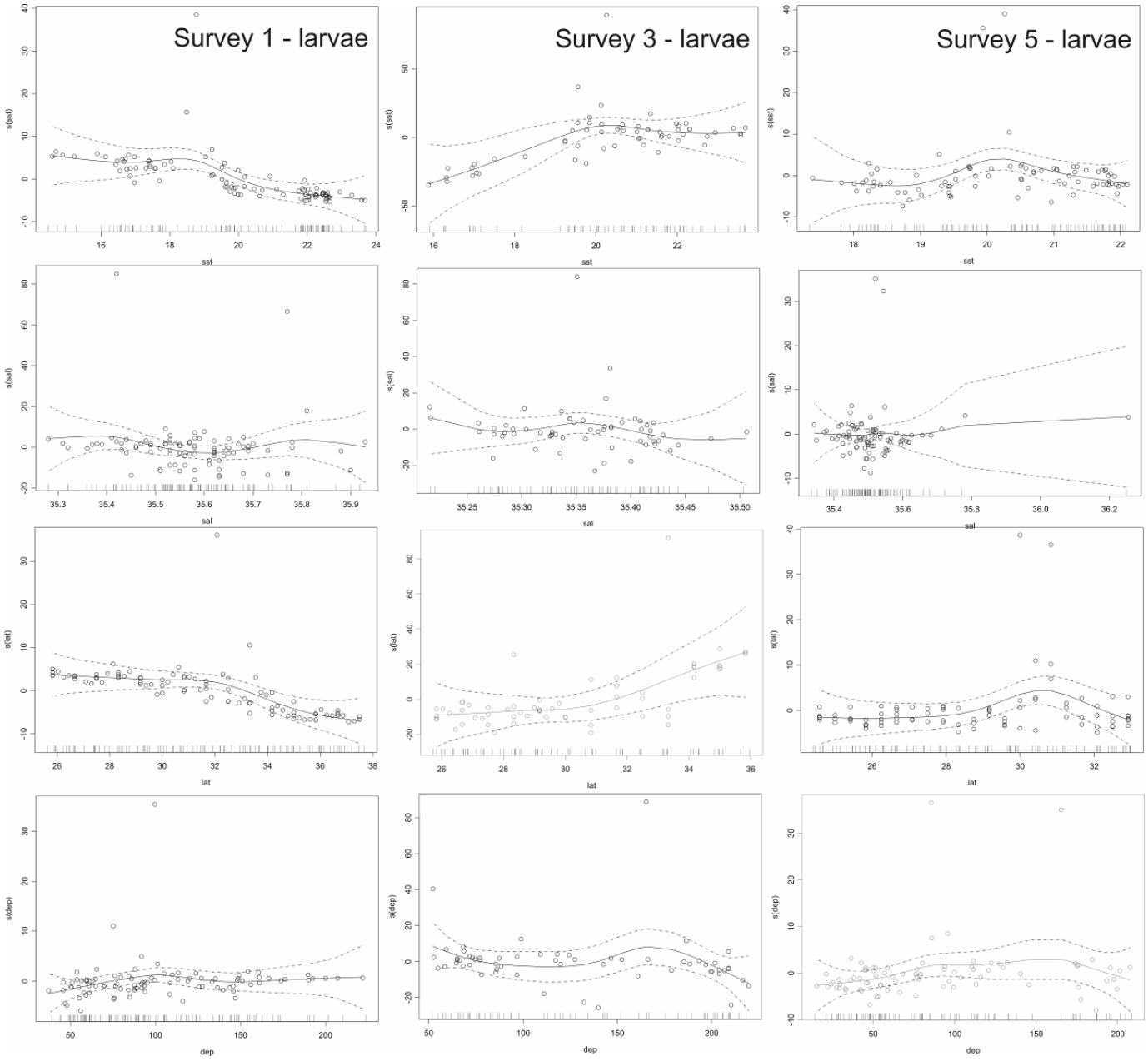

Figure 8.17. Generalised additive model fits to larval density and environmental variables for eastern Australian surveys in October 2002, October 2003 and July 2004. Plots include partial residuals (dots), 2 s.e. and rug-plot of explanatory data (along x-axis).

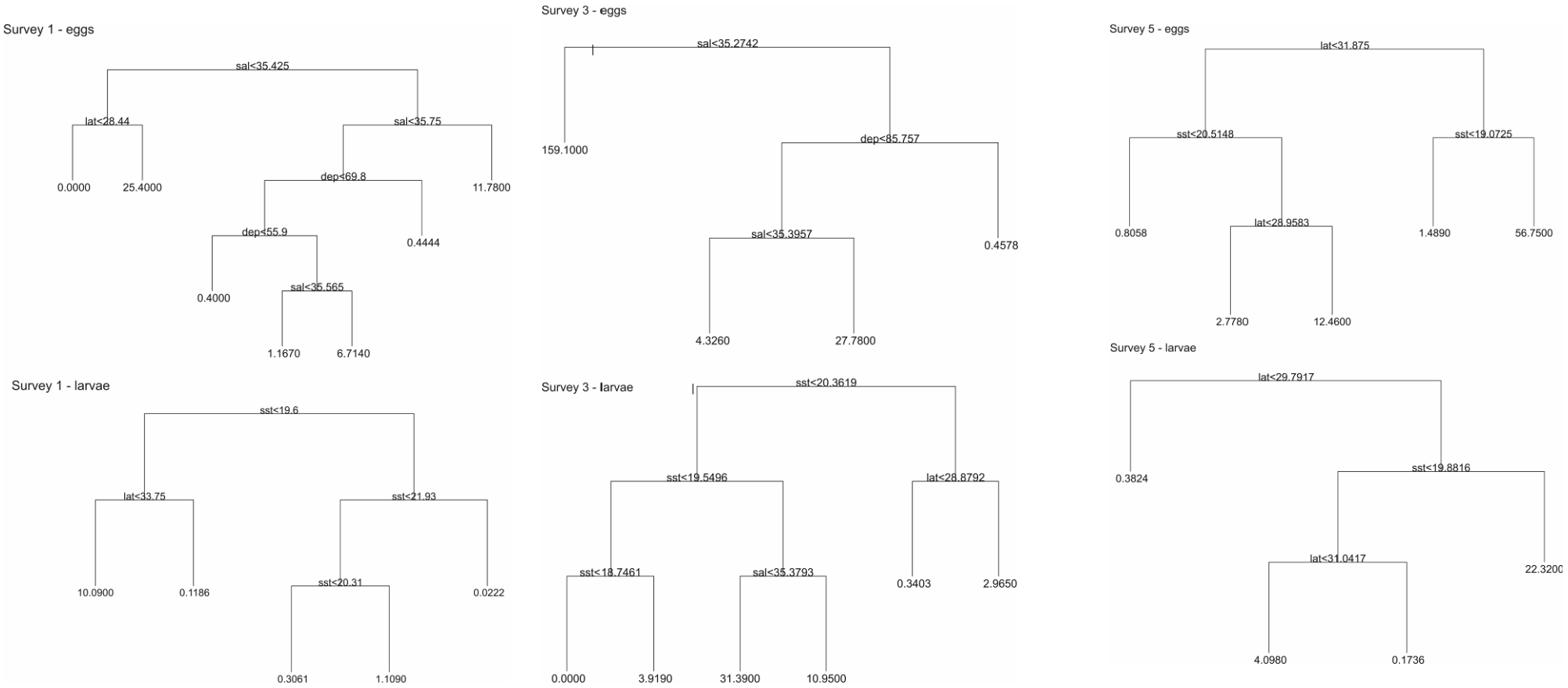

Figure 8.18. Regression trees showing the relationships between egg and larval density and environmental variables for eastern Australian October 2002 (survey 1), October 2003 and July 2004.

Table 8.4. Results of General Additive Model fits of *S. australasicus* eggs and larvae, SST, salinity, latitude and depth by station in eastern Australian waters in October 2002, October 2003 and July 2004. Significant *p*-values are shown in bold italics.

Eggs		**Df**	**Npar Df**	**Npar F**	**p(F)**	**Larvae**	**Df**	**Npar Df**	**Npar F**	***p*(F)**
Oct 2002	(Intercept)	1				(Intercept)				
	s(sst)	1	3	1.0669	0.3680	s(sst)	1		34.3119	***0.0072***
	s(sal)	1	3	1.8600	0.1432	s(sal)	1		30.8720	0.4592
	s(lat)	1	3	8.4564	***0.0000***	s(lat)	1		33.2573	***0.0259***
	s(dep)	1	3	0.4766	0.6996	s(dep)	1		31.3480	0.2649
Oct 2003	(Intercept)	1				(Intercept)	1			
	s(sst)	1	3	2.9388	***0.0438***	s(sst)	1		34.9482	***0.0049***
	s(sal)	1	3	1.8081	0.1599	s(sal)	1		30.9219	0.4384
	s(lat)	1	3	1.1932	0.3236	s(lat)	1		31.3172	0.2811
	s(dep)	1	3	1.8311	0.1558	s(dep)	1		32.4870	0.0733
July 2004	(Intercept)	1				(Intercept)	1			
	s(sst)	1	3	1.9332	0.1324	s(sst)	1		34.2014	***0.0087***
	s(sal)	1	3	0.5139	0.6741	s(sal)	1		30.3304	0.8034
	s(lat)	1	3	2.2077	0.0951	s(lat)	1		34.1912	***0.0088***
	s(dep)	1	3	0.9580	0.4177	s(dep)	1		31.6254	0.1916

8.4 Discussion

8.4.1 Timing of spawning

The spawning season of *S. australasicus* varies between regions. Off southern Australia, the main spawning season of *S. australasicus* off southern Australia is during summer and autumn, which coincides with the spawning season for this species in New Zealand (Crossland 1981; 1982; Jones 1983). The collection of large numbers of eggs and larvae during January-February is consistent with the findings of the adult reproductive study presented in Chapter 6 of this report, which suggest that off southern Australia *S. australasicus* spawns during the period between October and April, with the peak during December to March. Future DEPM surveys for *S. australasicus* off southern Australia should be conducted in the period between late December and early March.

The collection of large numbers of eggs and larvae from southern Qld and northern NSW during surveys conducted in July and October confirms previous evidence (e.g. Gray and Miskiewicz 2000) that suggests *S. australasicus* may spawn during late winter and early spring off eastern Australia. The monthly gonosomatic indices presented in Chapter 6 of the present report also suggest that *S. australasicus* spawns during July to October in this region, and that the peak spawning season is during August-September. Future surveys to support application of the DEPM to *S. australasicus* off eastern Australia should be conducted during August-September.

8.4.2 Location of spawning

The large differences in the number of *S. australasicus* eggs and larvae collected in surveys conducted between Cape Otway and the Head of Bight during 2002 to 2005 suggests that the location of spawning in this region may vary significantly between years, presumably in response to interannual variations in oceanographic conditions. The large number of eggs collected during the preliminary survey of the western GAB during 2006 also suggests that a large spawning area off southern Australia may lie to west of the region from which most samples were collected during the present study (i.e. Cape Otway and the Head of the GAB). This inference is supported by anecdotal advice from fishers in the South Australian Sardine Fishery and the Commonwealth Southern Bluefin Tuna and Small Pelagic Fisheries, which suggests that the main aggregation of *S. australasicus* off southern Australia occurs in the western GAB. To reliably define the spawning area of *S. australasicus* off southern Australia, future ichthyoplankton surveys to support application of the DEPM should include shelf waters between Cape Arid and Encounter Bay, the southern parts of the two South Australian gulfs and Investigator Strait. The highest priority area for future surveys is the western GAB.

Off eastern Australia, *S. australasicus* spawn in outer shelf waters of southern Queensland and northern NSW. Spawning appears to occur consistently in this region, although the northern and southern boundaries of the spawning area may vary between (and within) spawning seasons under the influence of the EAC. The absence of eggs or larvae in samples collected between southern NSW (Kiama) and eastern Tasmania (Four mile Creek) suggests that this region may not be an important spawning area for *S. australasicus*. This finding is important because significant catches of *S. australasicus* have been taken from these waters, especially off southern NSW, and it has been suggested that *S. australasicus* spawns in these waters throughout summer (e.g. Kailola *et al.* 1993). Future surveys to support the application of the DEPM to *S. australasicus* off eastern Australia should be conducted in waters between Wollongong NSW and Bundaberg Queensland, to ensure that the entire spawning area is sampled. Due to the relatively narrow width of the continental shelf in this region, future surveys should involve a relatively large number of closely spaced (e.g. 10 nm apart) cross-shelf (parallel) transects with relatively high numbers of stations on each transect (e.g. 8-10) as this approach is suitable for application and assessment of the DEPM.

8.4.3 Factors affecting distribution and abundance

Like the data from many ichthyoplankton surveys, the data presented in this chapter are highly skewed, or 'over-dispersed'. All of the surveys in which significant number of eggs/larvae were collected include many stations with no eggs or larvae, moderate to large numbers of stations with <20 eggs or larvae and a small number of stations with many (>50) eggs or larvae. The few stations with many eggs/larvae contain a significant proportion of the total number of eggs/larvae collected in each survey, and are not "outliers" but true reflections of the "real" pattern of distribution and abundance and cannot be excluded from statistical analyses (Pennington 1996). These highly skewed or over-dispersed distributions bias even simple analyses. For example, the outliers dominate estimates of mean abundance and variance and create significant biases in quotient analyses that are commonly used to examine the relationships of egg and larval abundance with SST and salinity (e.g. van der Lingen *et al.* 2005; Ibaibarriaga *et al.* 2007). No completely satisfactory methods for analysing these over-dispersed datasets have yet been developed. However, both the literature and our exploration of this dataset suggest that the use of GAMS on log-transformed data with quasi-likely hood distributions provide reasonably robust results (Crawley 2003).

8.4.3.1 Eggs

The absence of a statistically significant relationship between egg abundance and environmental variables off southern Australia could reflect the relatively small numbers of eggs collected from Cape Otway to the Head of Bight and the relatively narrow range of values of environmental parameters recorded in the 2004 and 2005 surveys (Fig. 8.11 and 8.12). It is notable that in southern Australia relatively high egg abundances were recorded at stations with depths (40 to 120 m), SSTs (18–22°C) and salinities (35.5–36.5) similar to those where high densities of eggs were collected off eastern Australia. These parameters may define the optimal spawning conditions for *S. australasicus* in Australian waters. However, surveys that include shelf waters of the western GAB, where large numbers of *S. australasicus* were found during this study, are needed to gain a better understanding of the factors that affect the spawning patterns of this species in southern Australia.

The relationship of egg abundance with latitude (October 2002) and SST (October 2003) off eastern Australia reflects the location of the spawning area in the waters of northern NSW and southern Queensland (29–34°S) and the high SSTs (19–22°C) in that region. The scatter plots of latitude versus SST shows that these two variables are inversely auto-correlated, with SST increasing as latitude decreases (Fig. 8.11). Nonetheless, we considered that including both these variables in the GAMs was preferable to omitting latitude from the model, because this approach would provide less information and may also bias the outputs (e.g. Quinn and Keough 2002). While statistical relationships of egg abundance with latitude and SST are interesting, the absence of eggs at stations located further south during periods when SSTs in those regions are suitable for spawning by *S. australasicus* (i.e. 18-22°C during February) may provide more telling evidence of the importance of location/latitude (c.f. SST) for spawning by this species (see Figure 8.8). It is also notable that the period during winter and early spring may be the only part of the year during which SSTs in southern Queensland and northern NSW are within the critical thermal limits for spawning by *S. australasicus* (Figure 8.19).

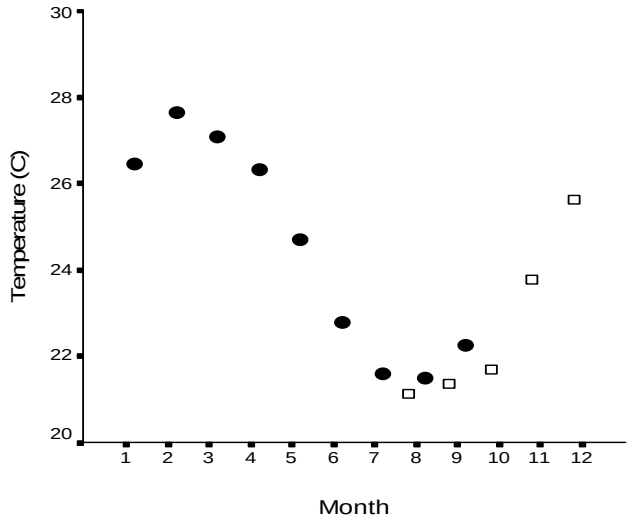

Figure 8.19. Mean monthly SSTs in southern Queensland in 1997 (open squares) and 1998 (closed circles) from wave rider bouy located offshore from Point Lookout. Data from Queensland Department of Primary Industries. Adapted from Ward *et al.* (2003b).

SST is commonly used as a key parameter for defining the spawning habitats of pelagic fishes (e.g. van der Lingen *et al.* 2005), but our results support the findings of previous studies that suggest SST is only a good indicator of the spawning activity of pelagic fishes in water temperatures near their critical thermal limits. In other circumstances SST is a poor predictor of spawning activity because spawning occurs over a wide range of temperatures, and is affected by other factors such as food availability, upwelling strength and, in this case, the prevailing currents (Lluch-Belda *et al.* 1992; Hutchings *et al.* 2002; Ward *et al.* 2003b).

The finding that *S. australasicus* is widely distributed off eastern Australia but that spawning occurs only in shelf waters off southern Queensland and northern NSW is consistent with the hypothesis that in this region *S. australasicus* migrates northwards to spawn and that eggs and larvae are transported southwards into juvenile and adult habitats by the prevailing EAC. This dispersal-migration strategy is similar to that which has been suggested for numerous pelagic fishes in western boundary current ecosystems, including *Sardinop sagax* and *Pomatomus saltatrix* off eastern Australia (Ward *et al.* 2003b). Similarly, Hutchins *et al.* (2002) suggested that many of the dominant fish species in shelf waters of southern Africa, where currents are also strong, move upstream to spawn.

8.4.3.2 Larvae

The statistical relationship of larval abundance off southern Australia with SST, latitude, longitude and depth in 2004, but not in 2005, may reflect both the complexities of analysing over-dispersed data and the relatively small numbers of larvae collected in both years of surveys of southern Australia. However, SST and latitude were also the environmental variables with the strongest relationships with larval abundance off eastern Australia (Table 8.4). In both locations, high larval abundances were recorded at stations with SSTs between approximately 18 and 22°C, which suggests that this temperature range may be optimal for the development of eggs and larvae of *S. australasicus* in Australian waters.

8.5 Conclusions

The results of the present study suggest that in southern and eastern Australian waters, *S. australasicus* spawns mainly over the continental shelf in locations with depths between ~40 and 120 m and SSTs between 18–22°C. Off southern Australia, the location of spawning may vary significantly between years, presumably in response to variations in oceanographic conditions. The high egg and larval abundances recorded in the preliminary survey of the western GAB emphasize the need for intensive surveys to be conducted in that region. The high abundances of eggs and larvae recorded off southern Queensland and northern NSW during winter and autumn suggest that this is the key spawning area for *S. australasicus* off eastern Australia. Our results are consistent with the hypothesis that off eastern Australia *S. australasicus* migrates northwards to spawn and that eggs and larvae are transported southwards into juvenile and adult habitats by the prevailing currents.

The finding that *S. australasicus* spawns in shelf and gulf waters between Encounter Bay (SA) and Esperance (WA) during summer and autumn, and that the location of spawning may vary between years, poses significant logistical challenges for future application of the DEPM off southern Australia. This is because an area of greater than 250,000 km^2 would need to be surveyed to determine the spawning area off southern Australia with a high degree of confidence. If future surveys cannot intensively sample the entire area between Encounter Bay and Esperance sampling effort should be concentrated in the central and western GAB. Future surveys to support application of the DEPM to *S. australasicus* off southern Australia should be conducted in the period between late December and early March.

The finding that *S. australasicus* spawns consistently in waters off southern Queensland and northern NSW during winter and autumn augers well for the future application of the DEPM in this region. Ichthyoplankton surveys conducted off eastern Australia during August-September in shelf waters between Bundaberg, Queensland and Wollongong, NSW, would be likely to coincide with the main spawning season and cover most of the spawning area. Future surveys should involve a relatively large number of closely spaced (e.g. 10 nm apart) cross-shelf (parallel) transects with relatively high numbers of stations on each transect (e.g. 8-10).

8.6 Acknowledgements

The authors are grateful to people who provided assistance during the ichthyoplankton surveys, especially the masters and crews of the RV *Ngerin* and FTV *Bluefin*, students of the Australian Maritime College (AMC) and staff the South Australian Research and Development Institute (SARDI) and NSW Department of Primary Industries (DPI). The in-kind contributions of the AMC, SARDI, NSW DPI and TAFI are also acknowledged. We thank Drs Jeremy Lyle (TAFI), Dr Mike Steer (SARDI) and Dr Richard Musgrove (SARDI) for comments on drafts of the chapter.

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8.8 Appendices

Backward stepwise regressions (BSR) in S-Plus software were used to investigate the relationships between log-transformed (ln(x+1)) egg and larval density, seas surface temperature (SST, °C), salinity (sal, psu), bottom depth (d, m), latitude (lat, dec degrees) and longitude (long, dec degrees) recorded at each station. Interactions between independent variables were investigated and terms were deleted one at a time in a backward step-wise manner, so that each deleted term did not decrease the goodness of fit of the final regression model for each species/egg/larval combination (Crawley 2003). Akaike Information Criteria (small AIC = better the fit) were used to determine the variables to be deleted after each model step.

Appendix 8.8.1.

Results of backward step-wise regressions between ln-transformed *S. australasicus* egg and larval densities, SST, salinity and depth by station in southern Australian waters in 2004 and 2005. Shows significant *p*-values in bold.

2004									
Eggs	value	s.e	t- value	p(>|t|)	Larvae	value	s.e	t- value	p(>|t|)
(Intercept)	-29.3927	9.0547	-3.2461	0.0016	(Intercept)	-107.367	48.9287	-2.1944	0.0304
Sal	1.1007	0.6097	1.8054	0.0738	sst	4.4654	2.3408	1.9076	0.0591
Lat	0.8031	0.2205	3.6422	0.0004	sal	3.1963	1.3594	2.3512	0.0205
Dep	0.1863	0.0881	2.115	0.0367	lat	0.2583	0.0852	3.0326	0.003
lat:dep	-0.0054	0.0025	-2.1982	0.0301	sst:sal	-0.1254	0.0656	-1.912	0.0585
long:sal	-0.0077	0.0041	-1.8594	0.0657	long:sal	-0.0031	0.0015	-2.1167	0.0366
2005									
Eggs	value	s.e	t- value	p(>|t|)	Larvae	value	s.e	t- value	p(>|t|)
(Intercept)	16.2089	17.4931	0.9266	0.3557	(Intercept)	-15.8851	11.246	-1.4125	0.1599
sal	-0.7405	0.5078	-1.4582	0.1469	sal	0.1127	0.2777	0.4058	0.6855
lat	0.3148	0.0771	4.0852	0.0001	lat	0.3478	0.1149	3.0268	0.0029
dep	-0.8787	0.3562	-2.4668	0.0148	dep	0.5359	0.2265	2.3655	0.0193
sal:dep	0.0246	0.0099	2.4759	0.0144	sal:dep	-0.0104	0.0056	-1.8585	0.0651
					lat:dep	-0.0047	0.0016	-2.8816	0.0046

Appendix 8.8.2. Results of backward step-wise regressions between ln-transformed *S. australasicus* egg and larval densities, SST, salinity and depth by station in eastern Australian waters in October 2002, October 2003 and July 2004. Shows significant *p*-values in bold.

Eggs	value	s.e.	t- value	p(>|t|)	Larvae	value	s.e	t-value	p(>|t|)
2002									
(Intercept)	3062.36	1278.438	2.3954	0.0188	(Intercept)	31.2753	10.3999	3.0073	0.0034
Sst	-73.7801	29.6395	-2.4893	0.0147	sst	-1.5954	0.4054	-3.9355	0.0002
Sal	-84.0899	35.8659	-2.3446	0.0214	lat	-0.9572	0.2523	-3.7931	0.0003
Lat	-51.7076	22.7392	-2.2739	0.0255	dep	0.1117	0.0701	1.5943	0.1144
Dep	-0.1824	0.1106	-1.6499	0.1026	sst:lat	0.0498	0.0106	4.6806	0
sst:sal	1.9965	0.8331	2.3964	0.0187	sst:dep	-0.0025	0.0017	-1.4612	0.1475
sst:lat	0.0626	0.0162	3.8578	0.0002	lat:dep	-0.0019	0.0012	-1.6567	0.1011
sst:dep	0.0048	0.0027	1.7692	0.0804	Larvae	value	s.e	t-value	p(>|t|)
sal:lat	1.405	0.638	2.202	0.0303	(Intercept)	31.2753	10.3999	3.0073	0.0034
lat:dep	0.0028	0.0018	1.5054	0.1359	sst	-1.5954	0.4054	-3.9355	0.0002
2003									
(Intercept)	38.6805	19.9024	1.9435	0.0571	(Intercept)	73.2972	20.3747	3.5975	0.0007
Sst	-1.7463	0.8886	-1.9652	0.0544	sst	-2.8886	0.7577	-3.8122	0.0004
Lat	-1.1888	0.58	-2.0495	0.0452	lat	-1.9444	0.5463	-3.559	0.0008
Dep	-0.0106	0.0035	-3.0471	0.0035	dep	-0.2309	0.1329	-1.7371	0.0882
sst:lat	0.0575	0.0268	2.1471	0.0362	sst:lat	0.0743	0.0263	2.8303	0.0066
					sst:dep	0.005	0.0034	1.4776	0.1454
					lat:dep	0.0041	0.0022	1.8507	0.0698
2004									
(Intercept)	-18.8674	4.5282	-4.1666	0.0001	(Intercept)	73.2972	20.3747	3.5975	0.0007
sst	0.7351	0.181	4.0618	0.0001	sst	-2.8886	0.7577	-3.8122	0.0004
lat	0.1827	0.0702	2.6041	0.011	lat	-1.9444	0.5463	-3.559	0.0008
dep	0.065	0.0366	1.7749	0.0797	dep	-0.2309	0.1329	-1.7371	0.0882
sst:dep	-0.0034	0.0018	-1.9389	0.056	sst:lat	0.0743	0.0263	2.8303	0.0066
					sst:dep	0.005	0.0034	1.4776	0.1454
					lat:dep	0.0041	0.0022	1.8507	0.0698

9. Distribution and abundance of eggs and larvae of four taxa of pelagic fishes off southern and eastern Australia

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Objective: To describe the distribution and abundance of eggs and larvae of small pelagic species (*Trachurus* spp., *Sardinops sagax*, *Engraulis australis* and *Etrumeus teres*) in south eastern Australia.

Summary: This chapter describes and compares the patterns of distribution and abundance of the eggs and larvae of *Trachurus* spp. (*T. declivis* and *T. novaezelandiae*), *Engraulis australis*, *Sardinops sagax* and *Etrumeus teres* off southern and eastern Australia. A total of 27,481 eggs and 25,202 larvae were collected from 2,386 stations between southern Queensland and the western Great Australian Bight during 2001-06. *S. sagax* and *E. australis* comprised over 87% of the eggs and larvae of these four species collected off southern Australia, whereas *Trachurus* spp. and *S. sagax* comprised over 82% of the eggs and larvae collected off eastern Australia (*E. teres* eggs were not identified for eastern Australia). The reason for the large difference in the proportion of eggs and larvae of *Trachurus* spp. collected from southern and eastern Australia is unclear, but could reflect the timing of the surveys or the lower relative abundance of *Trachurus spp.* off southern Australia. Eggs and larvae of *Trachurus* spp. collected from off southern Queensland and northern NSW during winter and spring may belong mainly to *T. novaezelandiae*, whereas those collected off southern NSW, Victoria and eastern Tasmania during summer may belong mainly to *T. declivis*. However, genetic studies are required to test this hypothesis. The high abundance of *S. sagax* eggs and larvae in samples from southern Australia reflects both the timing and location of these surveys and the large biomass of this species in this region. Shelf waters are important for spawning by *E. australis* off southern Australia, but off eastern Australia most spawning appears to occur in inshore waters. The timing and locations of

spawning by *E. teres* off southern and eastern Australia appear to coincide with the spawning seasons and areas of *S. sagax*. The Daily Egg Production Method (DEPM) can be applied relatively easily to species with distinctive eggs, such as *S. sagax* and *E. australis*, and has been used for stock assessment of *S. sagax* throughout Australian waters. Data collected in the present study were used to provide preliminary estimates of the *S. sagax* biomass off southern Queensland and northern NSW. Application of the method to *E. australis* is currently being investigated off southern Australia. Use of the DEPM for *E. australis* off eastern Australia may be complicated by the inshore spawning habit of this species in this location. Application of the DEPM to *T. declivis* or *T. novaezelandiae* will require the development of effective molecular techniques for differentiating between the eggs of these two species. These techniques should be developed and applied before further consideration is given to the application of the DEPM to *Trachurus* spp. in Australia

9.1 Introduction

Coastal waters of southern and eastern Australia support diverse assemblages of small to medium sized pelagic fishes, including jack mackerel *Trachurus declivis*, yellowtail scad *T. novaezelandiae*, Australian anchovy *Engraulis australis*, Australia sardine *Sardinops sagax,* and maray *Etrumeus teres*, as well as blue mackerel *Scomber australasicus* (see chapter 8 of this report). Significant quantities (almost 40,000 t in 1986/87) of *T. declivis* have been taken in the Commonwealth Small Pelagic Fishery, previously the Jack Mackerel Fishery, and a large fishery for *Sardinops sagax* (annual catches of between 20,000 and 46,000 t between 2001 and 2006) has been established off South Australia (Kailola *et al.* 1993; Rogers and Ward 2005). However, minimal information is available regarding the patterns of distribution and abundance of most of these species in most locations; the exception is *S. sagax* in waters of South Australia, where annual stock assessments using the Daily Egg Production Method (DEPM) and related studies have been undertaken since 1995 (Rogers and Ward 2005).

International studies suggests that like *S. australasicus; Trachurus spp., E. australis*, *S. sagax* and *E. teres* are batch spawning fishes with indeterminate fecundity (Lasker 1985; Abaunza *et al.* 2003), and the DEPM has been identified as a potentially useful stock assessment tool for all of these species (see chapter 2 of this report). Knowledge of the timing and location of spawning is a critical prerequisite for application of the DEPM. Information from ichthyoplankton surveys is commonly used to determine where and when pelagic fishes spawn. Adult reproductive data is also important for determining the spawning season (see chapter 6). However, the collection of adult reproductive data on *T. declivis*, *T. novaezelandiae*, *E. australis*, *S. sagax* and *E. teres* was beyond the scope of this study.

Jack mackerel *Trachurus declivis* and yellowtail scad *T. novaezelandiae*, have similar overall distributions, with both occurring throughout temperate and sub-tropical Australian waters from Fraser Island to Shark Bay (Kailola *et al.* 1993). The eggs and larvae of these two species are difficult to distinguish on the basis of morphological characteristics alone and were not differentiated during this study. However, *T. novaezelandiae* is thought to be most abundant off NSW, whereas *T. declivis* appears to be more abundant off Victoria and eastern Australia and in the Great Australian Bight (Stevens *et al.* 1984; Kailola *et al.* 1993). Adult reproductive data indicate that off eastern Tasmania and in the Great Australian Bight *T. declivis* spawns during summer (Stevens *et al.* 1984; Marshall *et al.* 1993; Jordan 1994; Jordan *et al.* 1995). Larvae of *Trachurus* spp. have been collected off eastern Tasmania and in Bass Strait during this period

(Marshall *et al.* 1993; Neira 2005). Off NSW, *Trachurus* spp. larvae have been collected from Lake Macquarie (NSW) and adjacent coastal waters from September to June (Miskiewicz 1987) and in coastal waters off Sydney throughout the year (Gray *et al.* 1992; Gray 1993).

Australian anchovy *Engraulis australis*, is found throughout coastal waters of temperate and sub-tropical Australia (Kailola *et al.* 1993). The main spawning season appears to occur between spring and autumn in both sub-tropical locations, such as southern Queensland (Ward *et al.* 2003b), and in temperate waters, such as those off Victoria and South Australia (Hoedt and Dimmlich 1995; Ward *et al.* 2001b; Dimmlich *et al.* 2004; Neira 2005). Off eastern Australia spawning appears to be confined mainly to shallow embayments, whereas off southern Australia significant spawning activity also occurs in shelf waters (Ward *et al.* 2003a; Dimmlich *et al.* 2004). Small inshore fisheries for *E. australis* have operated for many years in all temperate states of Australia, with most of the catch sold for recreational fishing bait (e.g. Kailola *et al.* 1993). However, no large fisheries for *E. australis* have yet been established.

Australian sardine *Sardinops sagax*, is found throughout shelf waters of southern Australia and is the most well studied of Australia's small pelagic fishes (see Rogers and Ward 2005). The spawning season of *S. sagax* varies between locations, and occurs during winter and spring off southern Queensland (Ward *et al.* 2003b) and during summer and autumn off South Australia (e.g. Ward *et al.* 2001c; Ward and Staunton-Smith 2002). *S. sagax* does not spawn extensively in inshore bays and inlets, but during the spawning season eggs and larvae are highly abundant in shelf waters. As well as supporting the large South Australian Sardine Fishery (39, 000 t in 2005), *S. sagax* is taken in smaller fisheries off NSW, Victoria and Western Australia. Annual catches off Western Australia peaked at approximately 12,000 t in 1996, but are currently less than 2000 t (Fletcher and Head 2006).

Like the other species considered in this chapter, maray *E. teres* occurs throughout temperate and subtropical waters of Australia from approximately Fraser Island to Shark Bay. However, *E. teres* does not appear to be highly abundant in any location and few data have been published on this species' reproductive biology in Australian waters. Where data are available, the location and timing of spawning appear to coincide with those of *S. sagax* (Ward *et al.* 2003b).

This chapter describes and compares the spatial and temporal patterns of distribution and abundance of eggs and larvae of *Trachurus* spp., *E. australis*, *S. sagax* and *E. teres* in waters off

southern (Cape Otway, Victoria to Archipelago of the Recherche, Western Australia) and eastern Australia (Bundaberg, Queensland to Four Mile Creek, Tasmania). Information is used to provide advice regarding the future application of the DEPM for stock assessment of these species. The provision of ichthyoplankton data for these four taxa was not an original objective of the blue mackerel project (FRDC 2002/061), and resources were not provided to support the sorting and identification of eggs and larvae (of these species) or the analysis and interpretation of these data. Hence, eggs and larvae of all four species were not sorted for all surveys and quantitative analyses of the relationships of egg and larval abundance with environmental parameters were not undertaken here (due to both resource constraints and limitations in the datasets, including the aggregation of data for *T. declivis* and *T. novaezelandiae*).

9.2 Materials and methods

The timing and location of surveys, survey design, sampling regime and methods used to collect samples and environmental data are described in chapter 8 of this report. Details of the surveys from which the eggs and larvae of *Trachurus* spp., *Engraulis australis*, *Sardinops sagax* and *Etrumeus teres* were sorted and identified are shown in Table 9.1.

9.2.1 Identification of eggs and larvae

The eggs of *Trachurus* spp., *E. australis, S. sagax* and *E. teres* were identified using the descriptions of Robertson (1975), Crossland (1981), and White and Fletcher (1996). Larvae of *Trachurus* spp., *E. australis, S. sagax* and *E. teres* were identified using the descriptions provided by Neira *et al.* (1998).

9.2.2 Data analyses

The total numbers of eggs and larvae were counted and converted to abundance per unit surface area (numbers/m^{-2}) using data on the sampling depth and the volume of water filtered by the plankton nets. Egg and larval abundances were plotted using SURFER and MapInfo software.

Table 9.1. Details of ichthyoplankton surveys conducted off eastern and southern Australia between 2001 and 2006.

Survey date	Shelf region sampled (States)	Method	Range	n Transects	n stations sampled
Southern Australia					
1. 19 Feb–29 Mar. 01	Encounter Bay – Head of Bight (SA)	CalVET	130.5–138.5 °E	32	315
2. 1 Feb–18 Mar. 02	Encounter Bay – Head of Bight (SA)	CalVET	129.5–138.5 °E	33	328
3. 21 Feb–3 Apr. 03	Encounter Bay – Head of Bight (SA)	CalVET	130.5–138.5 °E	32	320
4. 3–15 Feb. 03	Cape Northumberland – Head of Bight (SA)	Bongo	130.7–141.0 °E	21	74
5. 14 Feb–26 Mar. 04	Encounter Bay – Head of Bight (SA)	CalVET	130.4–138.5 °E	28	284
		Bongo	130.7–138.5 °E	26	137
6. 5 Feb–19 Mar. 05	Encounter Bay – Head of Bight (SA)	CalVET	130.4–138.5 °E	31	334
		Bongo	130.4–138.5 °E	29	152
7. 2 Feb–7 Feb. 06	Archipelago of the Recherche (WA)	Bongo	122.3–124.4 °E	1	75
			Total	**233**	**2,019**
Eastern Australia					
1. 12–22 Oct. 02	Wide Bay – Cape Howe (Qld-NSW)	Bongo	25.8–37.5 °S	15	97
2. 5–11 Feb. 03	Cape Howe – Four Mile Creek (NSW-Tas)	Bongo	37.5 –41.7 °S	10	55
3. 1–8 Oct. 03	Wide Bay – Cape Howe (Qld-NSW)	Bongo	25.8–37.5 °S	15	74
4. 5–12 Feb. 04	Kiama – Cape Conran (NSW-Vic)	Bongo	34.7–38.2 °S	14	60
5. 19–28 July 04	Bundaberg – Newcastle (Qld-NSW)	Bongo	24.6–32.9 °S	21	81
			Total	**75**	**367**

9.3 Results

9.3.1 Environmental Data

SST and current information for the surveys is provided in chapter 8 of this report.

9.3.2 Total eggs and larvae

A total of 27,481 eggs and 25,202 larvae belonging to four taxa of small pelagic fishes, namely *Trachurus* spp., *E. australis*, *S. sagax* and *E. teres* were collected from 2,386 stations off southern and eastern Australia between 2001 and 2006 (Tables 9.1-9.5). Off southern Australia, a total of 12,158 eggs and 13,771 larvae were collected from 2,019 stations, whereas off eastern Australia a total of 15,323 eggs and 11,431 larvae were collected from 367 stations (Tables 9.1-9.5).

Off southern Australia, eggs of *S. sagax* comprised 61.0% of the eggs collected, followed by *E. australis* 30.3%, *Trachurus* spp. 6.5% and *E. teres* 2.2%, whereas off eastern Australia *Trachurus* spp. comprised 76.9% of eggs collected, *S. sagax* 21.2% and *E. australis* 2.0% (Tables 9.1-9.5). *E. teres* eggs comprised 2.1% of eggs collected from southern Australia, but were not identified in samples collected from eastern Australia (Tables 9.1-9.5).

S. sagax comprised 70.2% of the larvae collected from southern Australia followed by *E. australis* 27.1%, *Trachurus* spp. 2.0% and *E. teres* 0.6%. Off eastern Australia, *Trachurus spp.* comprised 56.5% of larvae, and *S. sagax, E. australis* and *E. teres* comprised 35.8%, 4.7% and 2.9%, respectively.

9.3.3 *Trachurus* spp.

9.3.3.1 Occurrence

Trachurus spp. eggs and larvae were sorted and identified in four of the seven surveys conducted in southern Australia and all five of the surveys conducted off eastern Australia (Table 9.2). *Trachurus* spp. eggs and larvae were not sorted and identified in surveys conducted between Encounter Bay and the Head of Bight in 2001 and 2002, or in the samples obtained using bongo nets between Cape Northumberland and the Head of Bight in February 2003 (Table 9.2; Figs. 9.1 and 9.2). Over 54% of the 793 eggs and 61% of the 275 larvae collected off southern Australia were obtained from bongo net tows during the 2005 and 2006 surveys (Table 9.2). Approximately 96% of the 11,776 eggs and 80% of the 6,464 larvae collected from eastern Australia were obtained from surveys conducted between Wide Bay and Cape Howe in October 2002 and 2003, and Bundaberg and Newcastle in July 2004 (Table 9.2; Figs. 9.3 and 9.4).

9.3.3.2 Abundance

Eggs

In surveys, where *Trachurus* spp. eggs were collected and identified off southern Australia, mean egg density for a survey ranged between 2.9 and 25.2 eggs.m^{-2}, whereas off eastern Australia mean egg density ranged between 1.6 and 40.2 eggs.m^{-2} (Table 9.2). The highest egg densities recorded in a single tow in southern and eastern Australia were 498.9 and 2167.3 eggs.m^{-2}, respectively (Table 9.2).

Larvae

Mean density for surveys where *Trachurus* spp. larvae were collected and identified ranged between 0.54 and 11.2 larvae.m^{-2} in southern Australia. Off eastern Australia mean larval density ranged between 3.0 and 45.5 larvae.m^{-2} (Table 9.2). The highest larval densities recorded in a single tow in southern and eastern Australia were 155.2 and 756.8 larvae.m^{-2}, respectively (Table 9.2).

9.3.3.3 Distribution

Eggs

Trachurus spp. eggs occurred at between 5.1 to 28.3% of stations sampled between Encounter Bay and the Head of Bight in 2004 and 2005, and 28.0% of stations sampled in the WGAB in February 2006 (Table 9.2). In 2004 and 2005, eggs were collected from stations located in the southern parts of the Spencer, south of Kangaroo Island and over the mid-shelf in the GAB (Fig. 9.1). Most eggs collected from the WGAB in February 2006 were obtained from shelf waters, although a few eggs were collected near the shelf-break (200 m depth, Fig. 9.1).

Off eastern Australia, eggs of *Trachurus* spp. were collected during all surveys and from stations located between southern Queensland and eastern Tasmania (Table 9.2). The percentage of stations from which *Trachurus* spp. eggs were collected ranged from 20.0% in February 2004 to 50% in October 2002. The highest egg densities (up to 2,167.3 eggs.m^{-2}) were recorded off southern NSW in October 2002. Fewer eggs were collected from this region in October 2003, when more eggs of *Trachurus* spp. were collected from southern Queensland and northern NSW (Fig. 9.3). Relatively few eggs of *Trachurus* spp. were caught off southern NSW, Victoria and eastern Tasmania during February 2003 and 2004 (Fig. 9.3).

Larvae

Off southern Australia, *Trachurus* spp. larvae were collected from 4.5 to 19.7% of stations at locations to similar those where eggs were collected, including the southern parts of the Spencer Gulf, south of Kangaroo Island and the mid-shelf in the GAB. Relatively few larvae were collected from WGAB in February 2006 (Table 9.2; Fig. 9.2).

Trachurus spp. larvae were generally dispersed more broadly off eastern Australia than eggs (Table 9.2; Figs. 9.3 and 9.4). The percentage of stations from which *Trachurus* spp. larvae were collected ranged from 44.0% in February 2003 to 85.0% in February 2004. Larvae were most widespread and densities were highest in the July 2004 survey that was conducted between Bundaberg and Newcastle. Larvae were also widespread and abundant in the surveys conducted in October 2002 and October 2003 (Fig. 9.4). Larvae were more sparsely distributed in the survey conducted off Victoria and eastern Tasmania in February 2003, but widespread and abundant in the survey conducted off southern NSW and Victoria in February 2004 (Fig. 9.4).

Table 9.2. Summary of the total number of eggs and larvae of *Trachurus* spp. collected in surveys conducted off southern and eastern Australia during 2001 to 2006, including the percentage of stations containing eggs/larvae and mean egg/larval density (positive stations only) for each survey. (NI = Not identified).

Survey	Net	n eggs	n larvae	% eggs	% larvae	# (%) Stations containing eggs	# (%) Stations containing larvae	Mean egg density eggs.m^{-2} (Range)	Mean larval density larvae.m^{-2} (Range)
Southern Australia									
1. Encounter Bay – Head of Bight (Feb. – Mar. 2001)	CalVET	NI	NI	-	-				
2. Encounter Bay – Head of Bight (Feb. –Mar. 2002)	CalVET	NI	NI	-	-				
3. Encounter Bay – Head of Bight (Feb. - 3 Apr. 2003)	CalVET	11	28	1.4	10.2	4 (1.3)	22 (6.9)	25.2 (9.0-36.7)	11.2 (7.7-31.6)
4. Cape Northumberland – Head of Bight (Feb. 2003)	Bongo	0	0	0.0	0.0				
5. Encounter Bay – Head of Bight (Feb – Mar. 2004)	CalVET	234	27	29.5	9.8	43(15.2)	23 (8.1)	4.9 (5.2-498.9)	0.54 (4.0-13.9)
	Bongo	76	21	9.6	7.6	23 (20.2)	10 (7.9)	7.2 (0.8-85.1)	2.9 (1.4-6.7)
6. Encounter Bay – Head of Bight (Feb. - Mar. 2005)	CalVET	38	30	4.8	10.9	17 (5.1)	15 (4.5)	14.7 (6.0-14.5)	5.2 (5.2-13.6)
	Bongo	246	157	31.0	57.1	43 (28.3)	30 (19.7)	2.9 (1.4-76.9)	1.72 (1.3-155.2)
7. Archipelago of the Recherche (Feb 2006)	Bongo	188	12	23.7	4.4	21(28.0)	7 (9.3)	12.6 (0.9-108.5)	2.2 (1.3-3.9)
	Total	**793**	**275**						
Eastern Australia									
1. Wide Bay – Cape Howe (Oct. 2002)	Bongo	4,884	1,321	41.5	20.4	48 (50)	65 (67.7)	36.9 (0.45-2167.3)	8.7 (0.19-229.9)
2 Cape Howe – Four Mile Creek (Feb. 2003)	Bongo	109	196	0.9	3.0	15 (27)	24 (44)	1.6 (0.6-19.0)	3.0 (0.5-75.0)
3. Wide Bay – Cape Howe (Oct. 2003)	Bongo	1,132	957	9.6	14.8	27 (36.5)	55 (74.3)	12.0 (1.1-261.6)	10.8 (0.6-206.6)
4. Kiama – Cape Conran (Feb. 2004)	Bongo	341	1,082	2.9	16.7	12 (20)	51 (85)	6.7 (0.6-163.7)	19.5 (0.5-215.5)
5. Bundaberg – Newcastle (July 2004)	Bongo	5,310	2,908	45.1	45.0	27 (31.8)	62 (72.9)	40.2 (0.4-568.4)	45.5 (0.5-756.8)
	Total	**11,776**	**6,464**						
Grand total		**12,569**	**6,739**						

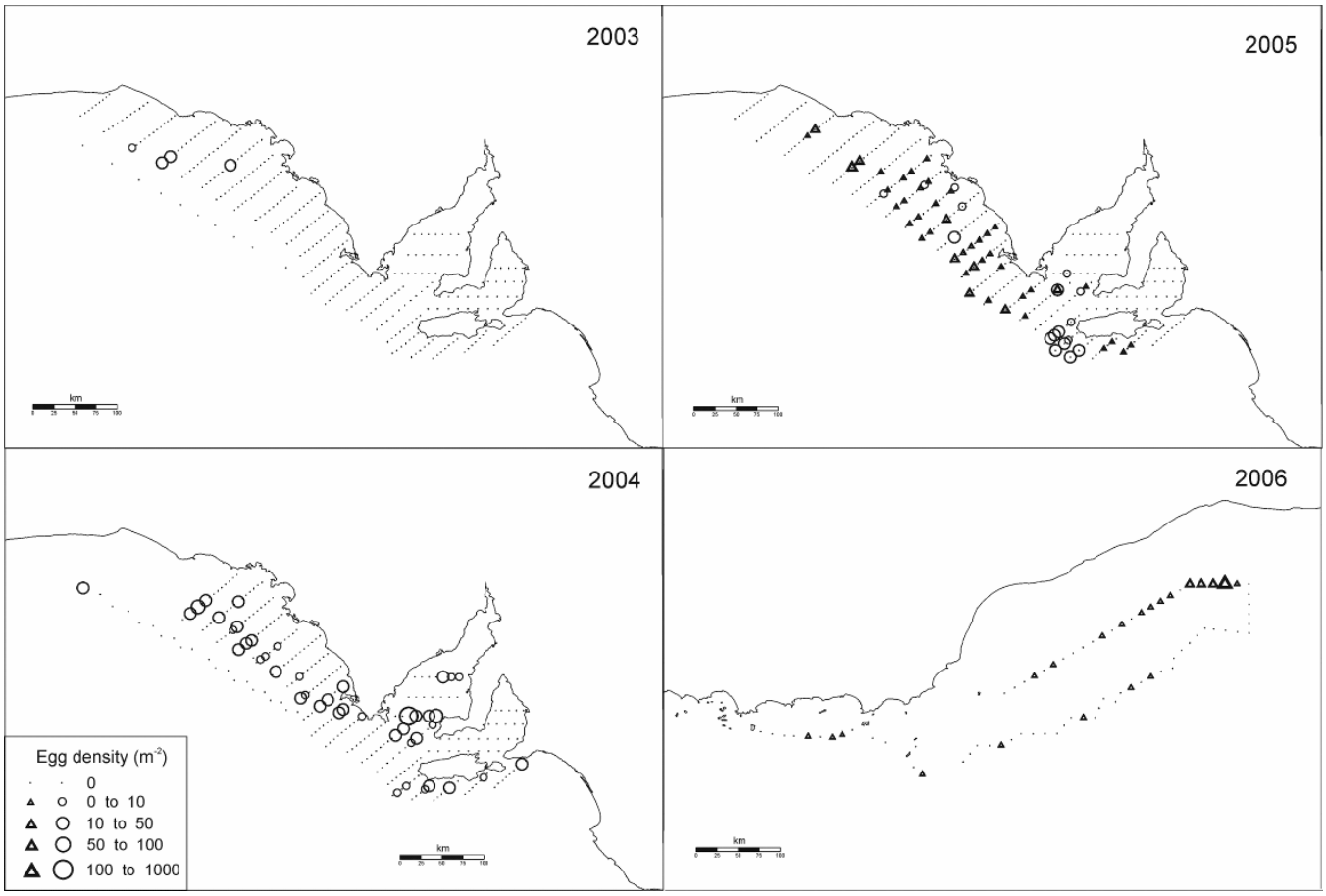

Figure 9.1. Density of *Trachurus* spp. eggs (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006. Circles and triangles represent samples collected with the CalVET and Bongo nets respectively.

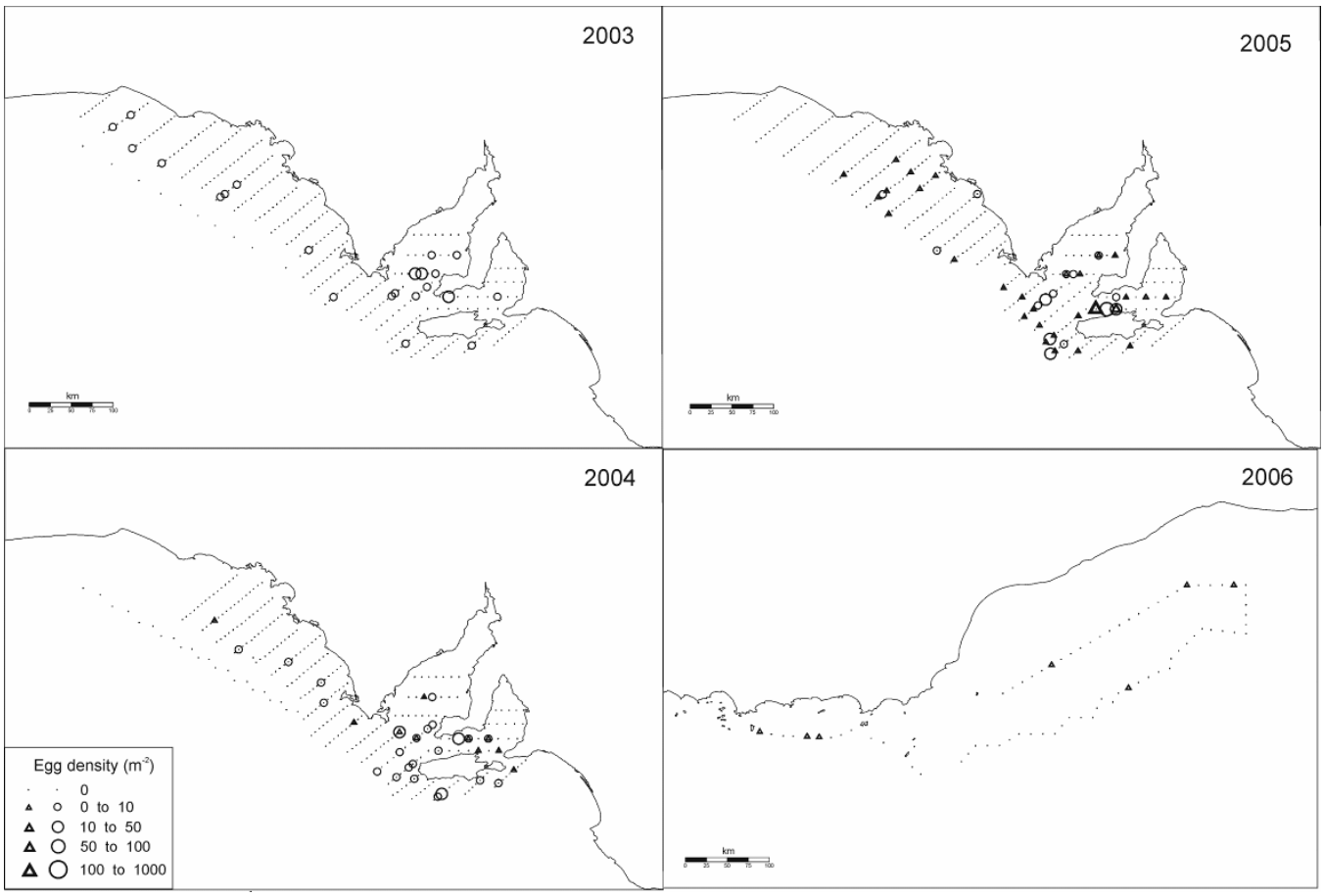

Figure 9.2. Density of *Trachurus* spp. larvae (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006. Circles and triangles represent samples collected with the CalVET and Bongo nets respectively.

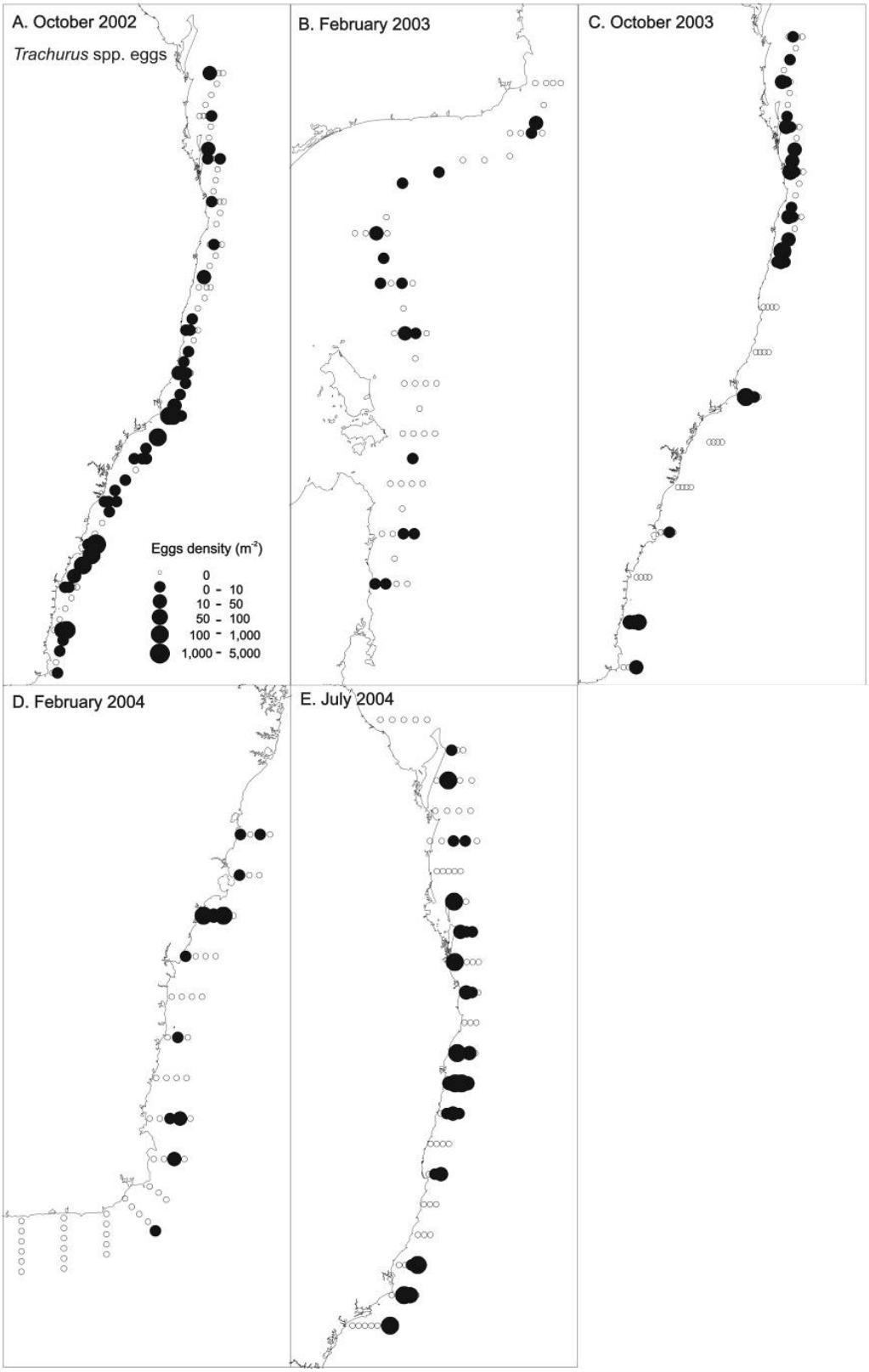

Figure 9.3. Density of *Trachurus* spp. eggs (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

Figure 9.4. Density of *Trachurus* spp. larvae (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

9.3.4 *Engraulis australis*

9.3.4.1 Occurrence

E. australis eggs and larvae occurred in all samples taken using bongo nets, but were not sorted and identified in samples taken with CalVET nets (Table 9.3). More than 19.0% of the total number of *E. australis* eggs collected from southern Australia (3,687) was obtained in each of the 2001, 2003, 2004 and 2005 surveys, but only 6.9% of the eggs collected were obtained in the 2002 survey (Table 9.3; Fig. 9.5). Similarly, over 18.0% of *E. australis* larvae collected from southern Australia (3,729) were obtained during the 2001, 2004 and 2005 surveys, whereas only 6.9% and 6.3% were collected from the 2002 and 2003 surveys respectively (Table 9.3; Fig. 9.6). Over 99% of the 303 *E. australis* eggs collected from eastern Australia were obtained during the surveys conducted in February 2003 and February 2004, with 73.6% being collected in February 2003 (Table 9.3, Fig.9.7). In contrast, only 52% of the 541 larvae were collected during these two surveys, and at least 6.7% of the total *E. australis* larvae collected from eastern Australia was obtained during each survey (Table 9.3, Fig. 9.8).

9.3.4.2 Abundance

Eggs

Mean density of *E. australis* eggs ranged between 8.1 and 20.8 eggs.m^{-2} per survey in southern Australia and 0.02 and 4.4 eggs.m^{-2} in eastern Australia (Table 9.3). The highest egg densities recorded in a single tow in southern and eastern Australia were 1,222.3 and 143.0 eggs.m^{-2}, respectively (Table 9.3).

Larvae

Mean larval density in surveys where *E. australis* eggs were collected and identified ranged between 6.3 and 30.3 larvae.m^{-2} in southern Australia and between 0.6 and 3.7 larvae.m^{-2} in eastern Australia (Table 9.3). The highest larval densities recorded in a single tow in southern and eastern Australia were 2196.0 and 62.1 larvae.m^{-2}, respectively (Table 9.3).

9.3.4.3 Distribution

Eggs

E. australis eggs occurred at between 13.4% and 35.6% of stations sampled between Encounter Bay and the Head of Bight using CalVET nets in 2001, 2002, 2003, 2004 and 2005 (Table 9.3, Fig. 9.5). In all these years, eggs were collected from the two gulfs, south of Kangaroo Island and from shelf waters of the GAB (Fig. 9.5). Few eggs were collected near the shelf-break (200 m

depth). Off eastern Australia, eggs of *E. australis* were collected from only 1.2 to 5.6% of stations sampled in February 2003, February 2004 and July 2004 (Table 9.3). Eggs were collected from a small number of stations off north-eastern Tasmania during February 2003, south-eastern Victoria during February 2004 and northern NSW in July 2004 (Fig. 9.7).

Larvae

Off southern Australia, *E. australis* larvae were collected from between 27.8% and 52.7% of stations, and at locations similar those where eggs were collected (i.e. the two gulfs, south of Kangaroo Island and from shelf waters of the GAB (Fig. 9.6). In contrast, *E. australis* larvae were distributed more broadly than the eggs off eastern Australia, with larvae occurring at 20.0% to 43.4% of stations sampled in each of the five surveys (Figs. 9.7 and 9.8). *E. australis* larvae were collected at sites between southern Queensland and eastern Tasmania during surveys conducted in February 2003 and 2004, October 2002 and 2003, and July 2004 (Fig. 9.8).

Table 9.3. Summary of the total number of eggs and larvae of *E. australis* collected in surveys conducted off southern and eastern Australia during 2001 to 2006, including the percentage of stations containing eggs/larvae and mean egg/larval density (positive stations only) for each survey. (NI = Not identified).

Survey	Net	n eggs	n larvae	% eggs	% larvae	# (%) Stations containing eggs	# (%) Stations containing larvae	Mean egg density (eggs.m^{-2} Range)	Mean larval density (larvae.m^{-2} Range)
Southern Australia									
1. Encounter Bay – Head of Bight (Feb. - Mar. 2001)	CalVET	930	1,179	25.2	31.6	96 (30.5)	166 (52.7)	20.8 (1.0-825.0)	26.3 (2.0-245.1)
2. Encounter Bay – Head of Bight (Feb. - Mar. 2002)	CalVET	254	257	6.9	6.9	44 (13.4)	84 (25.6)	8.1 (5.9-393.7)	7.7 (4.9-176.1)
3. Encounter Bay – Head of Bight (Feb. - Apr 2003)	CalVET	712	236	19.3	6.3	77 (24.1)	89 (27.8)	19.9 (6.7-1222.3)	6.3 (7.2-217.2)
4. Cape Northumberland – Head of Bight (Feb. 2003)	Bongo	NI	NI	-	-				
5. Encounter Bay – Head of Bight (Feb. - Mar. 2004)	CalVET	843	673	22.9	18.0	101 (35.6)	147 (51.8)	18.6 (4.9-1156.0)	13.8 (4.0-191.6)
	Bongo	NI	NI	-	-				
6. Encounter Bay – Head of Bight (Feb. - Mar. 2005)	CalVET	948	1,384	25.7	37.1	90 (26.9)	101 (30.2)	18.7 (3.0-614.7)	30.3 (4.1-2196.0)
	Bongo	NI	NI	-	-				
7. Archipelago of the Recherche (Feb. 2006)	Bongo	NI	NI	-	-				
	Total	**3,687**	**3,729**						
Eastern Australia									
1. Wide Bay – Cape Howe (Oct. 2002)	Bongo	0	141	0.0	26.1		29 (30.2)		0.86 (0.661-14.9)
2 Cape Howe – Four Mile Creek (Feb. 2003)	Bongo	223	212	73.6	39.2	3 (5.6)	15 (27.8)	4.4 (6.9-143.0)	3.7 (0.7-62.1)
3. Wide Bay – Cape Howe (Oct. 2003)	Bongo	0	82	0.0	15.2		16 (21)		0.64 (0.8-6.9)
4. Kiama – Cape Conran (Feb. 2004)	Bongo	78	70	25.7	12.9	3 (5)	26 (43.4)	1.2 (2.8-60.2)	1.2 (0.7-10.4)
5. Bundaberg – Newcastle (July 2004)	Bongo	2	36	0.7	6.7	1 (1.2)	17 (20)	0.02 (2-2)	1.3 (0.3-3.5)
	Total	**303**	**541**						
Grand total		**3,990**	**4,270**						

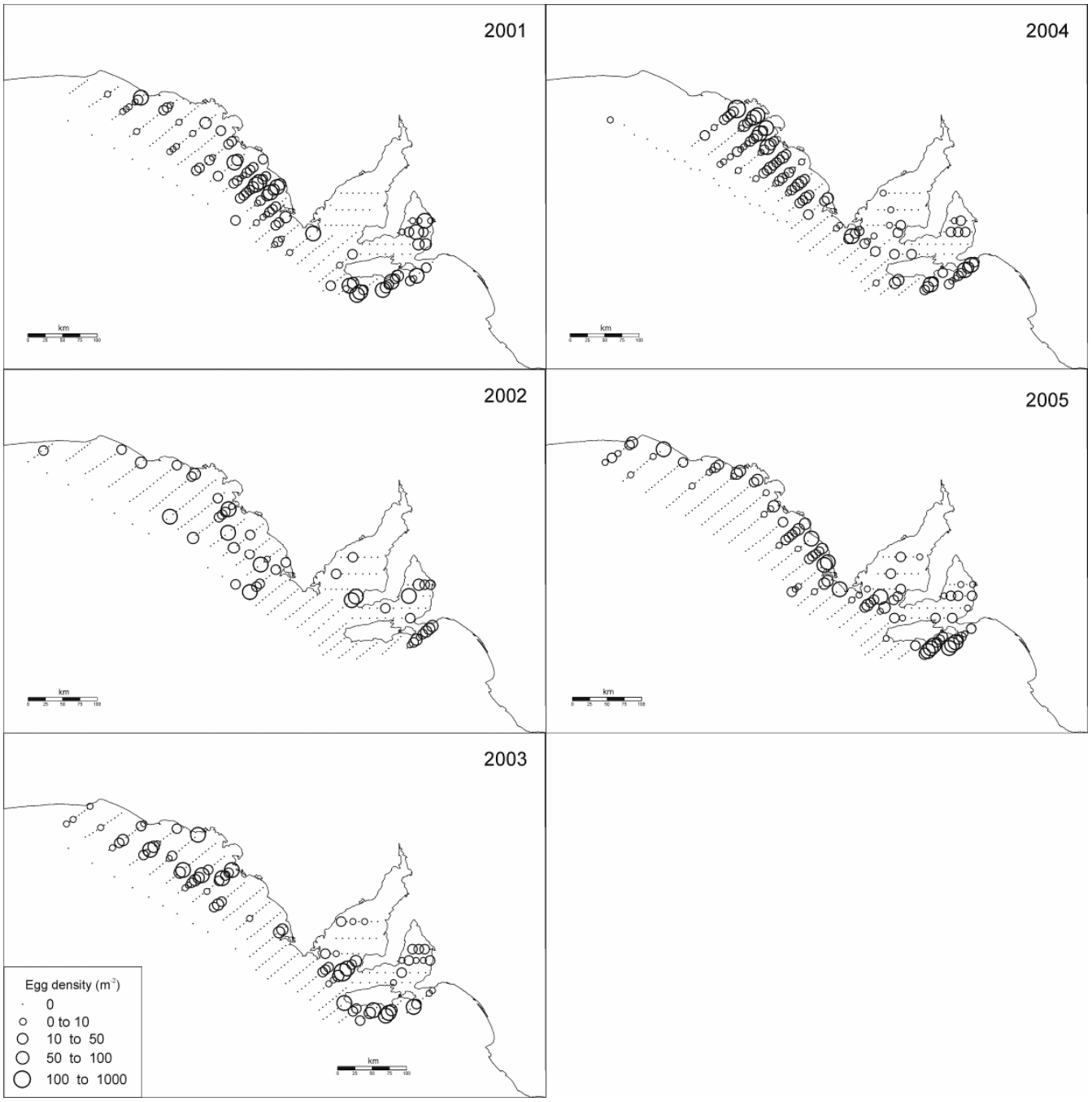

Figure 9.5. Density of *E. australis* eggs (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

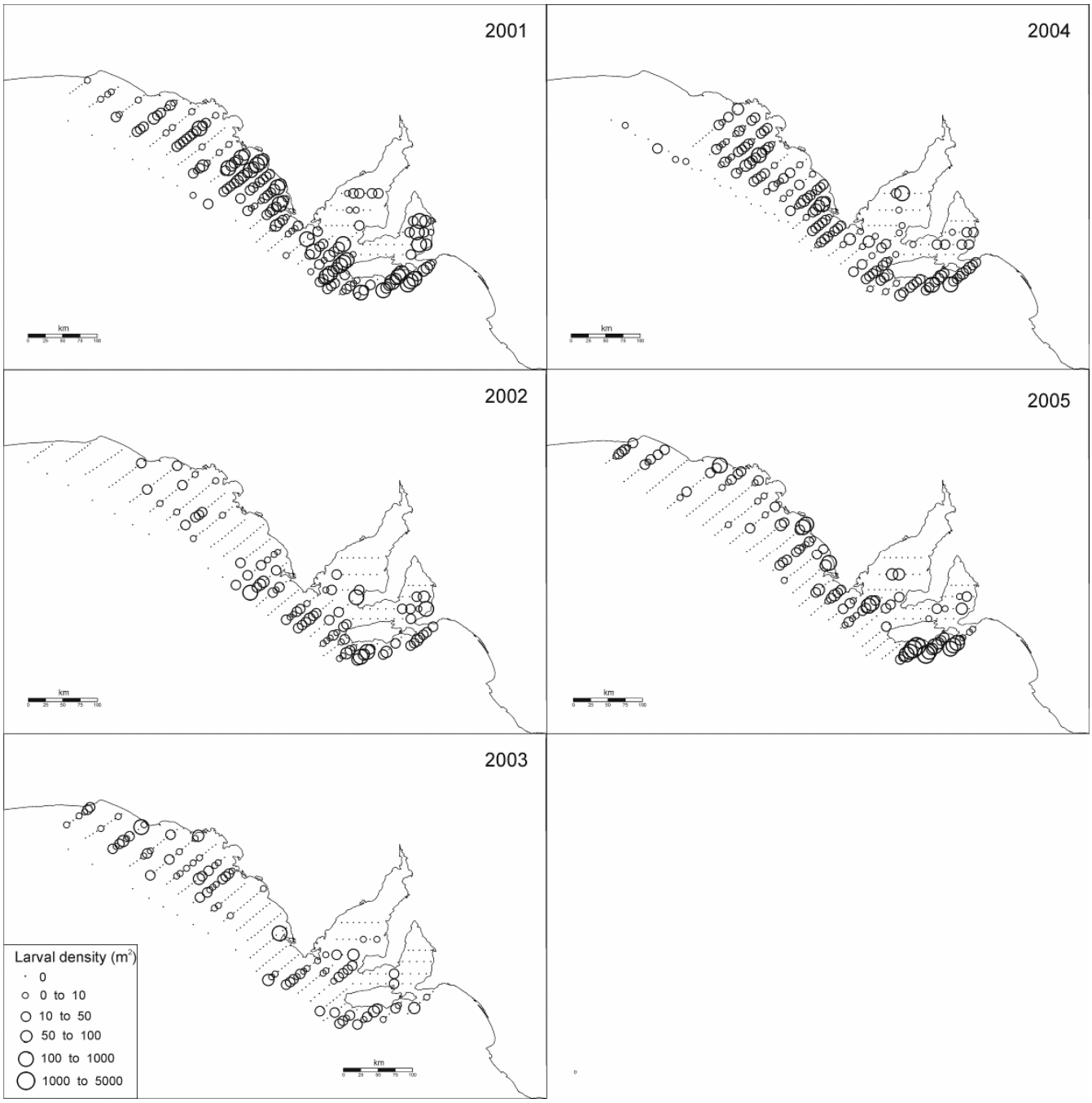

Figure 9.6. Density of *E. australis* larvae (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

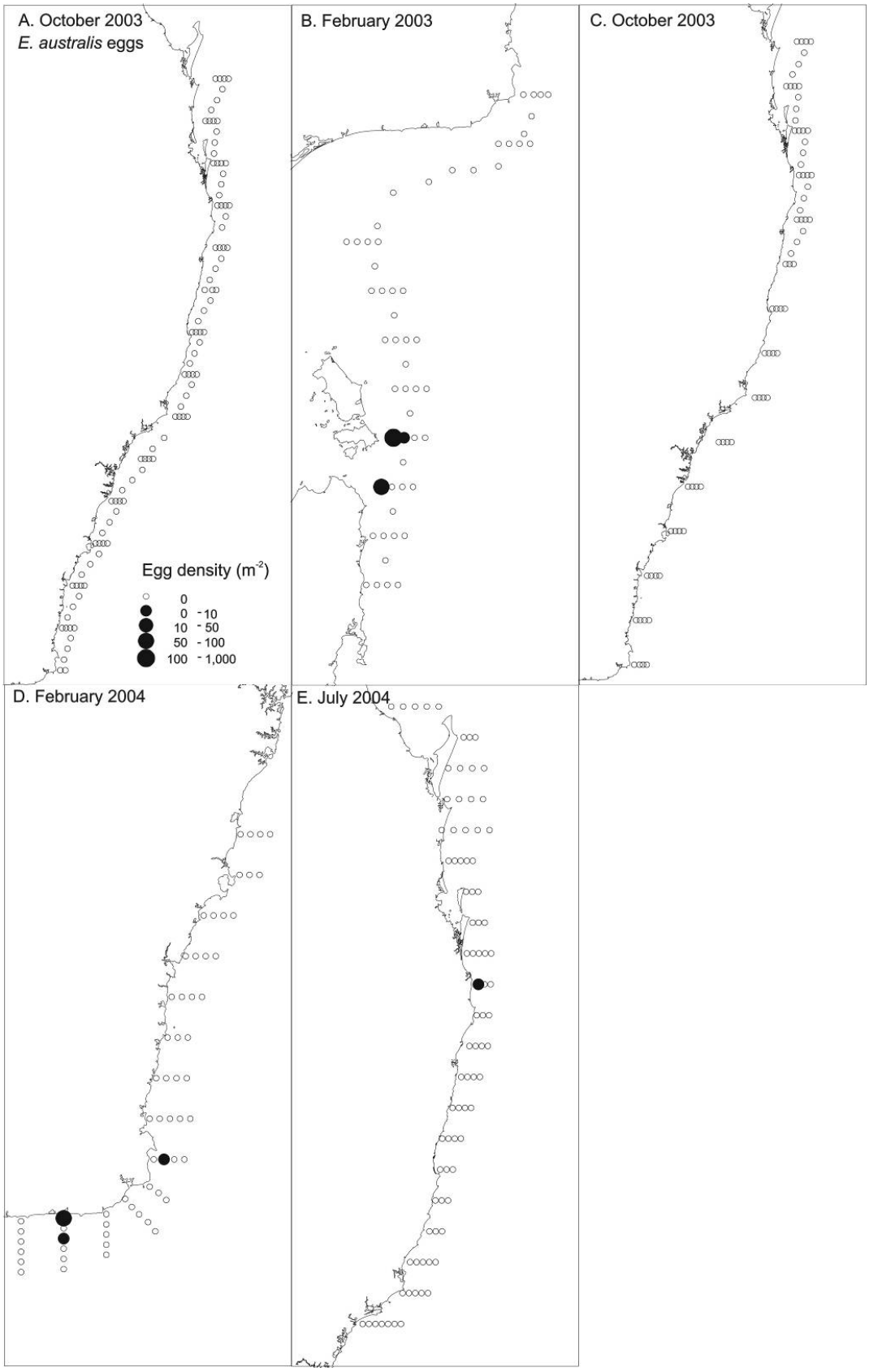

Figure 9.7. Density of *E. australis* eggs (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

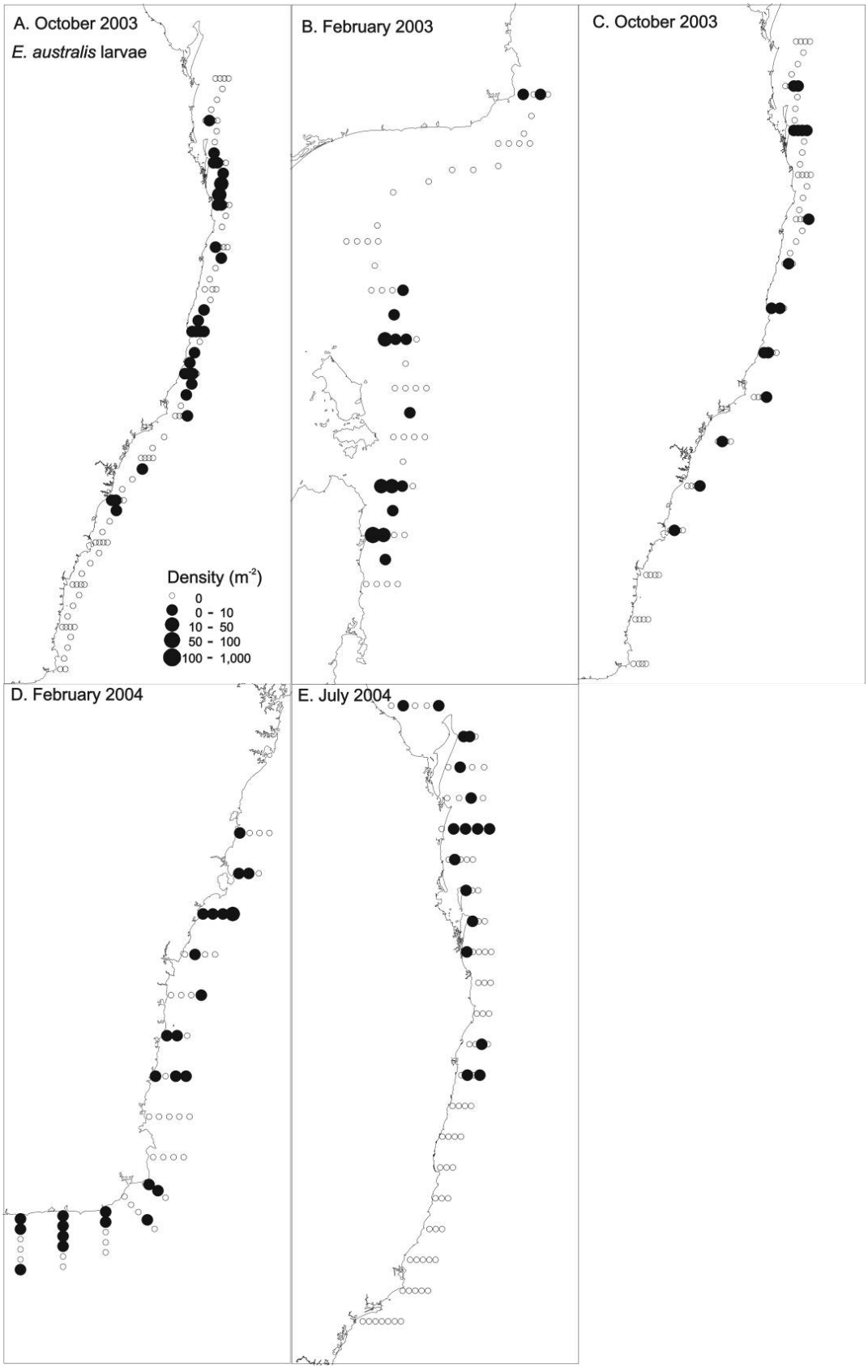

Figure 9.8. Density of *E. australis* larvae (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

9.3.5 *Sardinops sagax*

9.3.5.1 Occurrence

S. sagax eggs and larvae occurred in all samples that were taken off southern Australia using CalVET nets, but were not sorted and identified in samples taken with bongo nets (Table 9.4). More than 15.0% of the total number of *S. sagax* eggs collected from southern Australia (7,418) was obtained in each of the 2001, 2002, 2003, 2004 and 2005 surveys. Similarly, over 13.0% of the *S. sagax* larvae (9,762) were collected during each survey (Table 9.4, Figs. 9.9 and 9.10). Over 82% of the 3,244 *S. sagax* eggs and over 58% of the 4,089 larvae collected from eastern Australia were obtained during the July 2004 survey (Table 9.4, Figs. 9.11 and 9.12).

9.3.5.2 Abundance

Eggs

Mean density of *S. sagax e*ggs for a survey ranged between 27.0 and 55.6 eggs.m^{-2} in southern Australia and 0.06 and 27.8 eggs.m^{-2} in eastern Australia (Table 9.4). The highest egg densities recorded in a single tow in southern and eastern Australia were 3302.6 and 723.3 eggs.m^{-2}, respectively (Table 9.4).

Larvae

Mean larval density in surveys where *S. sagax* eggs were collected and identified ranged between 36.4 and 62.9 larvae.m^{-2} in southern Australia and between 0.7 and 23.3 larvae.m^{-2} in eastern Australia (Table 9.4). The highest larval densities recorded in southern and eastern Australia were 2033.2 and 386.4 larvae.m^{-2}, respectively (Table 9.4).

9.3.5.3 Distribution

Eggs

S. sagax eggs occurred at between 28.4% and 37.0% of stations sampled between Encounter Bay and the Head of Bight using CalVET nets in 2001, 2002, 2003, 2004 and 2005 (Table 9.4). In all these years, eggs were collected from the southern parts of the two gulfs, south of Kangaroo Island and from shelf waters of the GAB (Table 9.4, Fig. 9.9). In each year, relatively few eggs were collected directly south of the southern Eyre Peninsula or near shelf-break (200 m depth). Off eastern Australia, *S. sagax* eggs were collected from between 5.6 and 33.3% of stations sampled in February 2003 and 2004, October 2003 and July 2004 (Table 9.4). No *S. sagax* eggs were collected during the October 2002 survey. Eggs were collected from stations between Bundaberg and Newcastle in July 2004, at eight stations in southern Queensland and northern

NSW in October 2003 and off southern NSW, Victoria and eastern Tasmania in the two February surveys (Table 9.4, Fig. 9.11).

Larvae

Off southern Australia, *S. sagax* larvae were collected from between 45 and 63.0% of stations, and at locations similar to those where eggs were collected (i.e. the two gulfs, south of Kangaroo Island and from shelf waters of the GAB (Table 9.4, Fig. 9.10). In contrast off eastern Australia, *S. sagax* larvae were distributed more broadly than the eggs, with larvae occurring at between 16.7% and 72.9% of stations sampled in each of the five surveys (Table 9.4). *S. sagax* larvae were more prevalent a stations in the northern parts of the surveys conducted in October 2002 and 2003 and July 2004, than at stations located further south. *S. sagax* larvae were widespread in the surveys conducted between eastern Tasmania and southern NSW in February 2003 and 2004 (Table 9.4, Fig. 9.12).

Table 9.4. Summary of the total number of eggs and larvae of *S. sagax* collected in surveys conducted off southern and eastern Australia during 2001 to 2006, including the percentage of stations containing eggs/larvae and mean egg/larval density (positive stations only) for each survey. (NI = Not identified).

Survey	Net	n eggs	n larvae	% eggs	% larvae	# (%) Stations containing eggs	# (%) Stations containing larvae	Mean egg density (eggs.m^{-2} Range)	Mean larval density (larvae.m^{-2} Range)
Southern Australia									
1. Encounter Bay – Head of Bight (Feb. - Mar. 2001)	CalVET	1122	1996	15.1	20.6	98 (31.1)	160 (50.8)	31.5 (0.9-1250.7)	55.8 (2.9-1381.3)
2. Encounter Bay – Head of Bight (Feb. - Mar. 2002)	CalVET	1117	1331	15.1	13.8	93 (28.4)	148 (45.1)	34.5 (7.1-1830.1)	41.2 (6.7-2033.2)
3. Encounter Bay – Head of Bight (Feb. - Apr. 2003)	CalVET	1260	1470	17.0	15.2	97 (30.3)	144 (45)	33.9 (7.7-585.2)	39.0 (7.4-696.0)
4. Cape Northumberland – Head of Bight (Feb. 2003)	Bongo	NI	NI	-	-				
5. Encounter Bay – Head of Bight (Feb. - Mar 2004)	CalVET	2576	3040	34.7	31.4	105 (37.0)	179 (63)	55.6 (4.0-3302.6)	62.9 (4.9-595.8)
	Bongo	NI	NI	-	-				
6. Encounter Bay – Head of Bight (Feb. - Mar. 2005)	CalVET	1343	1835	18.1	19.0	110 (32.9)	180 (54.0)	27.0 (5.6-2320.9)	36.4 (4.3-877.0)
	Bongo	NI	NI	-	-				
7. Archipelago of the Recherche (Feb. 2006)	Bongo	NI	NI	-	-				
	Total	**7,418**	**9,672**						
Eastern Australia									
1. Wide Bay – Cape Howe (Oct. 2002)	Bongo	0	113	0.0	2.8		16 (16.7)		0.7 (0.3-13.6)
2 Cape Howe – Four Mile Creek (Feb 2003)	Bongo	87	86	2.7	2.1	3 (5.6)	15 (27.8)	1.5 (3.9-53.7)	1.3 (0.6-25.5)
3. Wide Bay – Cape Howe (Oct. 2003)	Bongo	8	488	0.2	11.9	8 (10.8)	35 (47.3)	0.06 (1.1-3.5)	5.4 (0.8-102.7)
4. Kiama – Cape Conran 5 (Feb. 2004)	Bongo	478	1,018	14.7	24.9	20 (33.3)	41 (68.3)	7.6 (1.2-98.2)	16.9 (0.6-116.2)
5. Bundaberg – Newcastle (July 2004)	Bongo	2,671	2,384	82.3	58.3	28 (32.9)	62 (72.9)	27.8 (0.6-723.3)	23.3 (0.6-368.4)
	Total	**3,244**	**4,089**						
Grand total		**10,662**	**13,761**						

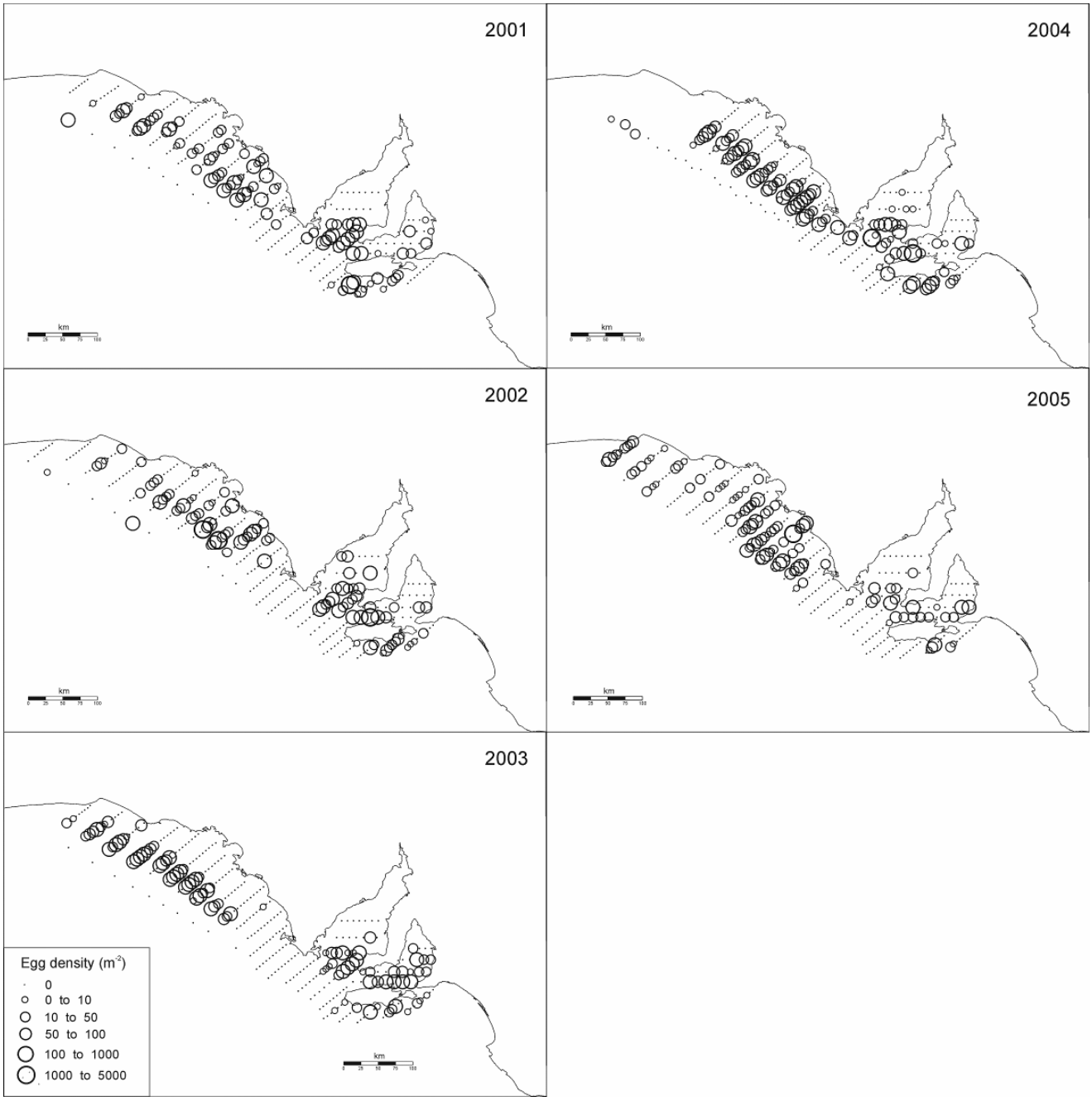

Figure 9.9. Density of *S. sagax* eggs (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

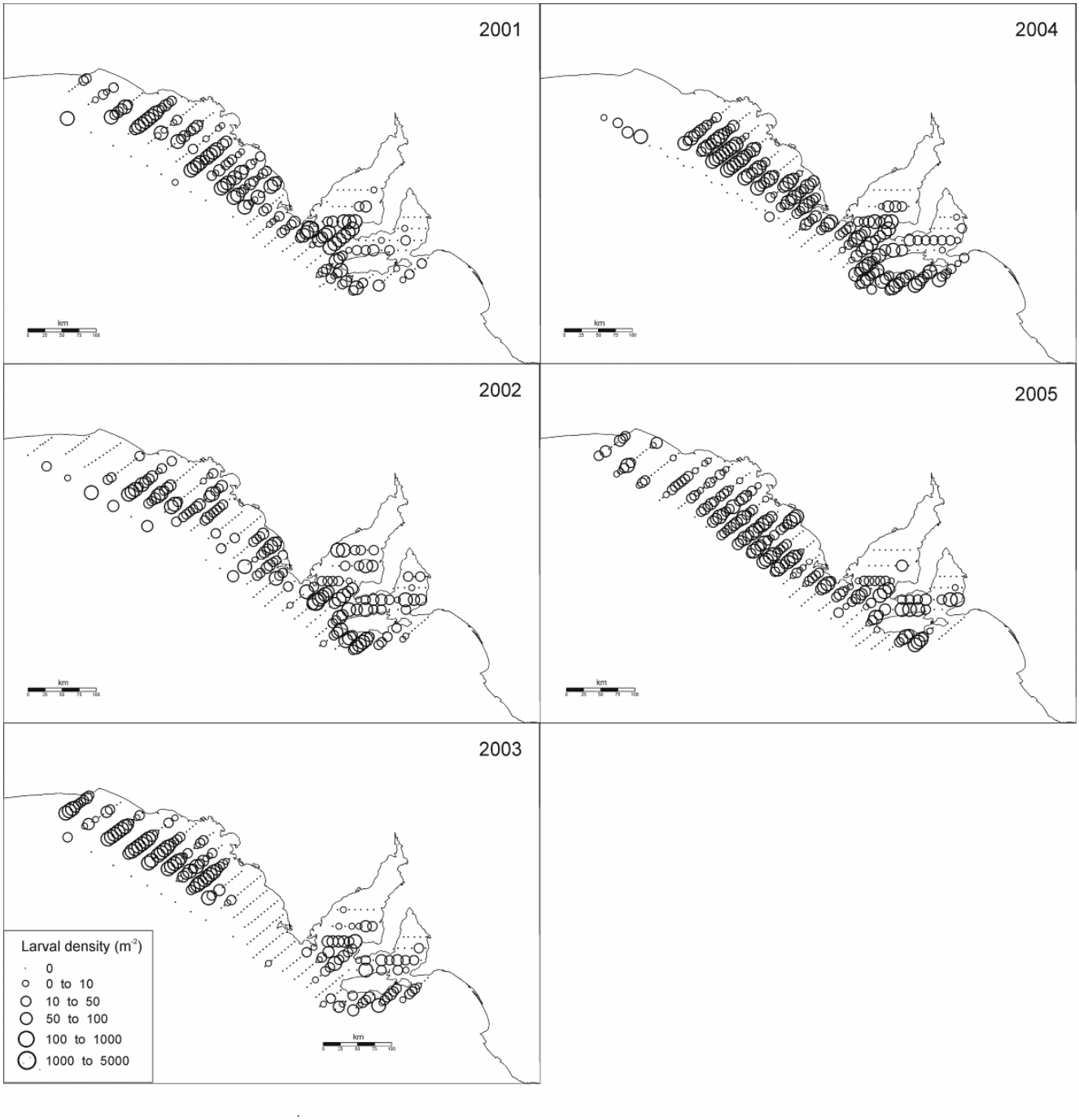

Figure 9.10. Density of *S. sagax* larvae (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

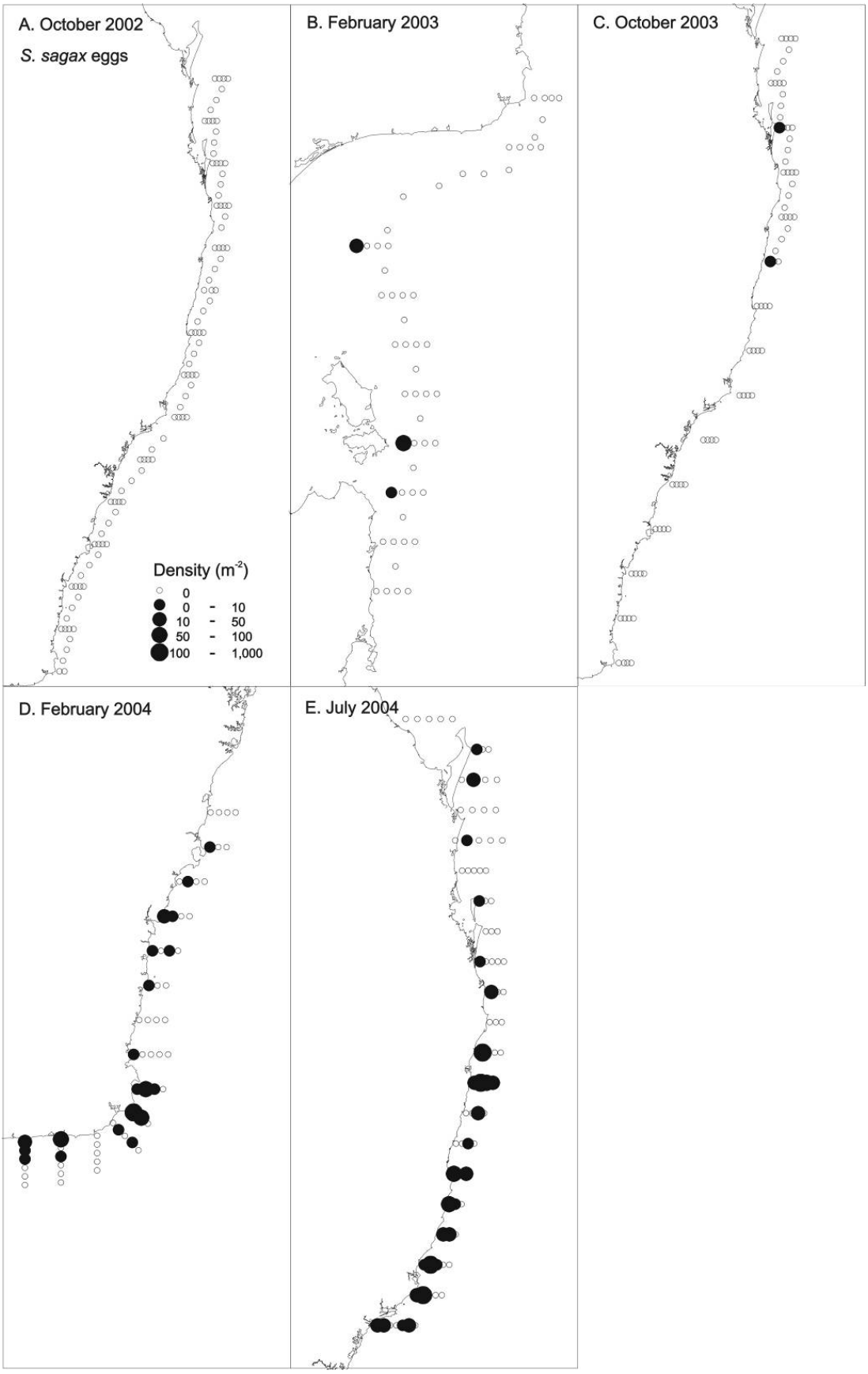

Figure 9.11. Density of *S. sagax* eggs (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

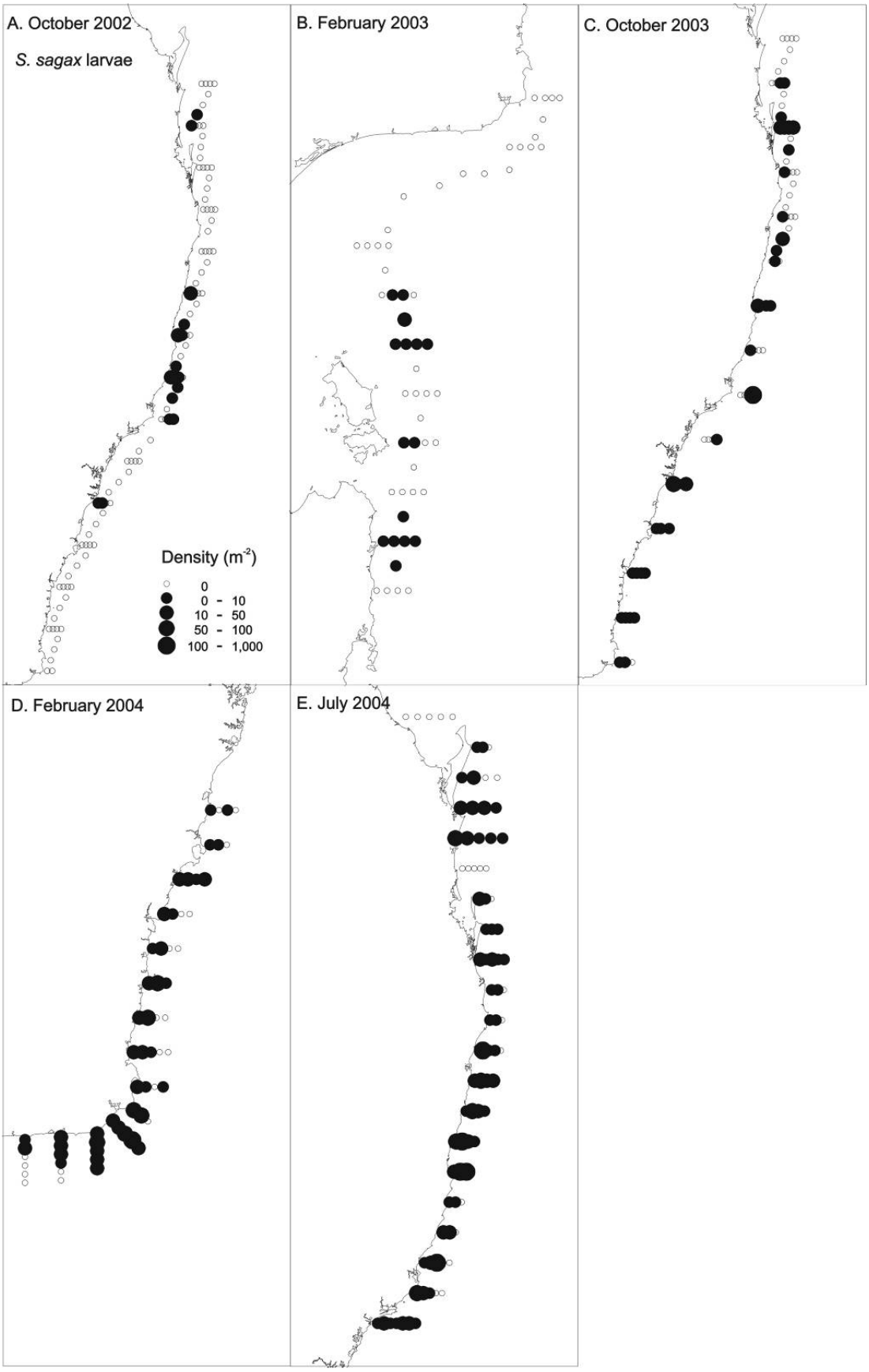

Figure 9.12. Density of *S. sagax* larvae (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

9.3.6 *Etrumeus teres*

9.3.6.1 Occurrence

E. teres eggs and larvae occurred in all samples that were taken off southern Australia using CalVET nets, but were not sorted and identified in samples taken with bongo nets (Table 9.5). More than 9.6% of the total number of *E. teres* eggs collected from southern Australia (260) was obtained in each of the five surveys (Table 9.5; Fig. 9.13). Similarly, over 10.0% of the *E. teres* larvae (95) were collected during each survey. *E. teres* eggs were not collected from eastern Australia during any survey (Table 9.5; Fig. 9.14). Over 94% of the 337 *E. teres* larvae collected from eastern Australia were obtained during the October 2002, October 2003 and July 2004 surveys (Table 9.5; Fig. 9.15).

9.3.6.2 Abundance

Eggs

Mean density of *E. teres* eggs for a survey ranged between 0.7 and 1.8 eggs.m^{-2} in southern Australia (Table 9.5). The highest egg densities recorded in a single tow in southern Australia was 74.5 eggs.m^{-2} (Table 9.5).

Larvae

Mean larval density in surveys where *E. teres* larvae were collected and identified ranged between 0.2 and 0.9 larvae.m^{-2} in southern Australia and between 0.3 and 1.3 larvae.m^{-2} in eastern Australia (Table 9.5). The highest larval densities recorded in southern and eastern Australia were 65.6 and 18.7 larvae.m^{-2}, respectively (Table 9.5).

9.3.6.3 Distribution

Eggs

E. teres eggs occurred at between 5.3% and 13.7% of stations sampled between Encounter Bay and the Head of Bight using CalVET nets in 2001, 2002, 2003, 2004 and 2005 (Table 9.5). Eggs were collected mainly from southern Spencer Gulf and mid-shelf waters of the GAB. Relatively few eggs were collected directly south of the southern Eyre Peninsula (Fig. 9.13).

Larvae

Off southern Australia, *E. teres* larvae were collected from between 2.1 and 6.9% of stations, and at locations similar to those where eggs were collected (Table 9.5). *E. teres* larvae were collected from between 18.8 and 49.4% of stations sampled off eastern Australia in October 2002,

October 2003 and July 2004, but only 10% of stations sampled in February 2004 and none of the stations sampled in February 2003 (Table 9.5, Fig. 9.14). Most *E. teres* larvae were collected from stations located between southern Queensland and northern NSW (Table 9.5, Fig. 9.15).

Table 9.5. Summary of total number of eggs and larvae of *E. teres* spp. collected in surveys conducted off southern and eastern Australia during 2001 to 2006. (NI = Not identified).

Survey	Net	n eggs	n larvae	% eggs	% larvae	# (%) Stations containing eggs	# (%) Stations containing larvae	Mean egg abundance (eggs.m^{-2} Range)	Mean larval abundance (larvae.m^{-2} Range)
Southern Australia									
1. Encounter Bay – Head of Bight (Feb. – Mar. 2001)	CalVET	28	10	10.8	10.5	17 (5.4)	10 (3.2)	0.8 (7.6-65.9)	0.2 (2.0-10.0)
2. Encounter Bay – Head of Bight (Feb. – Mar. 2002)	CalVET	46	30	17.7	31.6	35 (10.7)	21 (6.9)	1.4 (8.1-40.4)	0.9 (8.3-33.2)
3. Encounter Bay – Head of Bight (Feb. – Apr. 2003)	CalVET	25	16	9.6	16.8	17 (5.3)	12 (3.8)	0.7 (6.7-27.9)	0.5 (8.6-28.2)
4. Cape Northumberland – Head of Bight (Feb. 2003)	Bongo	NI	NI	-	-				
5. Encounter Bay – Head of Bight (Feb. - Mar 2004)	CalVET	83	19	31.9	20.0	39 (13.7)	6 (2.1)	1.8 (3.6-74.5)	0.4 (4.9-65.6)
	Bongo	NI	NI	-	-				
6. Encounter Bay – Head of Bight (Feb. - Mar. 2005)	CalVET	78	20	30.0	21.1	41 (12.3)	15 (4.5)	1.5 (5.5-43.1)	0.4 (5.2-28.9)
	Bongo	NI	NI	-	-				
7. Archipelago of the Recherche (Feb 2006)	Bongo	NI	NI	-	-				
	Total	**260**	**95**						
Eastern Australia									
1. Wide Bay – Cape Howe (Oct. 2002)	Bongo	NI	54	-	16.0		18 (18.8)		0.3 (0.2-5.9)
2 Cape Howe – Four Mile Creek (Feb. 2003)	Bongo	NI	0	-	0.0		0		0
3. Wide Bay – Cape Howe (Oct. 2003)	Bongo	NI	127	-	37.7		21 (28.4)		1.2 (0.5-18.7)
4. Kiama – Cape Conran (Feb. 2004)	Bongo	NI	20	-	5.9		6 (10)		0.4 (0.6-9.3)
5. Bundaberg – Newcastle (July 2004)	Bongo	NI	136	-	40.4		42 (49.4)		1.3 (0.5-18.0)
	Total	**0**	**337**						
Grand total		**260**	**432**						

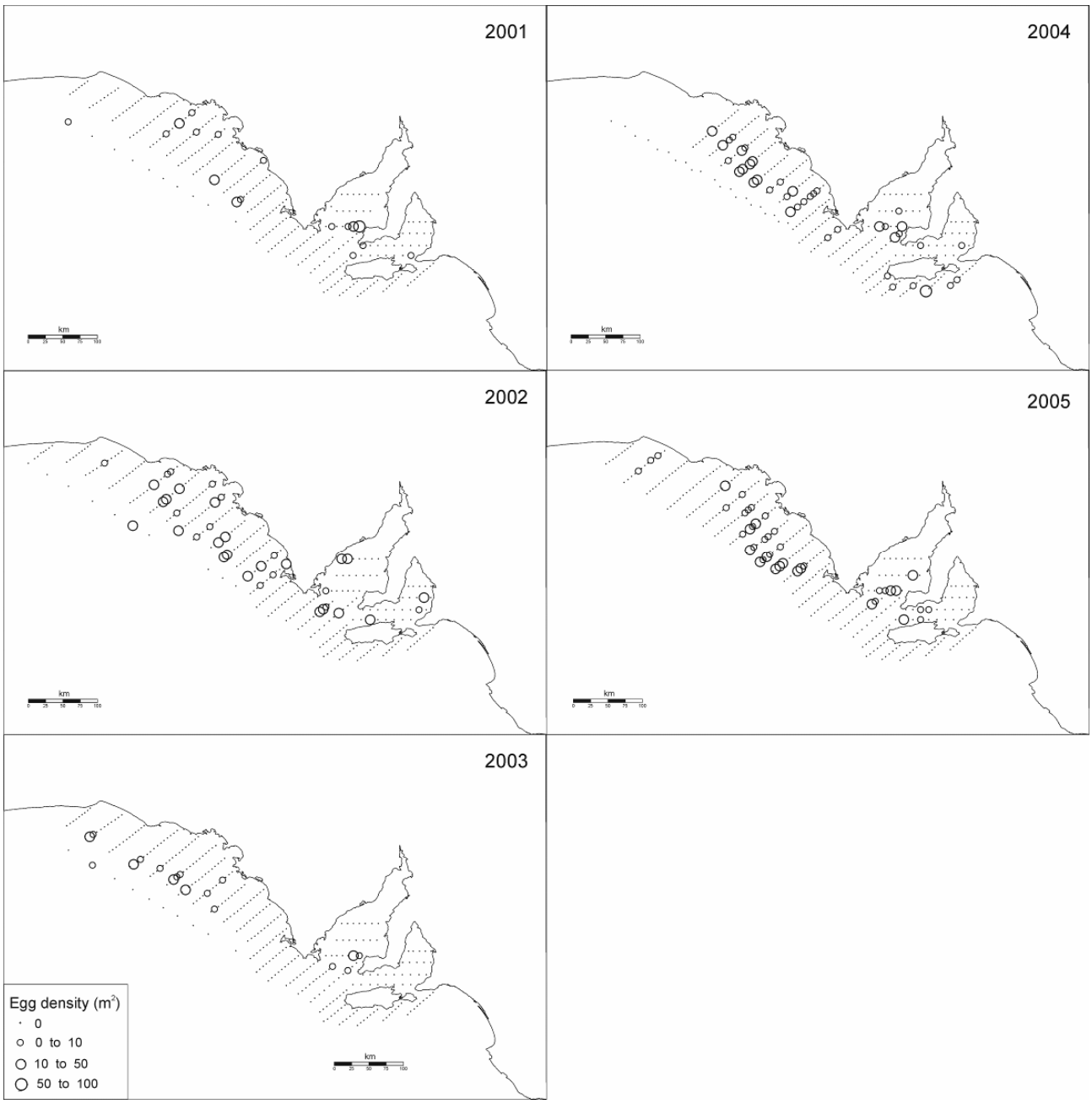

Figure 9.13. Density of *E. teres* eggs (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

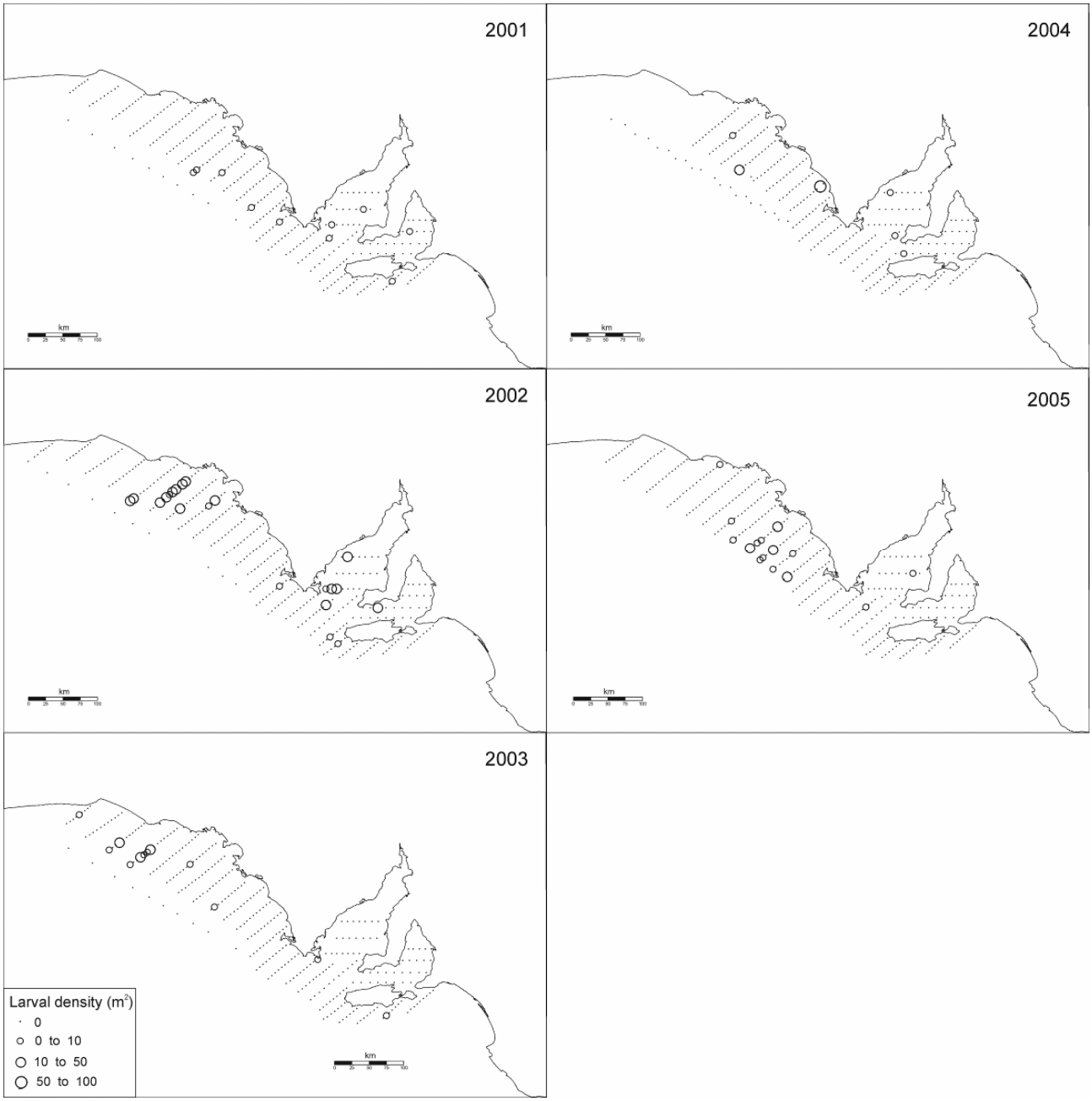

Figure 9.14. Density of *E. teres* larvae (number.m^{-2}) at stations sampled off southern Australia between 2003 and 2006.

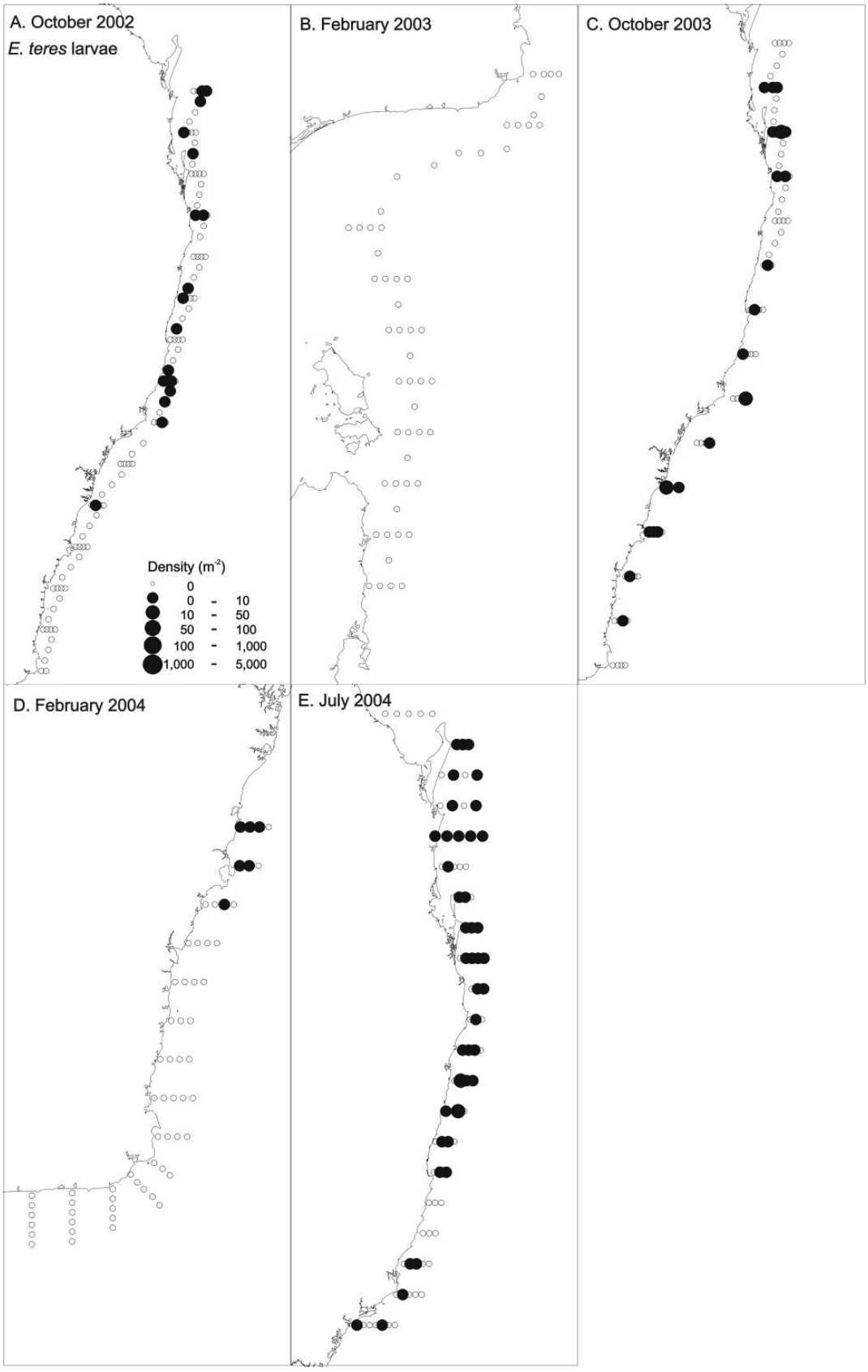

Figure 9.15. Density of *E. teres* larvae (number.m^{-2}) at stations sampled off eastern Australia between October 2002 and July 2004.

9.4 Discussion

9.4.1 *Trachurus* spp.

The reason for the large difference in the proportion of eggs and larvae of *Trachurus spp.* collected in ichthyoplankton samples from southern (6.5% eggs, 2.0% larvae) and eastern Australia (76.9% eggs, 56.5% larvae) is unclear. Reproductively active jack mackerel (*T. declivus*) have been collected between September and January in trawl surveys in the GAB (Stevens *et al.* 1984), so the surveys off southern Australia, which were conducted during February and March, may not have coincided with peak spawning season. Alternatively, *Trachurus spp.* may comprise a smaller proportion of the pelagic fish assemblage off southern Australia than it does off eastern Australia.

Eggs and larvae of *Trachurus spp.* were abundant in samples taken off eastern Australia in October and July, but less abundant in the surveys conducted further south during February, suggesting that the main spawning season of *Trachurus spp.* off eastern Australia may be winter and spring, at least in the northern portion of the eastern Australian study area. However, the spawning season of *Trachurus spp.* off eastern Australia could vary with latitude, occurring during summer-autumn in the south and during winter and spring in the north. Importantly, yellowtail scad *T. novaezelandiae*, occurs mainly in waters of southern Queensland and northern NSW, whereas jack mackerel *T. declivis* occurs further south off southern NSW, Victoria and Tasmania (Kailola *et al.* 1993). Hence, eggs and larvae collected in the northern part of the study area during winter and spring may belong mainly to *T. novaezelandiae*, whereas the eggs collected further south may belong mainly to *T. declivis*. This interpretation is consistent with the findings of previous studies that suggest *T. declivis* spawns during summer off eastern Tasmania (Marshall *et al.* 1993; Jordan 1994; Jordan *et al.* 1995). Preliminary molecular analysis (mtDNA) of early preflexion mackerel larvae also support this proposition and suggest that the distributions of the two species may overlap off the coast of central NSW (Neira, unpublished data). More detailed genetic studies are required to test this hypothesis.

Comparison of the distribution of the eggs and larvae of *Trachurus spp.* off southern and eastern Australia suggests that rates of dispersal/or and mortality may vary between the two regions. *Trachurus spp.* larvae were found at fewer stations than eggs off southern Australia (i.e. eggs at 5.1-28.3% of stations, larvae at 4.5-19.7%), whereas larvae were more widely dispersed than eggs off eastern Australia (eggs at 20.0-50% of stations, larvae at 44.0-85.0%). This difference could reflect high levels of dispersal off eastern Australia, resulting from the high current speeds in that

region, especially in the Eastern Australian Current (see chapter 8 of the present report). In this regard it is notable that larvae off eastern Australia were generally found further south (down current) than eggs, whereas off southern Australia eggs and larvae were generally found in the same locations (see Figs. 9.1 – 9.4). However, approximately three times more eggs (793) than larvae (275) were collected off southern Australia, compared with only two times as many eggs (11,776) than larvae (6,464) off eastern Australia, which suggests that egg and larval mortality rates may have been higher off southern Australia than eastern Australia during the survey period.

9.4.2 *Engraulis australis*

The reasons for the large disparity in the numbers of *E. australis* eggs and larvae collected off southern (3,687 eggs, 3,729 larvae) and eastern Australia (303 eggs, 541 larvae) are not clear. However, this disparity is due, at least in part, to the large difference in the number of stations sampled off southern and eastern Australia during this study (i.e. total of 1571 stations off southern Australia versus 367 stations off eastern Australia). It is also clear that the surveys off southern Australia were conducted during the peak spawning season of this species (e.g. Ward *et al.* 2001b), whereas the surveys conducted north of Cape Howe during October 2002 and 2003 and July 2004 may not have coincided with the peak spawning season. For example, Ward *et al.* (2003b) provided evidence to suggest that *E. australis* spawns mainly during February and March in southern Queensland, which coincides with the spawning season of this species in temperate Australian waters (Hoedt and Dimmlich 1995; Ward *et al.* 2001a; Dimmlich *et al.* 2004; Dimmlich and Ward 2006).

As *E. australis* appears to spawn during summer and autumn in southern and eastern Australia, it seems unlikely that sampling outside the spawning season explains the relative scarcity of *E. australis* eggs in surveys conducted between southern NSW and eastern Tasmania during February 2003 and 2004. Several studies have suggested that off eastern Australia *E. australis* spawns mainly in estuarine and inshore marine environments (Blackburn 1950; Miskiewicz 1987; Gray 1995; Ward *et al.* 2003b). This contrasts with the situation off southern Australia, where *E. australis* spawns extensively in shelf waters and the two gulfs (e.g. Ward *et al.* 2001a; Dimmlich *et al.* 2004). The current regime off eastern Australia is much stronger than southern Australia and is reflected in the contrasting spawning locations of *E. australis* in the two regions. Our data supports the hypothesis that off eastern Australia, *E. australis* spawns in estuaries to reduce the rates of transport of eggs and larvae southward by the EAC (see Ward *et al.* 2003b).

The broad scattering of the larvae of *E. australis* compared to eggs off eastern Australia contrasts the situation off southern Australia where the eggs and larvae of *E. australis* are found in similar locations (and at similar abundances). These different patterns in the two locations, which are similar to those observed for *Trachurus* spp. appear to provide further support for the hypothesis that the concentration of spawning by *E. australis* in inshore waters of eastern Australia may be related to the strong influence of the EAC on the dispersal of progeny.

9.4.3 *Sardinops sagax*

The dominance of *S. sagax* in samples collected using CalVET nets off southern Australia, reflects the fact that these surveys were designed to support stock assessment of sardine using the DEPM, and are conducted in the main spawning locations during the main spawning season (e.g. Ward *et al.* 2001b; Ward and Staunton-Smith 2002). This finding also reflects the high abundance of *S. sagax* in waters off southern Australia. The stock assessment report for 2006 suggests that the spawning biomass of *S. sagax* off South Australia was approximately 229,000 t (Ward *et al.* 2006).

The high abundances of *S. sagax* eggs and larvae recorded in surveys conducted in southern Queensland and northern NSW during July 2004 are also consistent with the results of previous surveys, which suggest that *S. sagax* spawns during winter and early spring in this area (e.g. Ward *et al.* 2003b). The absence of eggs in the surveys conducted in October 2002 and 2003 is notable and suggests that spawning in this region may be completed by the middle of spring. In addition, the relatively large numbers of eggs and larvae collected off southern NSW and Victoria in February 2004 is consistent with the findings of other studies (Blackburn 1941; Blackburn 1949; Miskiewicz 1987; Gray *et al.* 1992; Gray 1993) and suggests that the spawning season of this species in this area coincides with that in other temperate Australian locations, such as South Australia (Ward *et al.* 2001b; Ward and Staunton-Smith 2002).

9.4.4 *Etrumeus teres*

Previous Australian studies have suggested that the location and timing of spawning by *E. teres* may coincide with spawning by *S. sagax*. For example, Ward *et al.* (2003b) collected eggs and larvae of *E. teres* at the same location (southern Queensland) and time (July to November) that *S. sagax* eggs and larvae were collected. During the present study, eggs and larvae of *E. teres* were also collected (albeit in relatively small numbers) in samples from southern Australia that

contained *S. sagax* eggs and larvae. Reproductive information obtained from adult *E. teres* from southern Australia suggests that the spawning season occurs during summer-autumn (Ward unpublished data). It is likely that the small number of *E. teres* eggs and larvae collected off southern Australia, and the small number of larvae collected off eastern Australia, reflects the relatively low abundance of this species in these two regions.

9.5 Conclusions

The present project (FRDC 2002/061) did not include funds for the collection, sorting or identification of the eggs and larvae of *Trachurus* spp., *E. australis*, *S. sagax* and *E. teres*. Hence, the surveys were not designed to maximise the quantity or quality of information obtained on these species and there were insufficient resources to support either (i) the enumeration of eggs and larvae in all of the samples that were collected or (ii) the detailed quantitative analyses of these data. Hence, the information provided for these species in this chapter should be viewed with some caution. The lack of species-specific data on the eggs and larvae of *T. declivis* and *T. novaezelandiae* is a particularly important constraint that must be considered when this information is interpreted. Despite these limitations this chapter provides information that is useful for evaluating the suitability of the DEPM for stock assessment of these species. Previous studies have shown that the DEPM is suitable for species, such as *S. sagax*, which have distinctive eggs. It is notable that data obtained in the present study were used to provide a preliminary stock assessment of sardine off eastern Australia (See Chapter 10 Appendices). An evaluation of the DEPM for investigating the spawning biomass of *E. australis,* which also has distinctive eggs, is currently underway off southern Australia and preliminary findings are encouraging (Ward unpublished data). However, results presented here suggest that the use of the DEPM to estimate the spawning biomass of *E. australis* off eastern Australia may be complicated by the inshore spawning habit of this species in this location. This technique may be applicable to *T. declivis* and/or *T. novaezelandiae* but effective molecular techniques for differentiating between the eggs of these two species must be developed before the application of the DEPM is examined further for these species.

9.6 Acknowledgements

The authors are grateful to people who provided assistance during the ichthyoplankton surveys, especially the masters and crews of the RV *Ngerin* and FTV *Bluefin*, students of the Australian Maritime College (AMC) and staff of the South Australian Research and Development Institute (SARDI) and NSW Department of Primary Industries (DPI). The in-kind contributions of the AMC, SARDI, NSW DPI and TAFI are also acknowledged. We thank Dr Jeremy Lyle (TAFI), Greg Ferguson and Dr Scoresby Shepherd for comments on drafts of the chapter.

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10. Developing and evaluating the use of the Daily Egg Production Method to estimate the spawning biomass of blue mackerel *Scomber australasicus* off southern and eastern Australia

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Objective: To develop and evaluate methods for estimating the spawning biomass of blue mackerel in southern Australia.

Summary: This study develops and evaluates the use of the Daily Egg Production Method (DEPM) to estimate the spawning biomass of *S. australasicus* off southern and eastern Australia. Egg data used in this evaluation were obtained from ichythoplankton surveys conducted using Californian Vertical Egg Tow (CalVET) and bongo nets off southern Australia in February-March 2005, and a bongo net off eastern Australia in October 2003 and July 2004. Mean daily egg production was calculated using mean egg densities and assumed mortality rates of 0.1 to 0.5 per day. Higher estimates of mean daily egg production for southern Australia were obtained using data obtained from CalVET nets (12.99 to 18.62 eggs per m^2 per day) than bongo nets (9.94 to 14.25 eggs per m^2 per day). Estimates of mean daily egg production off eastern Australia ranged from 23.01 to 33.00 eggs per m^2 per day in 2003 and 6.82 to 9.78 eggs per m^2 per day in 2004. Estimates of spawning area for southern Australia were almost three times higher using bongo nets (34,895–36,370 km^2) than CalVET nets (11,840–11,898 km^2). This is because at least one egg was found in 35.5% of samples obtained using the bongo net compared with 10.5% of those taken with the CalVET net, presumably because bongo nets sample more water than CalVET nets. Estimates of spawning area for southern Australia obtained using data from the bongo nets and standard griding and voronoi natural neighbour (VNN) methods were similar (34,895-36,370 km^2). The sampling design used in eastern Australia in October 2003 was not suitable for estimating spawning area. Estimates of spawning area for eastern Australia during July 2004 obtained using uniform sized grids, contiguous grids and VNN methods ranged from 17,503 to 21,019 km^2. Numerous samples of spawning adults were collected from southern Australia. These samples appeared to provide robust mean estimates of all adult reproductive parameters: female weight (452 g); sex ratio (0.46); batch fecundity (52,182 eggs); and spawning

fraction (0.14). Few samples of spawning adults were collected off eastern Australia and estimates of adult reproductive parameters from southern Australia were used to calculate spawning biomass for eastern Australia. Preliminary estimates of the spawning biomass of *S. australasicus* off southern and eastern Australia calculated from the 'best' estimate of each parameter were 56,228 t and 23,009 t, respectively. Application of reproductive data from eastern Australia (except spawning fraction), resulted in a best estimate of spawning biomass for eastern Australia of 29,578 t. 'Minimum' and 'maximum' estimates ranged from 10,993 to 293,456 t in southern Australia and 7,565 to 116,395 t in eastern Australia, respectively. The best estimates of spawning biomass are conservative because the estimates of egg production on which they are based were obtained using the method of McGarvey and Kinloch (2001), which typically provides lower estimates than the internationally accepted method (i.e. linear version of exponential egg mortality model with application of a bias correction factor). In addition, there is evidence to suggest that spawning occurred outside the area surveyed in southern Australia (i.e. in the western GAB). Spawning may also have occurred outside the survey area off eastern Australia. The survey conducted off eastern Australia in July 2004 may have also been conducted outside the peak spawning season. Much higher estimates of egg production (23.01–33.00 eggs per m^2 per day) were obtained in October 2003 than July 2004, however spawning biomass could not be estimated for the 2003 survey due to limitations in the sampling design (non-parallel transects). If egg production estimates for October 2003 were used to calculate spawning biomass for July 2004, the best estimate of spawning biomass for eastern Australia would have been 77,648 t. Previous studies have shown that egg production and spawning area are key determinants of spawning biomass. However, sensitivity analyses conducted in the present study suggest that our estimates of spawning biomass were strongly affected by uncertainty in estimates of spawning fraction. Most estimates of spawning biomass in the areas surveyed off southern and eastern Australia, based on the conservative methods that were used to obtain estimates of egg production, lie within the range of 45,000–70,000 t and 20,000–60,000 t., respectively. Our results suggest that the DEPM is a suitable tool for assessment of Australia's *S. australasicus* populations. However, some technical refinements are required to maximize the reliability of the estimates of spawning biomass that are obtained using this method. The highest immediate priorities for additional research are: 1) developing cost-effective and reliable genetic techniques for identifying early stage eggs; 2) conducting the experiments required to develop temperature-egg development keys for this species; 3) establishing locations/methods for collecting samples needed to estimate the adult reproductive parameters of *S. australasicus* in eastern Australia; and 4) measuring the degeneration rates of post-ovulatory follicles to ensure that estimates of spawning fraction are robust.

10.1 Introduction

The Daily Egg Production Method (DEPM) is widely acknowledged to be a suitable technique for stock assessment of small pelagic fishes, especially anchovies *Engraulis* spp, and sardine *Sardinops sagax* (Stratoudakis *et al.* 2006). In Australia, the method has been applied successfully to sardine off Western Australia (Fletcher *et al.* 1996; Gaughan *et al.* 2004), South Australia (Ward and McLeay 1998; Ward *et al.* 2001b) and Queensland (Staunton-Smith and Ward 2000) and is currently being assessed as a tool for estimating the spawning biomass of redbait *Emmelichthys nitidus*, off Tasmania (Dr Jeremy Lyle TAFI, pers. comm.). The DEPM has been evaluated and used for stock assessment of the morphologically and genetically similar chub mackerel *Scomber japonicus* in Japan (Watanabe *et al.* 1999). Before the present study, the suitability of the DEPM for stock assessment of *Scomber australasicus*, in temperate Australia had not been assessed.

The central tenant of the DEPM is that spawning biomass can be calculated from the product of the estimates of 1) the mean number of pelagic eggs produced per day throughout the spawning area, i.e. total daily egg production and 2) the mean number of eggs produced per unit mass of adult fish, i.e. mean daily fecundity (Parker 1980; Parker 1985). Total daily egg production is the product of mean daily egg production (P_0) and total spawning area (A). Mean daily fecundity is calculated by dividing mean female weight (W) by the product of mean sex ratio by weight (R), mean batch fecundity (number of oocytes in a batch, F) and mean spawning fraction (proportion of mature females spawning each day/night S). Hence, spawning biomass (SB) is calculated according to the equation:

$$SB = \frac{P_0 \cdot A \cdot W}{R \cdot F \cdot S} \qquad \text{Eq. 1}$$

The DEPM can be applied to fishes that spawn multiple batches of pelagic eggs during an extended spawning season (e.g. Lasker 1985). Data used to estimate the DEPM parameters are typically obtained during fishery-independent surveys of populations or sub-populations during the spawning season. The key assumptions of the DEPM are that: the survey is conducted during the main (preferably the peak) spawning season; 2) the entire spawning area is sampled during the survey; 3) eggs are sampled without loss and identified without error; 4) levels of egg production and mortality are consistent across the spawning area; and 5) representative samples of spawning adults are collected during the survey period (Lasker 1985; Stratoudakis *et al.* 2006). The degree to which these assumptions are met in particular situations affects the accuracy and precision of estimates of spawning biomass. Some assumptions, especially that the levels of daily egg

production and mortality are consistent across the spawning area, are rarely, if ever, fully upheld and reduce confidence in the estimates of spawning biomass obtained using the DEPM. Stratoudakis *et al.* (2006) note that "Although recent methodological elements may … improve the precision of DEPM estimates …, it is unlikely that the DEPM will ever become a very precise method. Depending on resource management needs and alternative options for fisheries-independent estimation of biomass, the above limitation may be considered crucial or secondary … in southern and eastern Australia, [where alternative methods for estimation of sardine biomass are not currently available], DEPM is currently considered to provide the best available means to monitor the population … (Ward *et al.* 2001a; Gaughan *et al.* 2004)."

Estimates of each DEPM parameter, especially mean daily egg production, typically have high levels of variance (Stratoudakis *et al.* 2006). This factor combined with the multiplicative nature of the model means that estimates of spawning biomass are usually accurate but imprecise, e.g. a coefficient of variation for spawning biomass of 30% or more is considered normal (Smith 1993; Hunter and Lo 1997; Stratoudakis *et al.* 2006). Sensitivity analysis has shown that estimates of the spawning biomass of sardine are more affected by variations in estimates of mean daily egg production and total spawning area than in variations in the parameters used to estimate mean daily fecundity (Ward *et al.* 2005; Stratoudakis *et al.* 2006).

Like other ichthyoplankton-based stock assessment methods, successful application of the DEPM is more reliant on detailed knowledge of the biological and ecological characteristics of the species and population than most other fishery-independent stock assessment methods (Stratoudakis *et al.* 2006). Initial studies necessarily focus on identifying the timing and location of the spawning area (i.e. the patterns of distribution and abundance of eggs) and tend to place comparatively less emphasis on sampling spawning adults. Collecting representative samples of spawning adults has proven difficult for some species in some locations. As a result, many studies in which the DEPM has been used for stock assessment of small pelagic fishes have failed to obtain robust estimates of all parameters (e.g. Lo *et al.* 1996; Lo *et al.* 2005). In the absence of all of the specific detailed information that is required to estimate mean daily fecundity precisely, many studies have succeeded in providing information on the size of the spawning biomass used for fisheries assessment and management purposes (e.g. Hill *et al.* 2005). This is because the population parameters used to estimate mean daily fecundity, i.e. female weight, sex ratio, batch fecundity and spawning fraction, tend to be stable between years, and estimates of the spawning biomass are less sensitive to uncertainty in estimates of mean daily fecundity than estimates of

total mean daily egg production. A good example of the use of spawning biomass estimates obtained without the data required to estimate daily fecundity directly is the sardine stock assessments off the west coast of northern and central America, where estimates of spawning biomass were used as indices of abundance for stock assessment modelling between 1993/94 and 2004/05, even though the adult samples required to calculate estimates of reproductive parameters were not collected between 1995/96 and 2000/01 (Lo *et al.* 1996; Hill *et al.* 2005; Lo *et al.* 2005).

Results provided in Chapter 6 of the present report show that *S. australasicus* produces multiple batches of pelagic eggs, has indeterminate fecundity and is a species which is suited to stock assessment using the DEPM. Chapter 7 outlines the methods used to identity *S. australasicus* eggs. Chapter 8 presents information on the distribution and abundance of *S. australasicus* eggs and larvae obtained in surveys conducted in southern and eastern Australia.

This chapter evaluates the use of the DEPM to estimate the spawning biomass of *S. australasicus* in southern and eastern Australia. To achieve this goal we 1) conducted ichthyoplankton surveys and adult sampling programs off southern and eastern Australia to obtain estimates of P_0, A, W, R, F and S; and 2) assessed the sensitivity of estimates of spawning biomass to variations in the estimates of each parameter. Preliminary estimates of the spawning biomass in southern and eastern Australia are also presented. Findings are compared with information available for *Scomber japonicus*.

10.2 Methods

10.2.1 Total mean daily egg production

10.2.1.1 Timing and location of ichthyoplankton surveys

The aim of ichthyoplankton surveys conducted during DEPM studies is to collect the samples that are required to estimate mean daily egg production (density) and spawning area and to calculate total daily egg production. In preliminary studies such as this, when the timing and location of spawning is poorly understood, it is necessary to survey large areas in order to determine the full extent of the spawning area. This necessity makes it logistically challenging to collect enough samples from throughout the area surveyed to define the spawning area and estimate mean daily egg production with high levels of precision (Stratoudakis *et al.* 2006, p41).

Due to the paucity of biological information that was available for *S. australasicus* in south-eastern Australia before this study began, we generally conducted extensive surveys (with reduced sampling intensity) in order to determine the full extent of the spawning area, rather than conducting intensive surveys that focused on estimating spawning area and mean daily egg production with high levels of precision (see Chapter 8). The need to identify the timing and location of spawning meant that sampling designs also varied (were refined) between surveys, which limited the potential for direct inter-annual comparison of results. The regions and sites in southern and eastern Australia from which ichthyoplankton samples were collected for this chapter are shown in Figure 10.1.

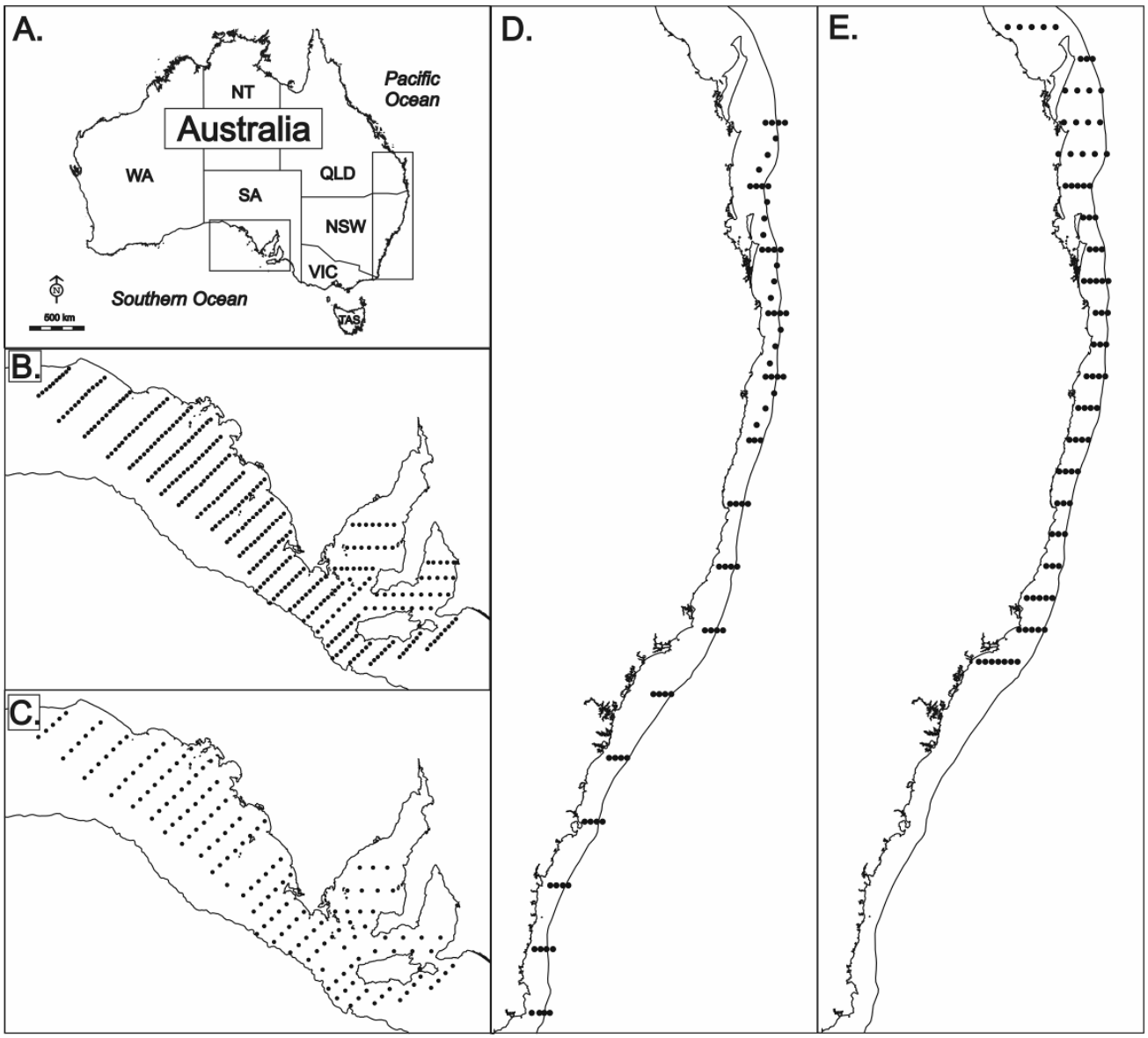

Figure 10.1. A) Location of sites where ichthyoplankton samples were collected from waters off southern Australia during February-March 2005 using B) a CalVET net and C) a bongo net and waters off eastern Australia in D) October 2003 and E) July 2004.

10.2.1.2 Sampling methods

Ichthyoplankton samples for application of the DEPM are usually collected using CalVET nets (Californian Vertical Egg Tow nets, California Cooperative Oceanic Fisheries Investigations, La Jolla, CA USA). However, samples can also be obtained using other types of ichthyoplankton samplers. The effect of net type/size on estimates of egg density is poorly understood.

In this study, ichthyoplankton samples were collected using both CalVET and bongo nets. CalVET nets, which were used in southern Australian waters only, had an internal mouth diameter of 300 mm and mesh size of 330 μm. Nets were deployed to within 10 m of the seabed at depths <80 m or to a depth of 70 m at depths >80 m. The bongo nets used in southern and eastern Australian waters had internal mouth diameters of 580 and 600 mm, respectively. The mesh sizes of bongo nets were 330 and 500 μm in southern Australia and 300 and 500 μm in eastern Australia. In southern Australia, bongo nets were deployed to within 10 m of the seabed at depths <100 m or to a depth of 100 m at depths >110 m. In eastern Australian waters, bongo nets were deployed to within 2–5 m of the seabed in waters up to 200 m in depth.

Environmental information to support the interpretation of biological data collected during ichthyoplankton surveys is now commonly collected by attaching conductivity-depth-temperature (CTD) recorders to the sampling equipment. Data from CTD can be used for temperature-egg development modelling and to identify physical parameters that may affect spawning activity. In this study, CTD were usually deployed in conjunction with the plankton nets. General Oceanics™ flowmeters were used to estimate the distance travelled by each net. Factory calibrations were used to estimate volumes of water filtered by the two nets. During the surveys in southern Australia wire length during each net deployment was measured to the nearest cm using a digital meter. In the eastern Australian surveys depth was estimated using a CTD and Scanmar depth sensor.

In SA, plankton samples from the two cod-ends were combined and stored in 5% buffered formaldehyde and seawater solution. Eastern Australian samples were also combined and fixed in 98% ethanol solution.

10.2.1.3 Egg identification and staging

Eggs of *S. australasicus* were identified using the morphological criteria identified in Chapter 7 of this report. Dr F. Neira and Mr J. Keane (TAFI) confirmed all egg identifications. Morphological identifications of some (49) eggs were confirmed using genetic techniques (Chapter 7). Due to

the uncertainties associated with the identification of early stage eggs outlined in Chapter 7 of this report, we only included early stage eggs that could be identified as *S. australasicus* with a high degree of confidence in the dataset analysed in this chapter. Hence, there may be negative bias in the number of *S. australasicus* eggs reported in this chapter.

The potential for bias in the estimates of egg abundance resulting from potential misidentification of young eggs was assessed by staging sub-samples of eggs from each location as being day-1 or day-2 to determine the proportion of early stage eggs in samples. Eggs were determined to be either day-1 or day-2 based on the criteria and stages of *S. japonicus* described by Watanabe (1970).

10.2.1.4 Egg density

Egg density under one square metre (m^2) of water (P_t) was estimated at each station using equation 1:

$$P_t = \frac{C.D}{V} \qquad \text{Eq. 2.}$$

where *C* is the number of eggs in each sample, *V* is the volume of water filtered (m^3) estimated using the flowmeters, and *D* is the maximum depth (m) to which the net was deployed as recorded by the wire length (in southern Australia) and from CTD (eastern Australia).

10.2.1.5 Estimating egg production

Mean daily egg production is typically estimated by fitting mortality models to estimates of egg abundance by age (Picquelle and Stauffer 1985). This approach requires temperature-development keys such as those that have been developed for *S. sagax* (White and Fletcher 1996) and northern anchovy *Engraulis mordax* (Lo 1985). Temperature-development keys of this type have not yet been developed for S. *australasicus*.

McGarvey and Kinloch (2001) identified many of the uncertainties that are associated with estimating egg production and mortality using the standard approach. These are mainly associated with the patchy distribution of young eggs and difficulties resolving spatial and temporal variability in egg mortality (Priede *et al.* 1995; Lo *et al.* 1996; Hunter and Lo 1997; Fletcher and Sumner 1999; Kim and Lo 2001). McGarvey and Kinloch (2001) described a method for estimating mean production that uses estimates of mean egg density and assumed rates of egg mortality. This approach reduces the effects of spatial and temporal variations in egg

abundance and mortality on estimates of egg production. Estimates of mean daily egg production of sardine obtained using the method of McGarvey and Kinloch (2001) are usually lower (i.e. more conservative) than those obtained using the methods of Picquelle and Stauffer (1985).

Mean daily egg production was estimated using the method of McGarvey and Kinloch (2001). This method assumes that:

$$P_0 = \frac{\overline{P}Z}{1-e^{-2Z}} \text{ if } z > 0 \qquad \text{Eq. 3}$$

where $\overline{P}$ is the mean density and Z is egg mortality. This method of estimating mean egg density from survey data requires that assumptions are made regarding egg mortality (z). In this study P_0 was calculated using assumed egg mortality rates of 0.1–0.5 day^{-1}, which reflect the range of values determined for similar pelagic fishes (Bunn *et al.* 2000).

10.2.1.6 Spawning area

Spawning area has typically been estimated by manually dividing the sampling area into a series of contiguous grids, i.e. the "original" method of Lasker (1985). This approach works best when sampling intensity is high and sites are located on parallel transects that are placed as close together as logistically feasible. In this situation, subjective decisions about the placement of grid boundaries have relatively minor effects on estimates of spawning area. However, the effect of grid size (which is related to sampling intensity) on estimates of spawning area is poorly understood. In recent years, new methods have been developed for optimising the distribution of grid boundaries based on the distance between stations (e.g. voronoi natural neighbour method VNN, MAPINFO Version 8 Vertical Mapper). To our knowledge, the similarity of estimates of spawning area obtained using the original method of Lasker (1985) and more modern approaches have not formally been compared.

In this study, we examined the effect of grid size on estimates of spawning area by comparing estimates calculated from data obtained using the CalVET and bongo nets using grids ranging in size between~160–220 km^2 during a survey in southern Australia during February-March 2005. Estimates of spawning area were calculated using the original method (Lasker 1985) as well as the VNN approach (Figs 10.2 & 10.3).

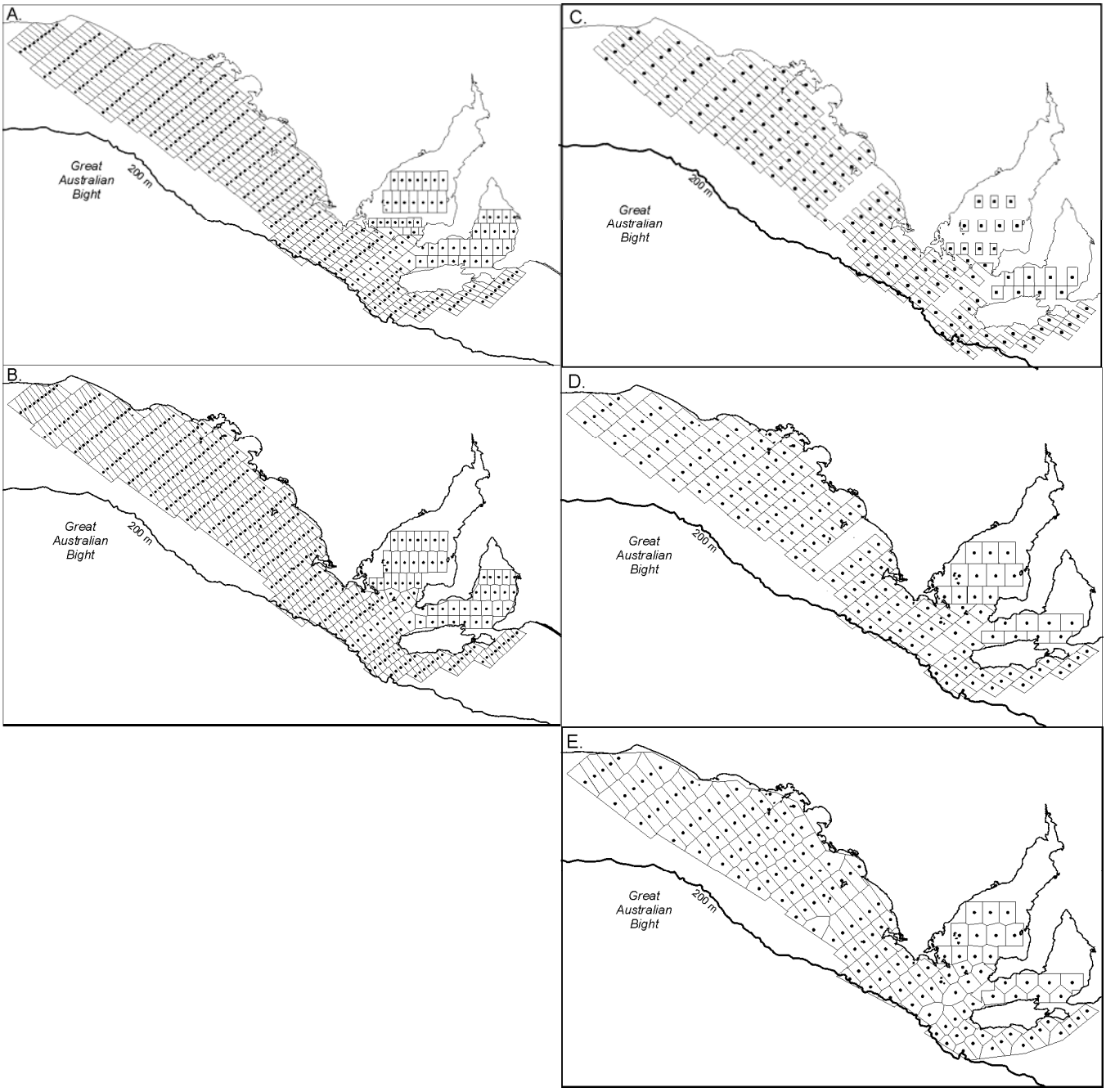

Figure 10.2. Grid areas determined using contiguous and VNN grids at sites sampled using a CalVET net (A and B respectively), and using small uniform, contiguous and VNN grids at sites using a bongo net (C, D and E respectively) in waters off southern Australia during February-March 2005.

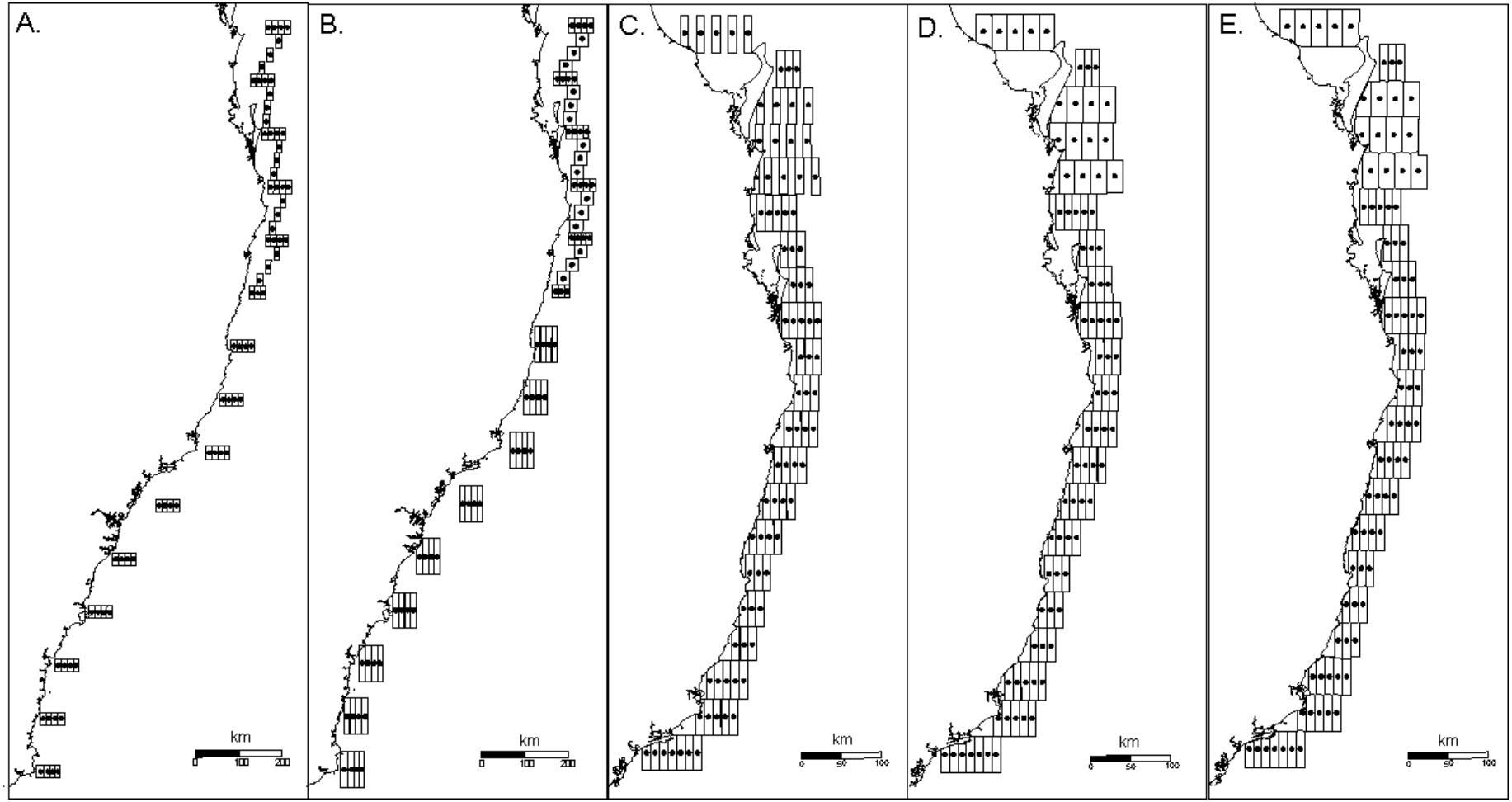

Figure 10.3. Grid areas determined for sites sampled in waters off eastern Australian in October 2003 using small uniform (A) and large uniform (B) grids and in July 2004 using (C) uniform grids, (D) contiguous grids and (E) VNN generated grids.

Adult reproductive parameters

10.2.1.7 Adult sampling

Most samples of blue mackerel were collected using lines and lures, small baits and or baitfish jigs. Some samples were also collected using a monofilament gillnet (mesh size 65 mm). In southern Australia, samples were collected from Gulf St Vincent, Backstairs Passage, Investigator Strait, Spencer Gulf and in the eastern GAB between 2002 and 2005 (Figure 10.4). Off eastern Australia, samples were collected during gamefishing tournaments, research surveys and from recreational catches (Fig. 10.4). Gonads were removed from mature females and fixed in 5% buffered formaldehyde solution. Immature females and males were frozen.

As previously noted, estimates of spawning biomass obtained using the DEPM tend to be less sensitive to variations in estimates of mean daily fecundity than estimates of total daily egg production (e.g. Hunter and Lo 1997; Stratoudakis *et al.* 2006). Estimates of adult parameters also tend to be relatively stable between years and locations for at least some species of small pelagic fishes (e.g. Stratoudakis *et al.* 2006). On this basis, several studies which have failed to obtain robust estimates of adult parameters (e.g. Lo *et al.* 1996; Lo *et al.* 2005), have provided estimates of spawning biomass that have been used in the assessment and management of fisheries. Therefore, in this study we used adult reproductive data from *S. australasicus* sampled in southern Australia to examine the sensitivity of estimates of spawning biomass to variations in adult reproductive parameters and to calculate preliminary estimates of spawning biomass for eastern Australia.

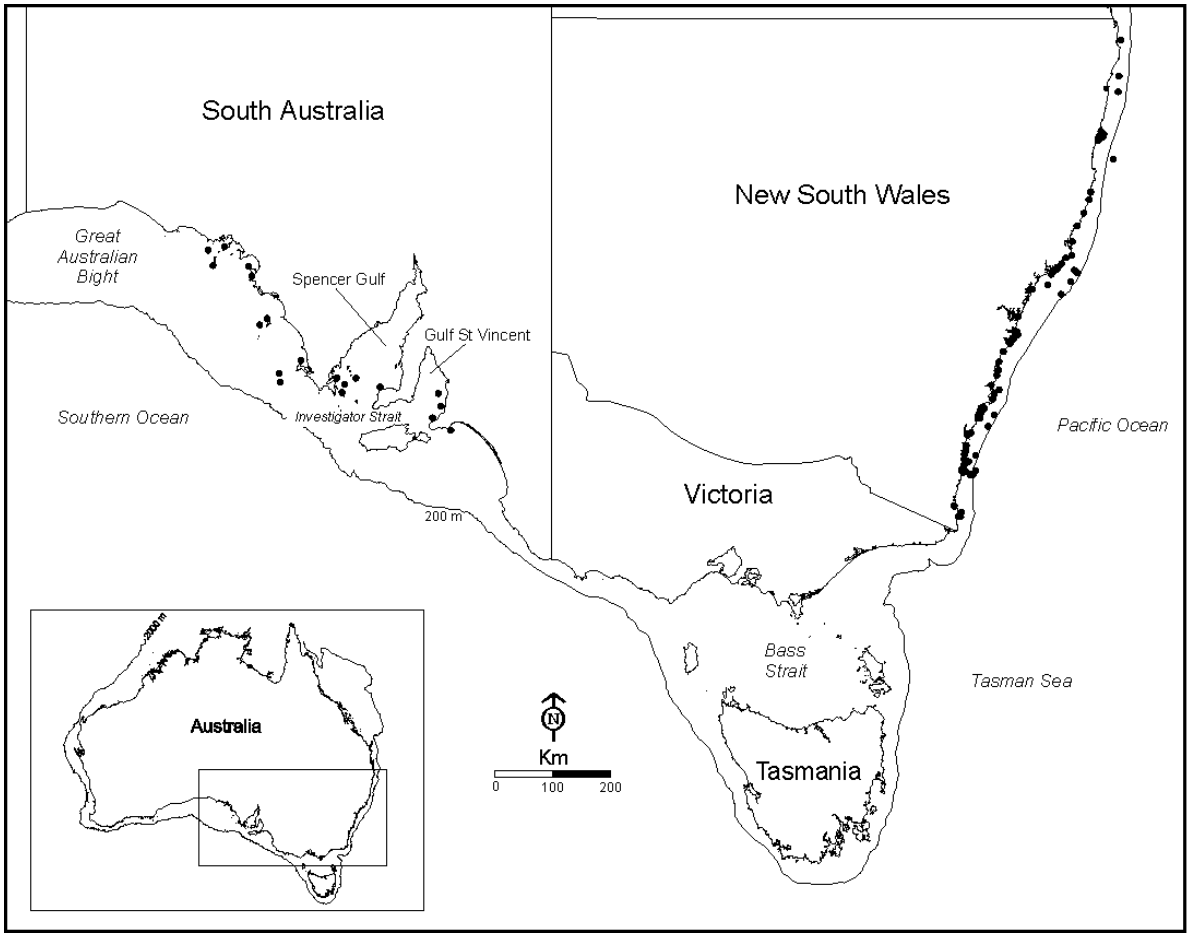

Figure 10.4. Locations in southern and eastern Australia where adult samples were collected for the estimation of adult reproductive parameters.

10.2.1.8 Female weight

Mature females from each sample were removed from formalin and weighed (+ 0.01 g). Fixation in formalin has a negligible effect on fish weight (Lasker 1985). The mean weight of mature females in the population was calculated from the average of sample means weighted by proportional sample size, which is represented by equation 4:

$$W=\overline{\left[\overline{W_i} * \frac{n_i}{N}\right]} \qquad \text{Eq. 4.}$$

where $\overline{W_i}$ is the mean female weight of each sample i; n is the number of fish in each sample and N is the total number of fish collected in all samples.

10.2.1.9 Sex ratio

The mean sex ratio of mature sardine in the population was calculated from the average of sample means weighted by proportional sample size, which is represented by equation 5:

$$R=\overline{\left[\overline{R_i} * \frac{n_i}{N}\right]} \qquad \text{Eq. 5.}$$

where n is the number of fish in each sample, N is the total number of fish collected in all samples and $\overline{R_i}$ is the mean sex ratio of each sample which is calculated using equation 6:

$$\overline{R_i} = \frac{F}{(F+M)} \qquad \text{Eq. 6}$$

where F and M are the respective total weights (g) of mature females and males in each sample i.

10.2.1.10 Batch fecundity

Batch fecundity was estimated from stage IV (hydrated) ovaries collected in South Australia using the gravimetric method (Hunter *et al.* 1985). Both ovaries were weighed and the number of hydrated oocytes in three ovarian sub-sections were counted and weighed. The total batch fecundity for each female was calculated by multiplying the mean number of oocytes per gram of

ovary segment by the total weight of the ovaries. The relationship between ovary-free fish weight and batch fecundity was determined by linear and allometric regression analysis and used to estimate the batch fecundity of mature females. Sharpiro-Wilk tests were conducted to test for normality of the error terms and estimates.

10.2.1.11 Spawning fraction

Ovaries of mature females were sectioned and stained with haematoxylin and eosin. Several sections from each ovary were examined to determine the presence/absence of post-ovulatory follicles (POFs). POFs were assigned approximate ages according to the criteria developed by Hunter and Macewicz (1985) for northern anchovy *Engraulis australis* and Dickerson *et al.* (1992) for Chub mackerel *S. japonicus*.

Spawning fraction of each independent sample was estimated as the mean proportion of females with hydrated oocytes (H), day-0 POFs (d0, assumed to be 0-24 hrs old), day-1+ POFs (d1+, assumed to be 24+ hours old). The mean spawning fraction of the population was estimated from the average of sample means weighted by proportional sample size, which is represented by equation 7.

$$S = \overline{\left[\overline{S_i} * \frac{n_i}{N} \right]} \qquad \text{Eq. 7}$$

where n is the number of fish in each sample, N is the total number of fish collected in all samples and $\overline{S_i}$ 1-3 were the mean spawning fraction estimates of each sample calculated using equation 8-10:

$$\overline{S_i}1 = \frac{H}{n_i} \qquad \text{Eq. 8}$$

$$\overline{S_i}2 = \frac{(d0POFs)}{n_i} \qquad \text{Eq. 9}$$

$$\overline{S_i}3 = \frac{[(d0 + d1^{+} POFs)/2]}{n_i} \qquad \text{Eq. 10}$$

where d0 POFs are assumed to be 0 – 24 hrs old, and d1+ POFs are assumed to be 24+ hrs old and n_i is the total number of females within a sample. In equations 9 and 10, d0 POFs include fish with hydrated ovaries.

10.2.2 Spawning biomass

We calculated 'minimum', 'best' and 'maximum' estimates of the spawning biomass of *S. australasicus* for southern Australia in 2005 using minimum, best and maximum estimate of each parameter, respectively. The best estimate of mean daily egg production was calculated from data obtained using the bongo net and by applying an egg mortality rate of 0.3. The best estimate of spawning area was calculated using data from the bongo net and the contiguous "original" (Lasker 1985) technique. The 'best' estimate of mean daily fecundity was calculated using the overall estimates of mean female weight, mean sex ratio, mean batch fecundity and mean spawning fraction obtained for southern Australia.

An estimate of 'minimum' spawning biomass of *S. australasicus* for southern Australia in 2005 was calculated using the most conservative or minimum estimate of each parameter. The minimum estimate of mean daily egg production was calculated from data obtained using the bongo net and by applying an egg mortality rate of 0.1. The minimum estimate of spawning area was calculated using data from the bongo net and uniform/similar sized grid squares. The minimum estimate of mean daily fecundity was calculated using the most conservative values of mean female weight, mean sex ratio, mean batch fecundity and mean spawning fraction obtained from fish collected in southern Australia.

An estimate of 'maximum' spawning biomass of *S. australasicus* for southern Australia in 2005 was calculated using the least conservative or maximum estimate of each parameter. The maximum estimate of mean daily egg production was calculated from data obtained using the bongo net and by applying an egg mortality rate of 0.5. The maximum estimate of spawning area was calculated using data from the bongo net and the VNN method. The maximum estimate of mean daily fecundity was calculated using the least conservative estimates of mean female weight, mean sex ratio, mean batch fecundity and mean spawning fraction obtained for a single season of southern Australia.

A similar approach was taken to calculating minimum, best and maximum estimates of the spawning biomass of *S. australasicus* off eastern Australia. The minimum, best and maximum estimates of mean daily egg production were calculated using data from the July 2004 survey and by applying a daily egg mortality rate of 0.1, 0.3 and 0.5 respectively. The minimum, best and maximum estimates of spawning area were calculated using the July 2004 data and uniform grids, contiguous grids and the VNN method respectively (Lasker 1985). As few reproductively active fish were collected during eastern Australian surveys, minimum, best and maximum estimates of mean daily fecundity used were those calculated for southern Australia. However, an estimate of spawning biomass was also calculated for eastern Australia using estimates of spawning area, mean daily egg production, mean sex ratio, mean female weight, mean batch fecundity (calculated from relationship between ovary-free female weight and batch fecundity) obtained for eastern Australia, and the estimate of mean spawning fraction for southern Australia.

10.2.3 Sensitivity Analysis

Sensitivity analyses were undertaken to determine the effects of variations in each parameter on the estimates of spawning biomass. The sensitivity analyses were done by calculating estimates of spawning biomass for southern and eastern Australia using the best estimates of five parameters (e.g. *P, A, W, R*, *S)* and by varying the estimate of the parameter being tested (e.g. *F*) over an appropriate range of values. The sensitivity analyses were conducted over the range values for each parameter used to calculate the minimum, best and maximum estimates of the spawning biomass in each location.

10.3 Results

10.3.1 Egg abundance, density and daily egg production

10.3.1.1 Southern Australia

More *S. australasicus* eggs were collected using the bongo net (512 eggs) than the CalVET net (127 eggs) (Table 10.1). The patterns of distribution and abundance of eggs determined using the two types of net were generally similar; eggs were present at sites located in the southern parts of both gulfs, in Investigator Strait and in shelf waters south of the Eyre Peninsula (Figure 10.5). Approximately 35.5% of samples obtained using the bongo net contained eggs, whereas only 10.5% of samples obtained using the CalVET contained eggs.

Mean egg density estimated using the CalVET data (23.5 eggs per m^2) was higher than the estimate obtained from bongo net data (17.7 eggs per m^2) (Table 10.1). Similarly, estimates of mean daily egg production obtained from the CalVET net (12.99-18.62 eggs per m^2) were higher than for the bongo net (9.94-14.25 eggs per m^2 per day) (Table 10.2). Day-1 eggs comprised less than 60% of eggs obtained using both bongo and CalVET nets, which suggest that the potential for a significant positive bias in egg production resulting from the misidentification of young eggs is low (Table 10.2).

We consider that the 'best' estimate of mean daily egg production (i.e. 11.98 eggs per m^2) is that obtained using the data from the bongo net, which was also used to collect samples in eastern Australia, and an assumed mortality rate of 0.3 eggs.m^2 day (Table 10.2). The minimum and maximum estimates of egg production are those obtained using the data from the bongo net and assuming mortality rates of 0.1 and 0.5 eggs.m^2 day, respectively (i.e. 9.94 and 14.25 eggs per m^2).

10.3.1.2 Eastern Australia

In October 2003 and July 2004, 1,639 and 837 eggs respectively were collected from eastern Australia. In October 2003, *S. australasicus* eggs were abundant in shelf waters in the northern portion of the sampling area only (mainly north of Forster), whereas in July 2004 eggs were abundant in shelf waters throughout the entire area surveyed between Indian Head, Fraser Island, Queensland and Newcastle, NSW (Table 10.1, Fig. 10.6).

Mean egg density was 41.7 eggs per m^2 in 2003 and 12.4 eggs per m^2 in 2004 (Table 10.1). Estimates of P_0 were 23.0–33.0 eggs per m^2 per day in 2003 and 6.8–9.8 eggs per m^2 per day in 2004 (Table 10.1). Day-1 eggs comprised less than 10 and 42% of eggs collected in 2003 and

2004, respectively (Table 10.1), which suggests that the potential for a significant positive bias in egg production resulting from the misidentification of young eggs is low (Table 10.2).

As data obtained in October 2003 were unsuitable for estimating spawning area, we consider that the best estimate of mean daily egg production for eastern Australia (8.22 eggs per m^2 per day) is that obtained from data collected in July 2004 and using an assumed mortality rate of 0.3 eggs per m^2 day. The minimum and maximum estimates of egg production are those obtained for July 2004 assuming mortality rates of 0.1 and 0.5 eggs per m^2 day, respectively (i.e. 6.82 and 9.78 eggs per m^2 per day).

Table 10.1. Summary of ichthyoplankton surveys conducted in southern and eastern Australian waters to evaluate the application of the DEPM.

Location	Survey date	Net Type	n Stations Sampled	n Positive Stations	% Positive Stations	No. Eggs (day-1 %)	Mean Egg Density (eggs per m^2)
Southern Australia	5 Feb – 19 Mar 2005	CalVET	334	35	10.5	127 (59)	23.5
		Bongo	152	54	35.5	512 (55)	17.7
Eastern Australia	1-7 October 2003	Bongo	74	29	39.2	1,639 (10)	41.7
	20-27 July 2004	Bongo	85	45	52.9	873 (42)	12.4

Table 10.2. Estimates of egg production calculated for different spawning area grid weightings for surveys in southern and eastern Australia.

Location	Year/Net type	Egg mortality rate (Z day-1)	Egg Production	
			05 CalVET	05 Bongo
Southern Australia	05 CalVET/Bongo	0.1	12.99	9.94
		0.2	14.28	10.93
		0.3	15.65	11.98
		0.4	17.10	13.10
		0.5	18.62	14.25
			03 Bongo	04 Bongo
Eastern Australia	03/04 Bongo	0.1	23.01	6.82
		0.2	25.31	7.50
		0.3	27.74	8.22
		0.4	30.30	8.98
		0.5	33.00	9.78

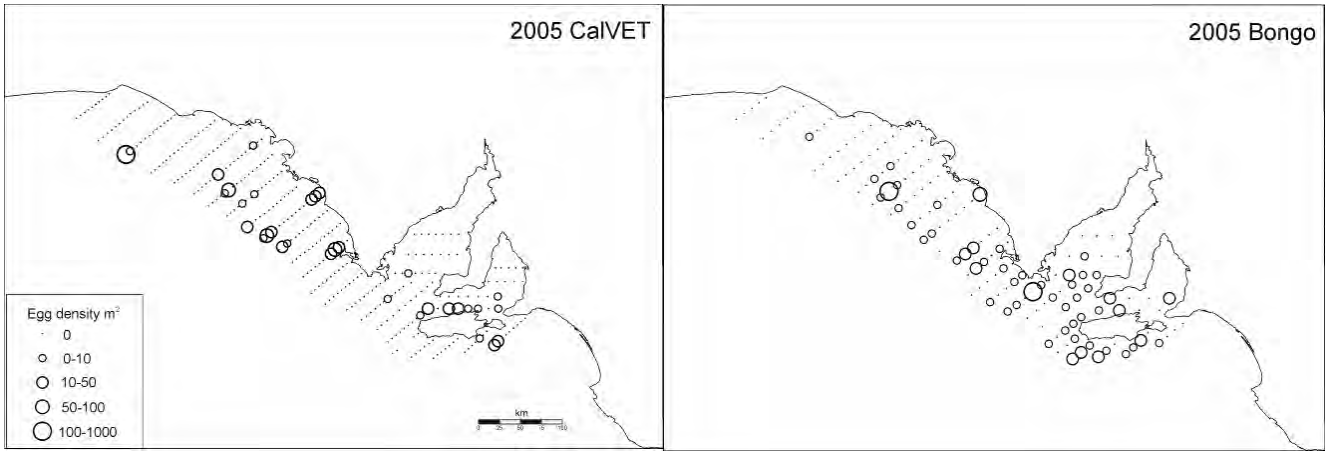

Figure 10.5. Distribution and abundance of *S. australsicus* eggs at sites sampled using a CalVET net and a bongo net in waters off southern Australia during February-March 2005.

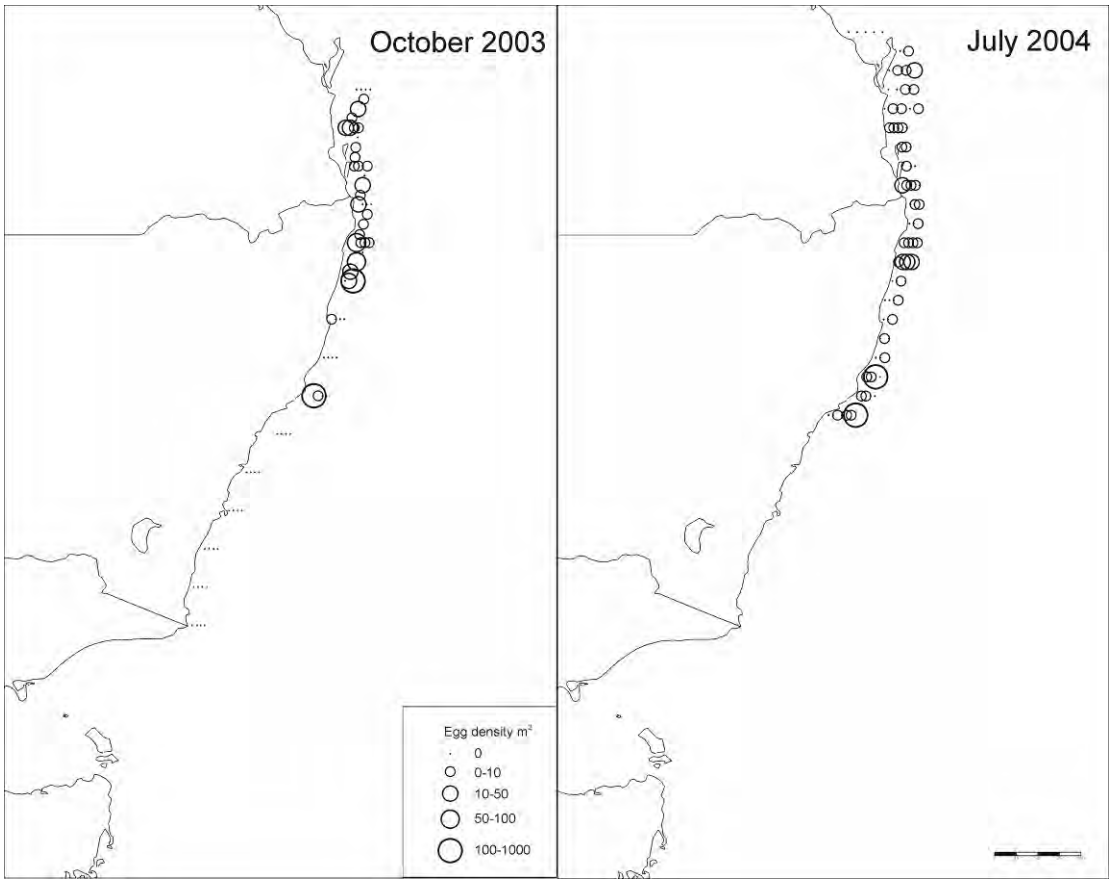

Figure 10.6. Distribution and abundance of *S. australasicus* eggs at sites in eastern Australian in October 2003 and July 2004.

10.3.2 Spawning area

10.3.2.1 Southern Australia

The total survey area in southern Australia in 2005 was estimated as 119,678.8 km^2 for the CalVET net and 108,961 km^2 for the bongo net (Fig. 10.1., Table 10.3). The number and percentage of positive stations (i.e. containing eggs) was much higher for the bongo net (35.5%) than for the CalVET net (10.5%) (Table 10.1). Hence, the estimates of spawning area obtained using the bongo net (e.g. contiguous grids, 34,895 km^2) were much higher than the estimates for the CalVET net (e.g. contiguous grids, 11,840 km^2). For both the bongo net and the CalVET net, estimates obtained using the contiguous grids and VNN were similar (Table 10.3; Fig. 10.1).

We consider the best estimate of spawning area for southern Australia (34,895 km^2) to be that obtained using data from the bongo net and contiguous grids established using the original method of Lasker (1985). The minimum and maximum estimates of spawning area for southern Australia are those obtained using small uniform sized grids (17,451 km^2) and the VNN griding technique (36,370 km^2), respectively (Table 10.3).

10.3.2.2 Eastern Australia

The area sampled off eastern Australia in October 2003 was 13,726 km^2 if grids were set at a small (conservative) uniform size and 30,422 km^2 if larger grid squares that covered the entire sampling area were used in the calculations (Table 10.3). Hence, the small uniform grid squares covered approximately 45% of the total survey area, and estimates of spawning area obtained using these grids had a strong negative bias. The estimates of spawning area obtained using the two types of grid squares reflect this difference, and were 5,931 km^2 for the small uniform grid squares and 10,078 km^2 for the larger grid squares that covered the entire sampling area (Table 10.3). Limitations in the sampling design prevented estimation of the spawning area using the VNN for eastern Australia in October 2003.

Estimates of spawning area obtained in July 2004 were 17,503 km^2 using uniformly sized grids which covered approximately 83% of the sampling area, 20,811 km^2 using larger continuous grids that covered the entire sampling area and 21,019 km^2using using VNN method (Fig. 10.3, Table 10.3). The best estimate of spawning area for eastern Australian is that based on data from July 2004 and obtained using large continuous grids that covered the entire sampling area (20,811 km^2). The minimum and maximum estimates of spawning area for eastern Australia are those

obtained using uniformly sized grids (17,503 km^2) of the sampling area and the VNN griding technique, respectively (21,019 km^2).

Table 10.3. Estimates of spawning area calculated using uniform grids, contiguous grids and the VNN method using a CalVET net and a bongo net in waters off southern Australia during February-March 2005 and a bongo net in waters off eastern Australia in October 2003 and July 2004.

Location	Year/Net type	n stations sampled	Survey area	SPAWNING AREA		
				Uniform/similar sized Grids	Contiguous Grids	VNN Method Grids
Southern Australia	05 CalVET	334	108,961	11,840	11,840	11,898
	05 Bongo	152	119,603	17,451	34,895	36,370
Eastern Australia	03 Bongo	74	30,422	5,931	10,078	
	04 Bongo	85	38,974	17,503	20,811	21,019

10.3.3 Adult reproductive parameters

10.3.3.1 Female weight

Southern Australia

Weighted mean weight of mature females in southern Australian waters was calculated for each of 52 samples containing a total of 812 (stage II–V) females (Table 10.4). Weighted mean female weights were calculated for spawning seasons between 2001/02 and 2005/06 in regions including Gulf St Vincent (GSV), Spencer Gulf (SG), Investigator Strait (IS), Encounter Bay (EB) and the Great Australian Bight (GAB). Estimates of weighted mean female weights for individual regions within a season ranged between 357.8 g in SG in 2001/02 and 668.4 g in EB in 2003/04. All estimates of mean female weight for EB, IS and the GAB were >500g, whereas all estimates of mean female weight for GSV and SG were less than 470 g. Whole season means ranged from 408.2 g in 2002/03 to 473.6 in 2003/04, which reflects the predominance of samples from GSV and SG. The weighted mean female weight for all samples combined was 452 g.

The best estimate of mean female weight for southern Australia is the weighted mean value for all samples combined was 452 g. The minimum and maximum estimates are those calculated for season means in 2002/03 (408.2 g) and 2003/04 (473.6 g) respectively.

Table 10.4. Adult reproductive parameters, Mean female weight, Sex ratio and Batch fecundity of blue mackerel obtained from samples collected from South Australian waters between 2001 and 2006. # denotes total number of fish collected. $_a$ denotes mean value weighted by individual sample size.

Season	Region	Sample Total	Males ♂	Females ♀	Mean wt (g)	Mean ♀ wt (g) $\overline{W_i}$	Total ♂ wt (g)	Total ♀ wt (g)	Sex Ratio $\overline{R_i}$	Mean ♀ wt (gonad free) (g)	Mean Batch Fecundity
2001/02	IS	46	19	27	480.6	502.7	9132	13 572	0.60	485.8	61 158
	SG	48	26	22	325.2	357.8	8456	7871	0.48	353.8	37 284
		94#	**45#**	**49#**		**437.6a**			**0.54a**		**50 439a**
2002/03	EB	30	17	13	615.7	645.4	10 467	8390	0.44	614.8	88 345
	GSV	44	22	22	292.1	394.7	6426	8682	0.57	376.5	41 083
	SG	97	23	74	367.7	370.5	8458	27 420	0.76	360.7	38 427
		171#	**62#**	**109#**		**408.2a**			**0.65a**		**46 468a**
2003/04	EB	25	11	14	581.8	668.4	6400	9358	0.59	627.0	91 113
	GAB	190	109	81	549.8	531.2	59 925	43 029	0.42	515.5	67 114
	GSV	493	294	199	427.0	442.0	125 536	87 951	0.41	419.3	48 601
	SG	390	197	193	415.9	468.0	81 939	90 316	0.52	442.4	52 853
		1098#	**611#**	**487#**		**473.6a**			**0.46a**		**55 053a**
2004/05	GSV	185	107	78	373.9	404.5	40 008	31 548	0.44	385.5	42 627
	SG	277	195	82	400.9	437.6	78 168	35 886	0.31	446.4	53 606
		462#	**302#**	**160#**		**421.5a**			**0.36a**		**48 961a**
2005/06	SG	12	5	7	358.3	428.2	1792	2997	0.63	415.0	47 832
		12#	**5#**	**7#**		**428.2a**			**0.63a**		**47 832a**
Grand Totals/ Means -all seasons		**1837#**	**1025#**	**812#**		**452.00a**			**0.46a**		**52 182a**

Table 10.5. Adult reproductive parameters, Mean female weight and Sex ratio of blue mackerel obtained from samples collected from NSW waters between 2002 and 2005. # denotes total number of fish collected. [a] denotes mean value weighted by individual sample size. gf = gonad free. W = weight (g).

Year	Sampling period	Region	N samples	N fish	n ♂	n ♀	Mean ♂ W (g)	Mean ♀ $\overline{W_i}$ (g)	Total ♂ wt (g)	Total ♀ wt (g)	Sex Ratio $\overline{R_i}$	Mean ♀ wt (gonad free) (g)	Mean Batch Fecundity
2002	23-Oct-02	South	1	3	2	1	291.3	229.6	582	230	0.28	220.1	17 764
	30 Aug - 4 Oct 02	Middle	2	5	3	2	242.3	336.4	727	673	0.48	320.5	31 946
	20 - 23 Sept 02	North	3	18	11	7	336.7	320.4	3703	2243	0.38	305.3	29 605
				26#	**16#**	**10#**		**314.5[a]**	**5013#**	**3145#**	**0.39[a]**		**29 127[a]**
2003	10-Oct-03	South	1	3	0	3	0	286	0	858	1	279.8	25 836
	6 July - 17 Oct 03	Middle	6	21	9	12	243.2	277.7	2189	3332	0.6	265.0	23 737
	9 Aug - 22 Sept 03	North	5	27	15	12	278	288.2	4169	3458	0.45	276.9	25 430
				51#	**24#**	**27#**		**283.2[a]**	**6358#**	**7648#**	**0.53[a]**		**25 105[a]**
2004	08-Jul-04	South	1	7	5	2	288.1	251.2	1441	502	0.26	244.4	20 920
	13 Aug - 28 Oct 04	Middle	6	17	10	7	300.4	254	3004	1778	0.37	242.9	20 716
	16 July - 4 Aug 04	North	13	199	101	98	240	263.6	24 243	25 836	0.52	252.5	22 015
	14 Aug - 3 Oct 04	unknown	8	51	26	25	266.2	239.2	6922	5980	0.46	228.9	18 884
				274#	**142#**	**132#**		**258.3[a]**	**35 609#**	**34 096#**	**0.5[a]**		**21 095[a]**
2005	13 July - 11 Aug 05	unknown	4	32	15	17	261.9	284.4	3929	4835	0.55	272.2	24 757
				32#	**15#**	**17#**		284.4[a]	**3929#**	**4835#**	**0.52[a]**		**24 421[a]**
Grand Total			**50#**	**383#**	**197#**	**186#**		**267.3[a]**	**50 909#**	**49 724#**	**0.5[a]**	**256.1[a]**	**22 085[a]**

Eastern Australia

Weighted mean weight of mature females off eastern Australia was calculated from 50 samples containing a total of 186 (stage III–V) females (Table 10.5). Mean female weight was 267.3 g.

10.3.3.2 Sex ratio

Southern Australia

Weighted mean sex ratio was calculated from the same samples that were used to estimate mean female weight (Table 10.4). Estimates of weighted mean sex ratio for individual regions within a season ranged between 0.31 in SG in 2004/05 to 0.76 in Spencer Gulf in 2002/03. Whole of season means ranged from 0.36 in 2004/05 to 0.65 in 2002/03. The mean weighted sex ratio for all years combined was 0.46. There were no clear geographical or temporal trends in sex ratio.

Eastern Australia

Weighted mean sex ratio for eastern Australia was calculated from the same samples that were used to estimate mean female weight (Table 10.5). The mean weighted sex ratio for all years was 0.50.

10.3.3.3 Batch fecundity

Southern Australia

Batch fecundity was estimated directly for 58 females collected in 2003/2004 (Fig. 10.7). Ovaries contained between 14,349 and 105,193 hydrated oocytes for females weighing 234.9 g and 607.4 g (gonad free weight), respectively. The relationship between ovary-free fish weight and batch fecundity calculated from these samples is shown if Figure 10.7 (Batch Fecundity – 3.9 Ovary-free Weight$^{1.56}$; $R^2 = 0.68$). Fig. 10.7 also shows the relationship between fork length (mm) and batch fecundity.

Estimates of weighted mean batch fecundity for individual samples that were calculated using the relationship shown in Figure 10.7 reflect the variation in mean female weight described above and ranged from 37,284 g in SG in 2001/02 and 91,113 in EB in 2003/04 (Table 10.4). Whole of season means ranged from 46,468 eggs in 2002/03 to 55,053 in 2003/04. The overall mean batch fecundity in southern Australia was 52,182 eggs (Table 10.4).

Eastern Australia

Based on the relationship between ovary-free fish weight and batch fecundity for southern Australia, the overall mean batch fecundity in eastern Australia was 22,085 eggs (Table 10.4).

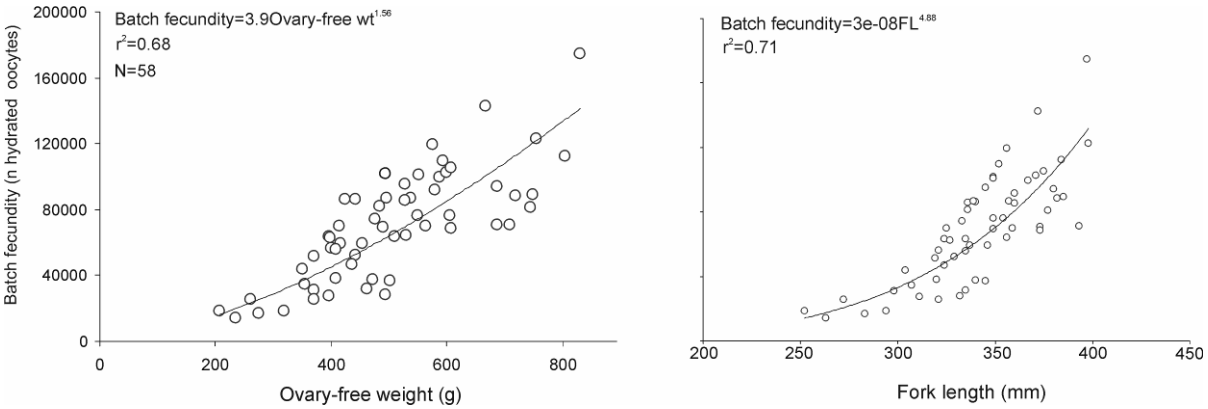

Figure 10.7. Relationship between (left) ovary-free body weight and (right) fork length and batch fecundity for *S. australasicus* sampled in South Australian between 2002 and 2005.

10.3.3.4 Spawning fraction

Southern Australia

Estimates of spawning fraction were obtained from 47 samples containing 702 mature females collected from southern Australian waters between 2001/02 and 2004/05 (Table 10.6). Of the 702 mature females collected, 153 had day 0 POFs, 49 had day 1+ POFs and 61 had hydrated oocytes. Estimates of weighted mean spawning fraction for individual regions within a season ranged from 0.0 at EB in 2002/03 and 2003/04 and 0.23 in SG in 2003/04 (Table 10.6.). Whole season means ranged from 0.05 in 2002/03 and 0.18 in 2001/02. The overall estimate of weighted mean spawning fraction was 0.14.

Eastern Australia

No data available.

Table 10.6. Spawning fraction estimates of blue mackerel obtained from samples collected from South Australian waters between 2001/02 and 2004/05. # denotes total number of fish collected. $_a$ denotes mean value weighted by individual sample size.

Season	Sampling period	Region	Sample size	n Day 0 POFs	n Day 1+ POFs	n Hydrated	S_i (Day 0 + Day 1+)
2001/02	11/04/2002	SG	20	0	7	0	0.18
			20#	**0#**	**7#**	**0**	**0.18a**
2002/03	17 - 24/3/03	EB	13	0	0	0	0.00
	11 - 25/3/03	GSV	18	0	1	0	0.03
	12/3 - 7/4/03	SG	52	1	6	1	0.07
			83#	**1#**	**7#**	**1#**	**0.05a**
2003/04	05/02/2004	EB	14	0	0	0	0.00
	5/11/03 - 27/4/04	GSV	190	32	12	10	0.12
	14/12/03 - 14/4/04	SG	181	68	14	38	0.23
	25/01/04 - 18/3/04	GAB	81	18	5	0	0.14
			466#	**118#**	**31#**	**48#**	**0.16a**
2004/05	08/11/04 - 20/4/05	GSV	61	10	2	3	0.10
	17/12/04 - 21/04/05	SG	72	24	2	9	0.18
			133#	**34#**	**4#**	**12#**	**0.11a**
Grand Totals/Means -all seasons			**702#**	**153#**	**49#**	**61#**	**0.14a**

10.3.3.5 Spawning biomass

South Australia

The best estimate of mean daily egg production was calculated from data obtained using the bongo net, applying a daily egg mortality rate of 0.3, and using the contiguous griding technique to estimate spawning area. The best estimate of mean daily fecundity was calculated using the overall estimates of mean female weight, mean sex ratio, mean batch fecundity and mean spawning fraction obtained for southern Australia during the course of this study. The best estimate of spawning biomass for southern Australia in 2005 was approximately 56,228 t. The minimum and maximum estimates were 10, 993 t and 293,456 t, respectively (Table 10.7).

Eastern Australia

Although the survey conducted in October 2003 was conducted closer to the peak of the spawning season, its sampling design made it inappropriate for calculating spawning area. Hence the 'best' estimate of mean daily egg production was calculated from data obtained in July 2004, applying an egg mortality rate of 0.3 and using the contiguous griding technique to estimate spawning area. Estimates of adult parameters from southern Australia were used to calculate spawning biomass for eastern Australia. The best estimate of spawning biomass for eastern Australia was approximately 23,009 t. The minimum and maximum estimates were 7,565 and 116, 395 t, respectively (Table 10.7). The estimate of spawning biomass off eastern Australia calculated using all parameter estimates (except mean spawning fraction) from eastern Australia was 29,578 t.

Table 10.7. Minimum, best and maximum estimates of each parameter and the spawning biomass of blue mackerel for southern Australia and eastern Australia in 2005.

Location		Minimum	Best	Maximum
Southern Australia	P_o	9.94	11.98	14.25
	A	17,451	34,895	36,370
	W	408.20	452.00	473.60
	R	0.65	0.46	0.36
	F	55,053	52,182	46,468
	S	0.18	0.14	0.05
	Biomass	**10, 993**	**56,288**	**293,456**
Eastern Australia	P_o	6.82	8.22	9.78
	A	17,503	20,811	21,019
	W	408.20	452.00	473.60
	R	0.65	0.46	0.36
	F	55,053	52,182	46,468
	S	0.18	0.14	0.05
	Biomass	**7,565**	**23,009**	**116,395**

10.3.3.6 Sensitivity analysis

Southern Australia

The sensitivity analysis showed that estimates of spawning biomass for southern Australia were most affected by variations in estimates of spawning area and spawning fraction. All estimates of spawning biomass obtained by varying other parameters within the bounds of information obtained in the study suggest that the spawning biomass in the survey area in southern Australia during 2005 ranged between ~45,000 and 68,000 t. (Figure 10.8). Only the estimate of spawning area obtained using small uniform grid squares, which covered only 14.5% of the sampling area, produced a lower estimate of spawning biomass (~28,000 t). Only assumed values of spawning fraction less than 0.10 produced estimates of spawning biomass greater than 80,000 t.

Eastern Australia

The sensitivity analysis showed that estimates of spawning biomass for eastern Australia were most affected by variations in estimates of spawning fraction (Fig. 10.9). All estimates of spawning biomass obtained by varying the other parameters within the bounds of information obtained in our study suggest that the spawning biomass in the survey area off eastern Australia

during 2005 ranged between approximately 20,000 and 60,000 t. Only assumed values of spawning fraction less than 0.05 produced estimates of spawning biomass greater than 60,000 t.

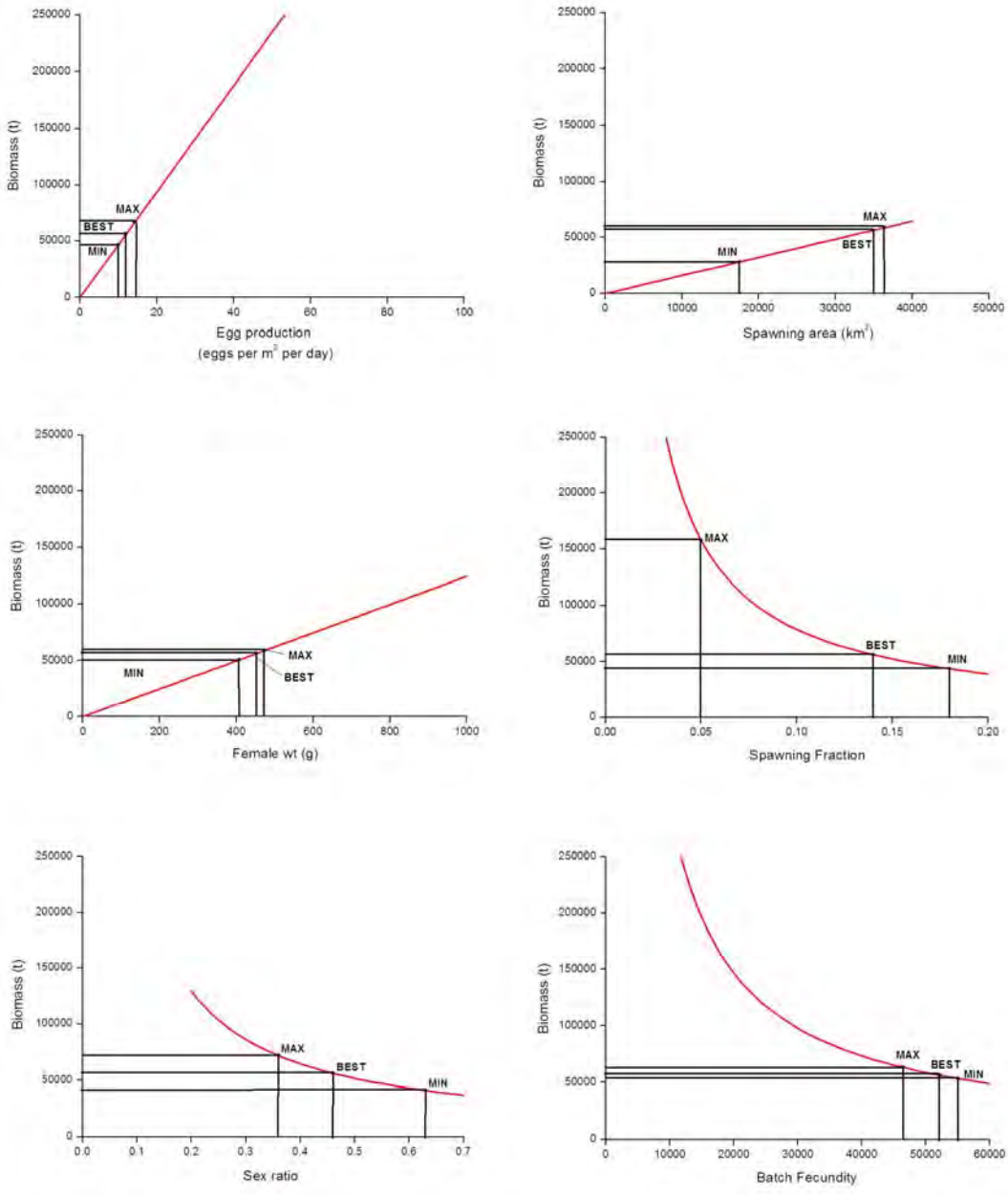

Figure 10.8. Sensitivity analysis showing minimum, "best" and maximum values of biomass calculated from upper, best and lower parameter estimates applied in the DEPM model for southern Australia.

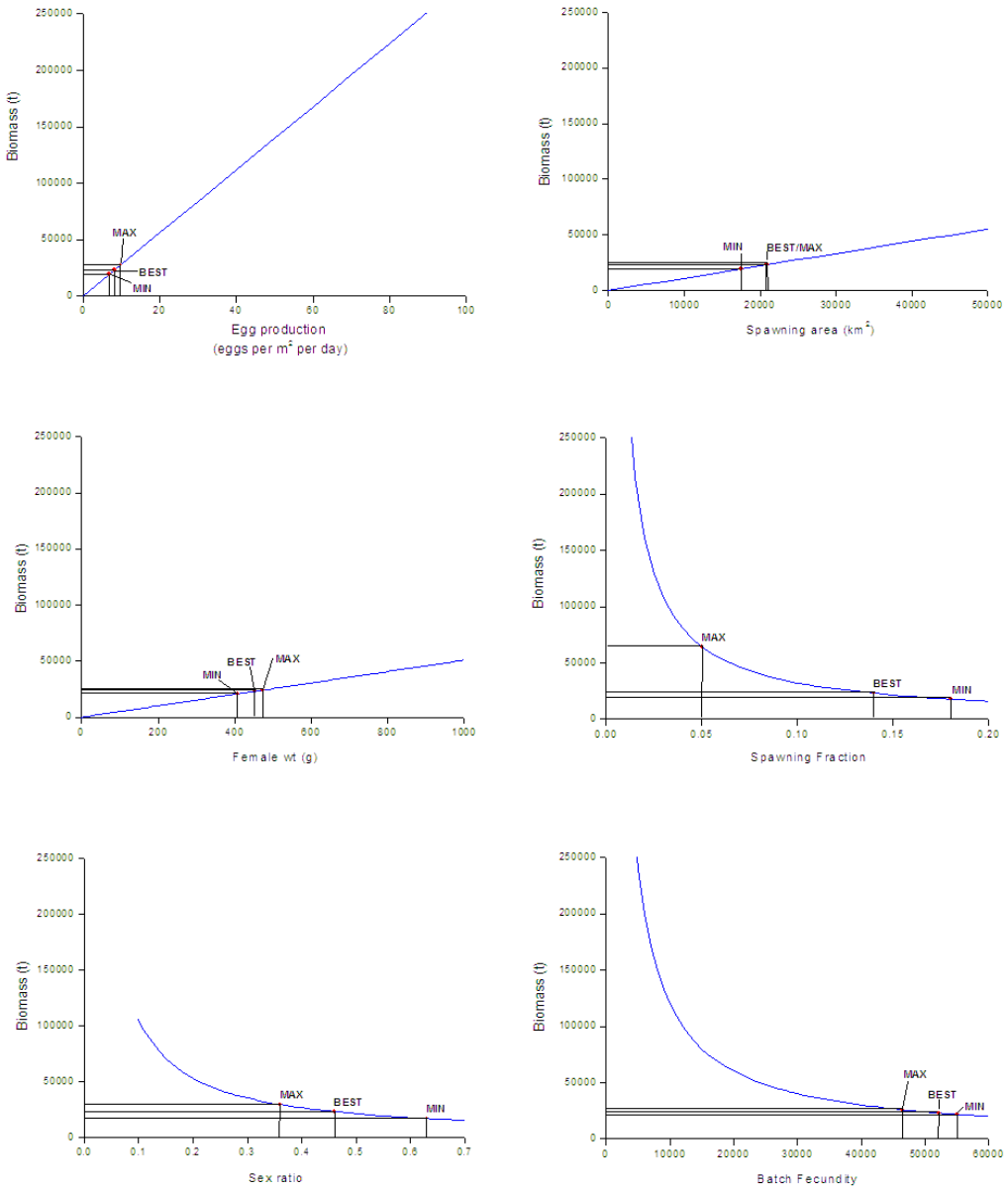

Figure 10.9. Sensitivity analysis showing minimum, "best" and maximum values of biomass calculated from upper, best and lower parameter estimates applied in the DEPM model for eastern Australia.

10.4 Discussion

10.4.1 Mean daily egg production

The large differences in the number of eggs collected using the CalVET and bongo nets in southern Australia in 2005 reflects the higher quantity of water sampled by bongo nets compared to CalVET nets. The finding that estimates of mean egg density are higher for the CalVET net than the bongo net suggests that the type/size of plankton net affects the estimates of egg production. This result has implications for other DEPM studies that typically use one type of net (usually a CalVET net) to estimate egg production. At this stage it is unclear which of the estimates of egg production (i.e. those obtained using CalVET or bongo nets) are more suitable for estimating egg production, or why the estimates differ. On this basis, we used data from the bongo nets (which are more conservative, and also available for eastern Australia) to determine the "best" estimates of egg production for this study.

There are several other reasons why the estimates of mean daily egg production for both southern and eastern Australia may be conservative. Most importantly, estimates of egg production obtained using the method of McGarvey and Kinloch (2001) are consistently lower than those obtained using the internationally accepted method of Piquelle and Stauffer (1985). For example, the estimate of mean daily egg production of sardine off eastern Australia in July 2004 (i.e. 35.63 eggs.m^{-2}) obtained using the method of McGarvey and Kinloch (2001) was almost 50% lower than the value obtained using the internationally accepted linear version of the exponential mortality model (i.e. 69.96 eggs.d^{-1}.m^{-2}, Appendix 10.1) of Piquelle and Stauffer (1985). As shown in Figures 10.8 and 10.9, variations in estimates of egg production have directly proportional effect on estimates of spawning biomass, i.e. a twofold increase in egg production results in a doubling of the spawning biomass. The estimates of daily egg mortality (i.e. Z = 0.1, 0.3, 0.5) used to calculate the minimum, best and maximum estimates of egg production in this study are also conservative values for small pelagic fishes (see Bunn *et al.* 2000).

The results of the surveys conducted off southern Australia also show that the type/size of net has a large effect on the estimate of spawning area. A much higher proportion of stations were identified as positive (i.e. containing eggs) using the bongo net than the CalVET. This finding suggests that estimates of spawning area obtained using CalVET nets may be negatively biased, especially when eggs are in low abundance. Bongo nets appear to be more suitable than CalVET nets for estimating the spawning area of *S. australasicus* in southern Australia. All estimates of spawning biomass presented in this study were calculated using data from bongo nets. Only the

methods used to estimate spawning area (i.e. uniform grids, contiguous grids, VNN method) were varied to establish minimum, best and maximum estimates of spawning area.

Eggs of *S. australasicus* were widespread and abundant in waters of southern Australia during the surveys conducted in February and March 2005. This finding supports adult reproductive data presented in Chapter 6 of this report that suggests the peak spawning season of *S. australasicus* in southern Australia extends from December to March. Hence, surveys conducted off southern Australia in February-March 2005 appear to have been suitably timed for a DEPM study.

The estimates of spawning area used to calculate the spawning biomass of *S. australasicus* in southern Australia during 2005 may be conservative as significant levels of spawning occurred outside the area sampled in this study. For example, results provided in Chapter 8 show that large numbers of *S. australasicus* eggs were collected from the western GAB during 2006. It is not clear whether significant spawning occurs outside the area surveyed off the east coast, but the occurrence of eggs on the southern most transects of the July 2004 survey suggests that spawning could have occurred further south.

The results from the surveys conducted off eastern Australia suggest that *Scomber* eggs are widespread and abundant in shelf waters between Indian Head (southern Qld) and Newcastle (central NSW) during winter and spring. The higher egg abundances recorded during October 2003 compared to July 2004 suggest that the peak spawning season may occur after July. Adult reproductive data presented in chapter 6 of this report suggest that future surveys would ideally be conducted during August-September. Much higher estimates of egg production (23.01-33.00 eggs per m^2 per day) were obtained in October 2003 than in July 2004, however spawning biomass could not be estimated for this survey due to limitations in the sampling design (e.g. non-parallel transects). It is notable that if egg production estimates for October 2003 were used to calculate spawning biomass for July 2004, the best estimate of spawning biomass for eastern Australia would have been 77,648 t rather than 23,009 t.

Data from eastern Australia show the importance of implementing the correct sampling design when estimating spawning area. To obtain reliable estimates of spawning area it is imperative that surveys are designed along parallel transects with the minimum logistically feasible distances between transects and stations. Inadequacies in the sampling design used off eastern Australia (i.e. non-parallel transects, too few stations) in October 2003 prevented the data from this survey

being used to estimate spawning area. The design of the July 2004 survey was suitable for estimating spawning area, but this survey was conducted outside the peak spawning season of *S. australasicus* off eastern Australia, and estimates of spawning area (and spawning biomass) obtained from this survey may be negatively biased.

The distances between transects and sites are critical elements of the sampling design. Estimates of spawning area are positively correlated with grid size. Therefore estimates of spawning area increase if grid sizes are enlarged. However, our results from southern Australia show that the effect of grid size on spawning area and estimates of spawning biomass can be smaller than the effect of net type (e.g. bongo or CalVET) in determining whether sites are positive or negative, i.e. with or without eggs, respectively. It is also important that the sampling design (and grids) covers the entire spawning area, which was does not appear to have been the case for the surveys of southern Australia. Results obtained in this study suggest that if the survey design is appropriate, reliable estimates of spawning area can be calculated using both the contiguous "original" method and the VNN approach.

10.4.2 Total mean daily fecundity

Robust estimates of all parameters were obtained from the large number of adult samples collected from southern Australian waters between 2001 and 2006. Estimates of these parameters for southern Australia are remarkably similar to those obtained for the morphologically and genetically similar *S. japonicus* in waters off California and Japan (Dickerson *et al.* 1992). The similarity of these parameters for these two separate species of *Scomber* in several locations, suggests that these parameters may not vary markedly within the Australian population of *S. australasicus*. Hence, the parameters obtained from southern Australia may be suitable for calculating preliminary estimates of the spawning biomass of *S. australasicus* off eastern Australia.

The higher estimate of mean female weight in southern Australia (452 g) compared to eastern Australia (267 g) may reflect differences in the locations from which samples were collected in the two regions. Most of the samples from eastern Australia were collected from inshore sites, whereas some of the samples from southern Australia were collected from offshore waters. Mean female weights in samples from inshore waters of southern Australia (i.e. the two gulfs) were significantly lower (<470 g) that those for samples obtained further offshore (>500 g). Dickerson *et al.* (1992) presented similar estimates of mean female weight for samples of *S. japonicus* obtained from the Southern Californian Bight (i.e. 355.05 – 528.55 g). Estimates of mean female weight in

samples of *S. japonicus* obtained by Yamada *et al.* (1998) from waters off Japan (i.e. 402.3 – 797.2 g) were higher than those obtained in the present study or by Dickerson *et al.* (1992). As few adult samples were collected from offshore waters of eastern Australia, but large numbers of eggs were obtained from sites located over the mid-shelf, we suggest that estimates of adult reproductive parameters obtained from these inshore fish may not be representative of the spawning population. On this basis, estimates of mean female weight from southern Australia were used as minimum, best and maximum estimates in calculations of the spawning biomass of *S. australasicus* off eastern Australia. Obtaining representative adult samples from eastern Australia during the spawning season is a high priority for future research on *S. australasicus* in Australia.

The estimate of mean batch fecundity provided in this report (i.e. 52,182 eggs) was based on 58 females with hydrated oocytes. In contrast, Dickerson *et al.* (1992) presented an estimate of mean batch fecundity (68,356 eggs) based on 13 females with oocytes in the late migratory nucleus stage and the estimate of Yamada *et al.* (1998)(i.e. 89,200 eggs) was based on 12 females with hydrated oocytes. These findings suggest that our estimates of mean batch fecundity are, by international standards, based on relatively large numbers of female fish and are likely to be robust. However, further investigations are warranted regarding the spatial variations in the size and fecundity of females, such as those between gulf and shelf waters of South Australia.

The estimates of mean spawning fraction obtained in the present study (0.14) is considerably higher than the overall estimate for *S. japonicus* in waters off California (0.87), but lower than the estimate for the peak spawning month in that location (i.e. 20.6%, Dickerson *et al.* 1992). The mean spawning fraction for *S. japonicus* in waters off Japan reported by Yamada *et al.* (1998) is 0.17. Hence, our estimates of spawning fraction are similar to those obtained in previous studies of similar species. Our estimates are likely to be robust because they are based on a large number of mature females (i.e.702), compared to previous studies in California (271) and Japan (192) by Dickerson *et al.* (1992) and Yamada *et al.* (1998), respectively.

10.4.3 Spawning biomass

As discussed above, there are several reasons why the best estimates of spawning biomass for southern and eastern Australia may be conservative (i.e. negatively biased). In both cases the estimate of egg production was calculated using a method (see McGarvey and Kinloch 2001), which is known to produce conservative estimates of egg production. In addition, the estimate of egg mortality used to calculate egg production was conservative. For southern Australia, there is

also clear evidence of significant spawning activity outside the area surveyed (i.e. in the western GAB), which suggests that the estimates of spawning areas and spawning biomass for southern Australia are negatively biased. Spawning may also have occurred outside the area surveyed off eastern Australia and the estimate of egg production for 2004 may be negatively biased.

Estimates of adult parameters for southern Australia appear to be robust, as they were based on relatively large samples of adult fish collected over several years, and are comparable to those obtained for a similar species in different locations. A major uncertainty, and potential source of positive bias for the estimates of spawning biomass off eastern Australia, lies with the use of reproductive data obtained from fish collected off southern Australia. If *S. australasicus* off eastern Australia does not reach similar sizes to those off southern Australia, then the estimates of spawning biomass calculated using adult parameters from southern Australia may be biased. However, the effect of this bias may be small as the estimate of spawning biomass obtained using reproductive data from eastern Australia (i.e. 29,578 t) is similar to the estimate calculated using adult data from southern Australia (23,009 t). Obtaining the representative samples of *S. australasicus* for eastern Australia that are required to estimate adult reproductive parameters is a high priority for future management of this species.

10.4.4 Sensitivity analysis

The results of the sensitivity analyses provide us with considerable confidence that the estimates of spawning biomass in the survey areas off southern and eastern Australia, based on the conservative method used to obtain estimates of egg production, lie within the range of 45,000-68,000 t and 20,000-60,000 t, respectively. For the reasons outlined above, these ranges and the best estimates of spawning biomass (i.e. 56,228 and 23,019 tonnes, respectively) are considered to be conservative and suitable for developing precautionary harvest strategies for this species. However, the sensitivity of estimates of spawning biomass to variations in estimates of spawning fraction emphasises the importance of measuring the degeneration rates of post-ovulatory follicles to ensure that estimates of spawning fraction are robust.

10.4.5 Future DEPM Surveys

Our results suggest that the DEPM is a suitable tool for assessment of Australia's *S. australasicus* populations. However, several important technical refinements are required to maximize the reliability of the estimates of spawning biomass that are obtained using this method. The highest immediate priorities for additional research are: 1) developing cost-effective and reliable genetic

techniques for identifying early stage eggs; 2) conducting the experiments required to develop temperature-egg development keys for this species; 3) establishing locations/methods for collecting samples needed to estimate the adult reproductive parameters of *S. australasicus* in eastern Australia; and 4) measuring the degeneration rates of post-ovulatory follicles to ensure that estimates of spawning fraction are robust. Additional surveys to support application of the DEPM should not be conducted until these research topics are properly addressed.

10.5 Acknowledgements

The authors would like to acknowledge the efforts of the support staff and crews of the research vessels RV Ngerin and RV Bluefin for their considerable efforts during the blue mackerel ichthyoplankton surveys. Dr Francisco Neira and Mr John Keane (TAFI) led the surveys off eastern Australia, sorted the samples and collated ichthyoplankton data. Mr Wetjens Dimmlich, Mr Nathan Strong, Mr David Schmarr, Mr Paul Van Ruth, Mr Richard Saunders, Mr Alex Ivey, Mr David Fleer and Ms Michelle Roberts helped collect and sort plankton samples and catch adult blue mackerel during research surveys. Ms Sandra Leigh, Mr Chris Leigh and Dr Bill Breed (University of Adelaide Anatomy Department) conducted the histological analyses. We thank Cameron Dixon (SARDI) and Dale McNeil (SARDI) for providing useful comments in their reviews of this chapter.

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10.7 Appendices

10.7.1 A preliminary investigation of the spawning biomass of sardine (pilchard, *Sardinops sagax*) off eastern Australia. Report to New South Wales Department of Primary Industries

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Date: March 2007

This publication may be cited as:
Ward *et al.* (2007). *A preliminary investigation of the spawning biomass of sardine (pilchard,* Sardinops sagax*) off eastern Australia.* Final Report for New South Wales Department of Primary Industry. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

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Preface

The daily egg production method (DEPM) has been used to estimate the spawning biomass of sardine (pilchard, *Sardinops sagax*) off California, South Africa, Western Australia, South Australia and southern Queensland. Prior to the present investigation, the method had not been used for stock assessment of *S. sagax* off the coast of New South Wales. As part of a project to evaluate the use of the DEPM to estimate the spawning biomass of blue mackerel *Scomber australasicus* in southern and eastern Australia, ichthyoplankton surveys were conducted along the east coast from 2002 to 2004. Large numbers of *S. sagax* eggs were collected in a survey conducted in southern Queensland and northern NSW in July 2004. This report uses samples obtained during that survey to provide a preliminary estimate of the spawning biomass of *S. sagax* off eastern Australia in July 2004 and identifies options for future assessment and management of *S. sagax* in this region.

Acknowledgments

Funds for the ichthyoplankton survey on which this report is based were provided by the Fisheries Research and Development Corporation (FRDC) and Australian Fisheries Management Authority (AFMA). The Australian Maritime College (AMC) and South Australian Research and Development Institute (SARDI) provided considerable in-kind support for the study. The authors thank the master and crew of the *FTV Bluefin* for their efforts during the survey. Dr Francisco Neira and Mr John Keane (TAFI) led the survey, sorted the samples and collated the data. Dr Tony Fowler and Dr Stephen Mayfield (SARDI Aquatic Sciences) provided valuable comments on a draft of the report.

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Executive Summary

1. This report provides information to support the future assessment and management of sardine (pilchard, *Sardinops sagax*) off eastern Australia.
2. Existing data and published parameter estimates were combined to provide best, minimum and maximum estimates of spawning biomass using the Daily Egg Production Method (DEPM).
3. Egg data were obtained from an ichthyoplankton survey conducted between Bundaberg and Newcastle during July 2004 as a study of blue mackerel, *Scomber australasicus*.
4. NSW DPI provided some reproductive data for sardine off southern NSW. Other adult parameter estimates were collated from previous Australian studies of this species.
5. The total area sampled during the July 2004 ichthyoplankton survey was ~41,585 km^2.
6. Sea surface temperatures ranged from 17.4 to 22.1 °C and were strongly influenced by the East Australian Current (EAC).
7. A total of 2,441 *S.sagax* eggs was collected from 85 stations. High densities of eggs were recorded between Cape Byron and Newcastle.
8. The best estimate of spawning area obtained using the Voronoi near neighbour method to estimate grid size was 9,363 km^2. Spawning may have occurred south of the area surveyed.
9. The best estimate of mean daily egg production (P_0) obtained using the linear version of the exponential mortality model was 69.96 $eggs.day^{-1}.m^{-2}$.
10. Best estimates of reproductive parameters were: female weight, W = 51.35 g; sex ratio, R = 0.56; spawning fraction, S = 0.14; and batch fecundity, F = 15,108 hydrated oocytes.
11. The best estimate of spawning biomass off eastern Australia during July 2004 was ~28,809 t. Minimum and maximum estimates were 9,161 and 58,673 t, respectively.
12. Spawning biomass estimates were relatively insensitive to variations in spawning area, female weight, sex ratio and batch fecundity. Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000–35,000 t.
13. Estimates of spawning biomass provide a context for assessing the suitability of recent catch levels. The highest annual catch of ~1,800 t is ~6.2% of the best estimate of spawning biomass, suggesting that fishing is being conducted within sustainable limits.
14. Significant increases in annual catches would require additional ongoing stock assessment, ideally involving application of the DEPM

1. Introduction

This report was commissioned by the NSW Department of Primary Industries to provide information to support future assessment and management of *S.sagax* off eastern Australia. It was undertaken because of recent interest in increasing the annual catch of *S. sagax* from NSW waters. This study utilises egg data collected in a recent FRDC funded study of blue mackerel. It was agreed from the outset that the present project would utilise data obtained from the literature relating to adult reproductive parameters of sardine, rather than specifically collect adult samples for this purpose. This approach is consistent with that recommended by Hunter and Lo (1997) who acknowledged that the use of historical data to estimate adult parameters is imperfect, but is preferable to operating in the absence of any scientific information.

1.1 Daily Egg Production Method

The concept of estimating fish biomass from estimates of the total number of eggs produced in a spawning season, mean fecundity and sex ratio was initially proposed by Hansen and Apstein (1887 in Fletcher 1996)(1887 in Fletcher *et al.* 1996). Prior to the 1980s, all attempts to apply this concept were relatively unsuccessful. Successful application of egg production techniques was facilitated by the development of methods for determining batch fecundity, i.e. counting hydrated oocytes, and estimating spawning fraction, i.e. identifying and aging post-ovulatory follicles.

The Daily Egg Production Method (DEPM) was developed to estimate the spawning biomass of northern anchovy, *Engraulis mordax* (Lasker 1985). The premise of the method is that spawning biomass can be calculated from estimates of the number of eggs produced per day within the spawning area (mean daily egg production, P_0) and the average number of eggs spawned per day per unit mass of the population (mean daily fecundity). Prerequisites for the application of the DEPM are that: fish are multiple (i.e. batch or serial) spawners; eggs can be caught in plankton nets without significant losses and identified reliably; egg surveys are conducted during the main (ideally peak) spawning season and cover the entire spawning area; levels of daily egg production and mortality are consistent across the spawning area; and representative samples of spawning and non-spawning adults are collected during the survey period (Parker 1980; Lasker 1985; Alheit 1993). The degree to which these prerequisites are met affects the accuracy and precision of estimates of spawning biomass. Some assumptions, e.g. that the levels of daily egg production and mortality are consistent across the spawning area, are rarely, if ever, fully upheld and reduce the confidence in estimates of spawning biomass that are obtained using the DEPM.

Spawning biomass (*B*) is calculated according to equation 1:

$$B = \frac{P_0 \cdot A \cdot W}{R \cdot F \cdot S} \qquad \text{…….. Eq. 1}$$

where P_0 is mean daily egg production per unit area, A is the spawning area, W is the mean weight of mature females, R is the sex ratio (proportion of females by weight), F is the mean batch fecundity (number of oocytes in a batch) and S is the mean spawning fraction (proportion of mature females that spawn each night) (Lasker 1985; Parker 1985).

Estimates of each parameter typically have high levels of associated variance (Stratoudakis *et al.* 2006). This factor combined with the multiplicative nature of the model means that estimates of spawning biomass are usually accurate but imprecise, e.g. a coefficient of variation of 30% or more is considered normal (Smith 1993; Hunter and Lo 1997; Stratoudakis *et al.* 2006). Sensitivity analyses have shown that estimates of spawning biomass are more sensitive to variations in estimates of mean daily egg production and total spawning area than to variations in adult reproductive parameters (Ward *et al.* 2005; Stratoudakis *et al.* 2006). Stratoudakis *et al.* (2006) noted that Although recent methodological elements may … improve the precision of DEPM estimates …, it is unlikely that the DEPM will ever become a very precise method. Depending on resource management needs and alternative options for fisheries-independent estimation of biomass, the above limitation may be considered crucial or secondary … in southern and eastern Australia, [where alternative methods for estimation of sardine biomass are not currently available], the DEPM is currently considered to provide the best available means to monitor the population … (Ward *et al.* 2001a; Gaughan *et al.* 2004).

The DEPM has been used to estimate the spawning biomass of *S. sagax* in California (Lo and Macewicz 2004), South Africa (e.g. van der Lingen and Huggett 2003), Western Australia (e.g. Gaughan *et al.* 2004), South Australia (Ward *et al.* 2001a)) and southern Queensland (Staunton - Smith and Ward 2000). The review by Stratoudakis *et al.* (2006) confirmed the suitability of the DEPM for estimating the spawning biomass of *S. sagax*.

A preliminary investigation of the spawning biomass of *S. sagax* in southern Queensland showed that the main spawning season was during July to October and that spawning occurred in the region between Sandy Cape and the Queensland-NSW border (Staunton-Smith and Ward 2000). No data or samples were collected from waters off NSW. The authors concluded that the spawning biomass of *S. sagax* in waters off southern Queensland exceeded 25,000 t in both 1997 and 1998. Information in related papers is consistent with the hypothesis that *S. sagax* migrates northward during winter into the waters of southern Queensland to spawn (Ward and Staunton-Smith 2002) and that larvae are transported southwards into temperate nursery areas by prevailing currents (Ward *et al.* 2003b). These findings suggest that *S. sagax* off eastern Australia, or at least in southern Queensland and northern NSW, belong to a single stock.

1.2 Previous studies of sardine off eastern Australia

Relatively few studies have been conducted on the fisheries biology of *S. sagax* off eastern Australia. Blackburn (1949) provided preliminary information on the age, size, growth, distribution and spawning seasonality of this species in NSW waters. As discussed above, Staunton-Smith and Ward (2000) and Ward and Staunton-Smith (2002) provided information on the fisheries biology of *S. sagax* and calculated preliminary estimates of spawning biomass off southern Queensland. Ward *et al.* (2003b) identified potential migration-dispersal pathways off eastern Australia. (Uehara *et al.* 2005) presented data on larval growth off northern NSW. Information on the distribution of eggs and/or larvae has been provided in several ichthyoplankton studies (Gray 1996; Gray 1997; Smith 2003).

1.3 NSW Sardine Fishery

S. sagax has been taken from NSW waters for many years, and is currently targeted by fishers in the NSW Ocean Hauling Fishery using bait nets and purse-seine nets. Up until 2002/03 annual catches in NSW waters remained below 500 t. Catches increased rapidly after 2002/03 and reached ~1800 t in 2005/06 (Fig. 1)(NSW Fisheries data). Data for the 06/07 financial year were incomplete when this report was prepared.

Currently, the NSW Ocean Hauling Fishery is managed through input controls, including limited entry, gear and vessel restrictions and spatial and temporal closures. No output controls are currently applied to the capture of *S. sagax*.

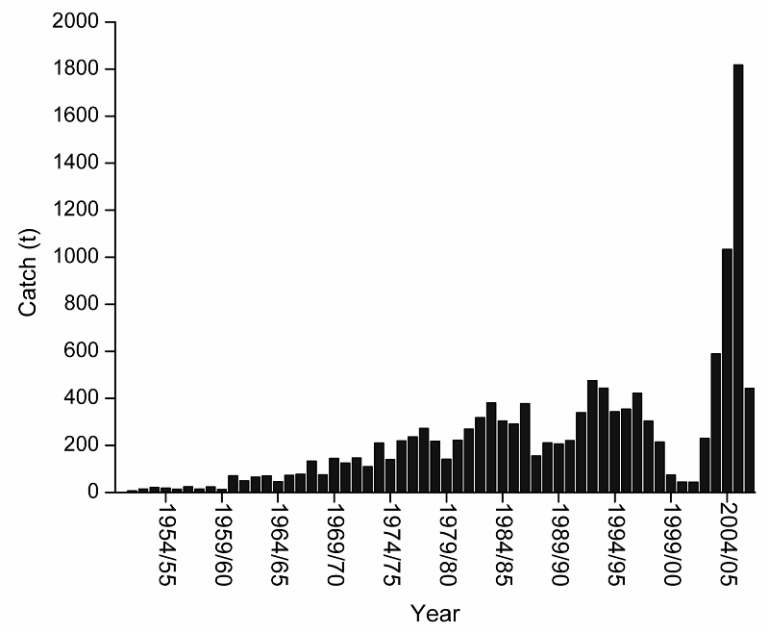

Figure 1. Annual catch (t) of *S. sagax* by financial year in the NSW Ocean Hauling Fishery.

1.4 Blue Mackerel Study

In 2002, the Fisheries Research and Development Corporation (FRDC) and Australian Fisheries Management Authority (AFMA) funded a project (2002/061) to evaluate the suitability of the DEPM for stock assessment of blue mackerel, *Scomber australasicus*, in southern Australia. As part of that project a series of ichthyoplankton surveys were conducted off eastern Australia. Large numbers of *S. sagax* eggs were collected during the survey, which was conducted between Bundaberg, Queensland and Newcastle, NSW during July 2004. This report utilises egg abundance and SST data collected during that survey.

The objectives of the report are:

1. To describe the patterns of distribution and abundance of *S. sagax* eggs off eastern Australia in July 2004;
2. To calculate estimates of spawning area (A) and mean daily egg production (P_0) from data collected during the survey;
3. To collate data on *S. sagax* provided by NSW DPI and parameter estimates presented in previous Australian publications to establish estimates of mean female weight (W), mean sex ratio (R), mean batch fecundity (F) and mean spawning fraction (S);
4. To calculate a best, minimum and maximum estimates of the spawning biomass of *S. sagax* off eastern Australia during July 2004;
5. To conduct sensitivity analyses to determine the effect of variations in each parameter on estimates of spawning biomass;
6. To use information obtained in the study to identify options for the future assessment and management of *S. sagax* off eastern Australia.

2. Methods

2.1 Study Area and Environmental Variables

2.1.1 Study area

An ichthyoplankton survey was conducted from *RTV Bluefin* in shelf waters off eastern Australia during July 19–28, 2004. Plankton samples were collected at 85 stations on 21 transects between Bundaberg, Queensland and Newcastle, New South Wales (Fig. 2A).

2.1.2 Water temperature

At each station (Fig. 2A), a vertical temperature profile was obtained by lowering a *Sea-Bird* Conductivity-Temperature-Depth (CTD) instrument to within 5 m of the seabed or to a maximum depth of 200 m. Sea surface temperature (SST, °C) and salinity (ppt) data were extracted from each profile at a depth of 3 m. Temperature-salinity-egg abundance (TSE) plots were prepared using classed-post maps in Surfer™ Version 8 software. Contour maps of SST were prepared using minimum curvature algorithms in Surfer™.

2.2 Daily Egg Production and Spawning Area

2.2.1 Plankton sampling

Plankton samples were collected at each station using a bongo net (0.6 m diameter; 3 m long; 300 and 500 μm mesh). During each tow, the bongo net was deployed to within 5 m of the seabed or to a maximum depth of 200 m and retrieved vertically at a speed of~1 $m.s^{-1}$. General Oceanics™ 2030 flow-meters and factory calibration coefficients were used to estimate the distance travelled by the nets during each tow. Samples from the two nets were washed into the cod-ends, combined in a sample jar and fixed in 98% ethanol. Selected plankton samples were fixed using 5% buffered formaldehyde and seawater.

2.2.2 Laboratory analysis

S. sagax eggs in plankton samples were identified using published descriptions (White and Fletcher 1996; Neira *et al.* 1998). Eggs were staged, assigned approximate ages and counted according to descriptions and temperature-development keys in White and Fletcher (1996).

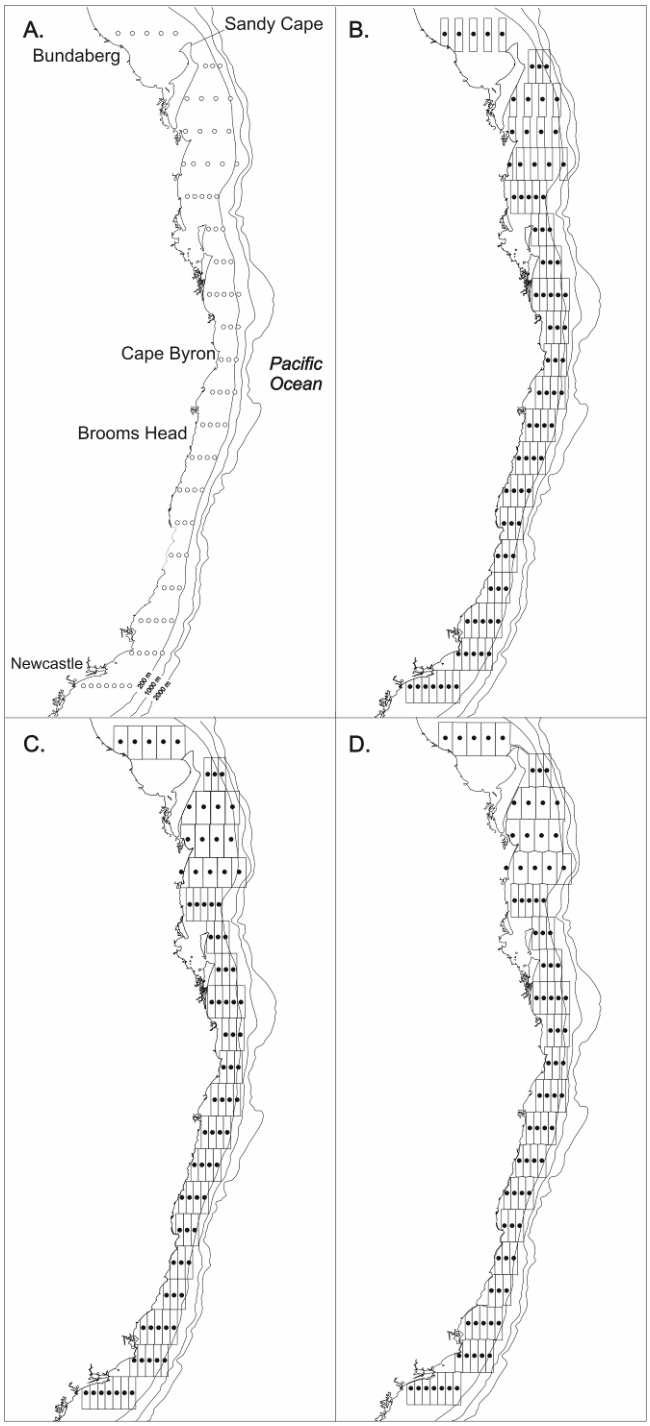

Figure 2. Map of Australian east coast showing: A) locations where samples were collected during the July 2004 ichthyoplankton survey, B) equal-sized grid areas surrounding each station, C) contiguous grid areas surrounding each station, and D) Voronoi nearest neighbour grid areas for each station.

2.2.3 Egg density

The number of eggs of each stage under one square metre of water (P_t) was estimated at each site according to equation 1:

$$P_t = \frac{C.D}{V} \qquad \text{…… Eq. 1}$$

where C is the number of eggs in each sample, V is the volume filtered (m^3), and D is the depth (m) to which the net was deployed (Smith and Richardson 1977). Plots of egg distribution and abundance were prepared using MapInfo Professional Version.8 software.

2.2.4 Spawning time and density weightings

Previous studies have shown that *S. sagax* in Australian waters spawn at ~2200 to 0200 hours (e.g. Staunton-Smith and Ward 2000; Ward *et al.* 2001a). Ages were assigned to day-1 eggs (i.e. stages 0–24 hours old) by subtracting the estimated spawning time (0200 hours) from the sampling time. Ages of day-2 eggs were assigned using the same approach, but an additional 24 hours was added to their ages. Densities of day-1 and day-2 eggs were weighted according to the relative size of the area from which they were taken.

2.2.5 Spawning area

After the survey was completed, the survey area was divided into a series of grids approximately centred on each sampling station (Fig. 2B–D). Three methods were used to divide the survey area: equal-sized grid areas (Fig. 2B), contiguous grid areas (Fig. 2C) and Voronoi nearest neighbour (VNN) grid areas (Fig. 2D). The area represented by each station (km^2) was calculated using MAPINFO® software. The sampling area was defined as the total area of grids. The spawning area (A) was defined as the total area of grids where live, Stage 1–8 (i.e. 0–24 hour old) *S. sagax* eggs were found.

2.2.6 Daily egg production and mortality

Mean daily egg production (P_0) was calculated from estimates of egg age and density at each station using three methods: 1) the exponential egg mortality model (Picquelle and Stauffer 1985); 2) the linear version of the exponential egg mortality model (Picquelle and Stauffer 1985); and 3) the method of (McGarvey and Kinloch 2001).

The exponential egg mortality model has the form:

$$P_t = P_0 e^{-zt} \qquad \text{Eq. 2}$$

where P_t is density of eggs of age t and z is the instantaneous rate of egg mortality.

The linear version of the exponential egg mortality model is:

$$lnP_b = \ln(P_i) - Zt \qquad \text{……. Eq. 3}$$

where P_i is the density of eggs of age t at site i and Z is the instantaneous rate of egg mortality.

Estimates of mean daily egg production obtained using the linear version of the exponential mortality model have a strong negative bias, therefore a bias correction factor was applied following the equation of Picquelle and Stauffer (1985):

$$P_0 = e^{(\ln P_b + \sigma^2/2)} \qquad \text{……Eq. 4}$$

where σ^2 is the variance of the estimate of biased mean daily egg production (P_b).

The method of McGarvey and Kinloch (2001) assumes that:

$$P_0 = \frac{\overline{P}Z}{1-e^{-2Z}} \text{ if } Z > 0 \qquad \text{…….Eq. 5}$$

where $\overline{P}$ is the non-zero mean egg density and Z is egg mortality. This method of estimating mean daily egg production from survey data requires that assumptions are made regarding egg mortality (Z). In this study, P_0 was calculated using of the mean of the two egg mortality rates estimated using the linerar and exponential versions of the egg mortality model (0.6).

2.3 Adult Reproductive Parameters

2.3.1 Data Sources

No samples of adult *S. sagax* were collected during the surveys conducted off eastern Australia in July 2004. NSW Department of Primary Industries provided some data for adult *S. sagax* from southern NSW. We collated parameter estimates from all relevant studies of *S. sagax* in Australia to calculate estimates of each adult reproductive parameter for this study. The following sections describe the types of methods that can be used to estimate these adult reproductive parameters, and are based on the methods used in South Australia. Details of the specific methods used in each previous study are not repeated in the present report but obtained from the methods sections of those studies (see Table 3 for references).

2.3.2 Female weight

Each mature female in samples is weighed ($\pm$ 0.01 g). The mean weight of mature females in the population is usually calculated from the average of sample means weighted by proportional sample size:

$$W = \overline{\left[\overline{W_i} * \frac{n_i}{N} \right]} \qquad \text{Eq. 6}$$

where $\overline{W_i}$ is the mean female weight of each sample *i*; *n* is the number of fish in each sample and *N* is the total number of fish collected in all samples.

2.3.3 Male weight

Mean male weight is calculated using the same method used for mean female weight.

2.3.4 Sex ratio

The mean sex ratio of mature individuals is typically calculated from the average of sample means weighted by proportional sample size:

$$R = \overline{\left[\overline{R_i} * \frac{n_i}{N} \right]} \qquad \text{Eq. 7}$$

where n is the number of fish in each sample, N is the total number of fish collected in all samples and $\overline{R_i}$ is the mean sex ratio of each sample calculated from the equation:

$$\overline{R_i} = \frac{F}{(F+M)} \qquad \text{Eq. 8}$$

where F and M are the respective total weights of mature females and males in each sample.

2.3.5 Batch fecundity

Batch fecundity is usually estimated from ovaries containing hydrated oocytes using the methods of (Hunter *et al.* 1985). Both ovaries are weighed and the number of hydrated oocytes in ovarian sub-sections are counted and weighed. The total batch fecundity for each female is usually calculated by multiplying the mean number of oocytes per gram of ovary segment by the total weight of the ovaries. The relationship between female weight (ovaries removed) and batch fecundity is determined by linear regression analysis and used to estimate the batch fecundities of mature females in all adult samples. In the present study, the mean relationship between female weight (ovaries removed) and batch fecundity in the Australian population was estimated by fitting a linear regression to population means provided in previous studies.

2.3.6 Spawning fraction

Ovaries of mature females are typically sectioned and stained with haematoxylin and eosin. Several sections from each ovary are then examined to determine the presence/absence of post-ovulatory follicles (POFs). POFs are aged according to the criteria developed by Hunter and Goldberg (1980) and (Hunter and Macewicz 1985). The spawning fraction of each sample is estimated as the mean proportion of females with hydrated oocytes plus day-0 POFs ($d0$) (assumed to be 0–24 hrs old), day-1 POFs ($d1$, 24–48 hrs old) and day-2 POFs ($d2$, 48+ hrs old). The mean spawning fraction is then calculated from the average of sample means weighted by sample size:

$$S = \overline{\left[\overline{S_i} * \frac{n_i}{N} \right]} \qquad \text{Eq. 9}$$

where n is the number of fish in each sample, N is the total number of fish in all samples and $\overline{S_i}$ is the mean spawning fraction of each sample calculated from the equation:

$$\overline{S_i} = \frac{[(d0 + d1 + d2POFs)/3]}{n_i} \qquad \text{Eq. 10}$$

where $d0$, $d1$ and $d2$ POFs are the number of mature females with POFs in each sample and n_i is the total number of females within a sample.

2.4 Spawning Biomass

In this study, 'minimum', 'best' and 'maximum' estimates of spawning biomass were calculated using the minimum, best and maximum estimate of each parameter, respectively (see Eq. 1). The best estimate of each parameter was the value that we considered to be the most statistically and biologically robust, based on data collected during the present study and/or information obtained in previous studies. The estimates of spawning area and mean egg production are calculated from data obtained in the present study. The estimates of adult reproductive parameters are calculated from estimates of these parameters provided in previous studies. Minimum estimates were the values considered to be the most conservative. Maximum estimates were the least conservative values. Rationales for choosing the minimum, best and maximum estimates of each parameter are documented in the results and discussion of this report.

2.5 Sensitivity Analysis

Sensitivity analyses were undertaken to determine the effects of variations in each parameter on the estimates of spawning biomass. The sensitivity analyses were done by calculating estimates of spawning biomass using the best estimates of five parameters (e.g. *P, A, W, R, S)* and by varying the estimate of the parameter being tested (e.g. *F*) over an appropriate range of values. The sensitivity analyses of *P* and *A* were conducted over the range of values obtained using the three methods used to calculate these parameters in this report. The sensitivity analyses of *W, R*, *F* and *S* were conducted over the range of values obtained in previous Australian studies of this species.

3. Results

3.1 Environmental Variables

3.1.1 Sea surface temperature and salinity

Sea surface temperatures in the sampling area ranged from 17.4 to 22.1 °C (Fig. 3) and were strongly influenced by the East Australian Current (EAC, Fig. 4). Salinities ranged from 35.34 to 36.26 ppt and had a weak negative correlation with SST (Pearsons Coefficient = -0.32).

3.2 Distribution and Abundance of Eggs

A total of 2,411 live *S. sagax* eggs were collected at 30 of 85 (35.3%) stations on 21 transects between Bundaberg and Newcastle (Fig. 2). Most eggs (94%) were collected between Cape Byron and Newcastle. High egg densities were recorded at between Cape Byron and Brooms Head (Fig. 1, 2). Densities reached up to 600 eggs.m^{-2}. Few eggs were collected from the warm waters of the EAC (Fig. 3). The highest densities of eggs were sampled in water with SST between 18 and 20.5 °C and salinities between 35.35 and 35.5 ppt (Fig. 4, 5).

3.3 Spawning Area

Estimates of the areas sampled were 35,064 km^2 for equal-sized grids, 41,585 km^2 for contiguous grids and 42,062 km^2 for VNN grids. Estimates of spawning area obtained using these three methods were 8,643, 9,422 and 9,363 km^2, respectively (Table 1, Figs. 2 and 3).

The estimate of spawning area obtained using uniform-sized grids is negatively biased, as it does not include all parts of the area sampled. The estimate of spawning biomass obtained using the VNN method is considered to be the best estimate of spawning area and is marginally smaller than the estimate obtained using the contiguous grids. All estimates of spawning area may be negatively biased as the presence of eggs at four sites on the most southern transect suggests that spawning may have also occurred south of the survey area.

3.4 Daily Egg Production (P_0)

Estimates of P_0 and Z obtained using the data from the contiguous grids and the exponential egg mortality model (79.51 eggs.d^{-1}.m^{-2}; 0.74), linear version of the exponential egg mortality model (69.96 eggs.d^{-1}.m^{-2}; 0.53) and McGarvey and Kinloch's (2001) method (35.63 eggs.d^{-1}.m^{-2}; 0.60) are summarised in Table 2 (also see Fig. 6).

The estimate of P_0 obtained following bias correction using the linear version of the exponential egg mortality provides the best value for the calculation of spawning biomass. Application of the exponential version of the model assumes that residuals are normally distributed. This assumption is often violated, and estimates of P_0 in such cases are typically inflated by a few samples (outliers) that contain high densities of young eggs. The estimate of egg production obtained using the exponential version of the egg mortality model is a suitable estimate of the maximum P_0.

Mean daily egg production estimates obtained using the method of McGarvey and Kinloch (2001) are usually lower (more conservative) than those obtained using the exponential and/or linear versions of the exponential mortality model, and is used as our minimum estimate.

Table 1. Area sampled, spawning area (A) and spawning area as a proportion of the total area sampled using three different grid area methods.

Grid Area Method	Area sampled	A (km ^{2})	A/ Area sampled
Equal	35,064	8,643	0.25
Contiguous	41,585	9,422	0.23
Voronoi	42,062	9,363	0.22

Table 2. Estimates of P_0 and Z obtained using the exponential egg mortality model, linear version of the model and method described by McGarvey and Kinloch (2001).

Method	P_0 (eggs.d^{-1}.m^{-2})	Z
Exponential egg mortality model	79.51	0.74
Linear version of model	69.96	0.53
McGarvey and Kinloch (2001)	35.63	0.60

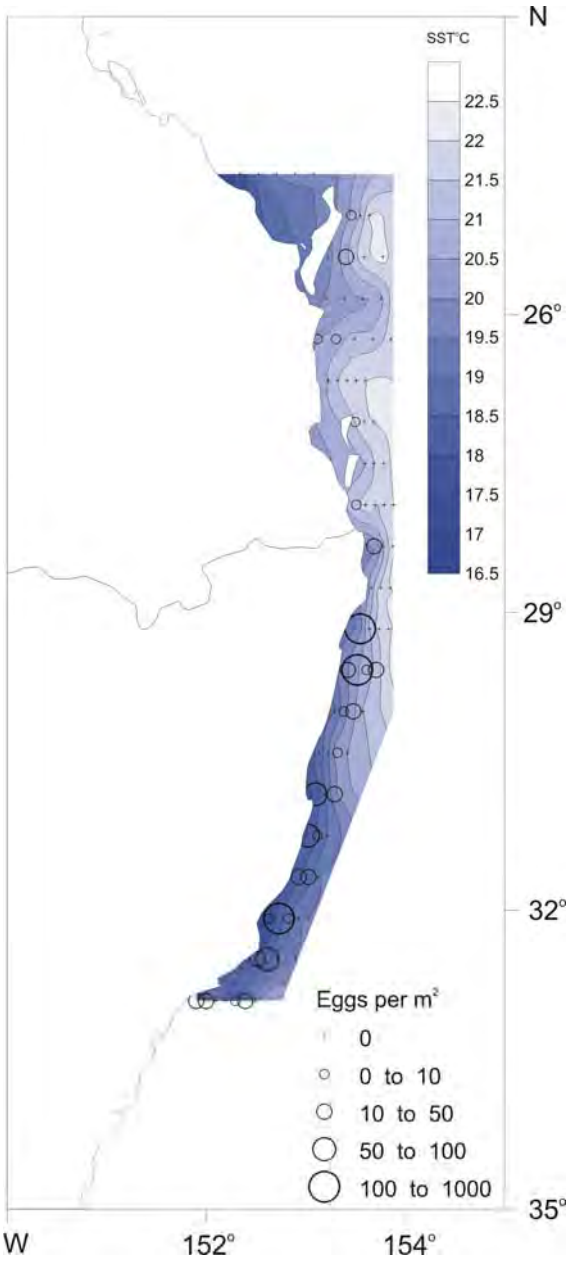

Figure 3. Distribution and abundance of *S. sagax* eggs in relation to sea-surface temperature in July 2004.

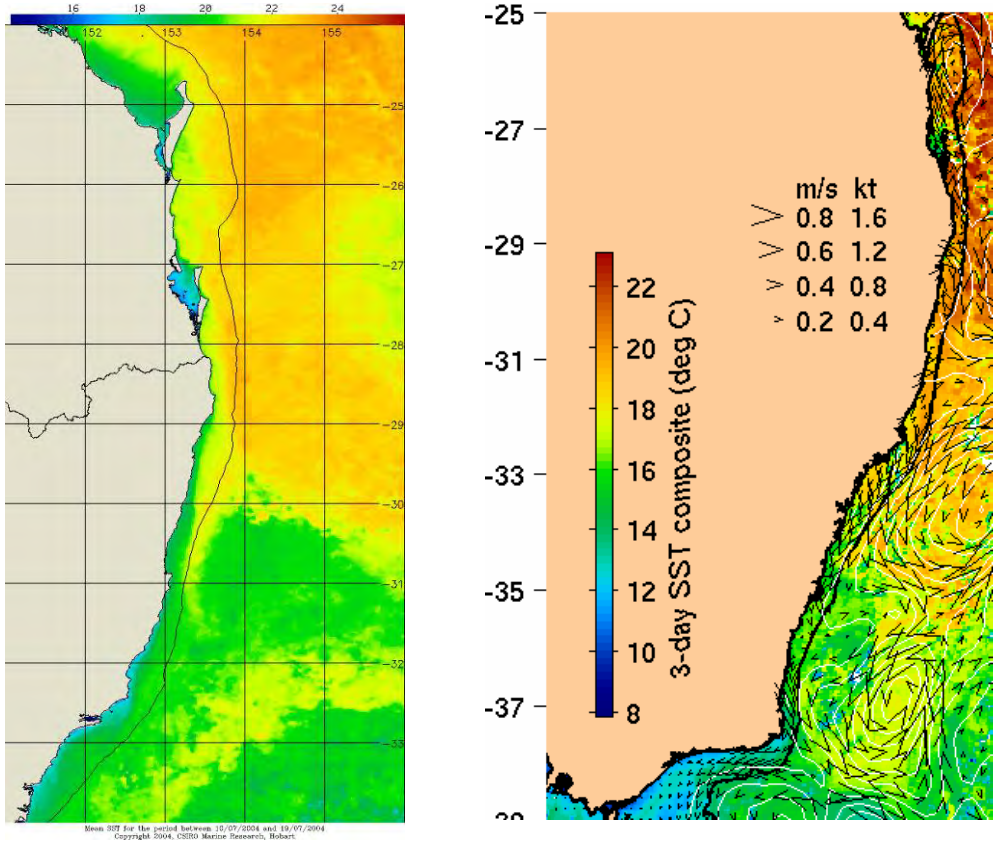

Figure 4. SST images of southern Queensland and northern NSW. (left) 10-19 July 2004 and (right) 22 July 2004. Shows current speed vectors (courtesy of CSIRO, CMAR, Hobart, http://www.cmar.csiro.au/).

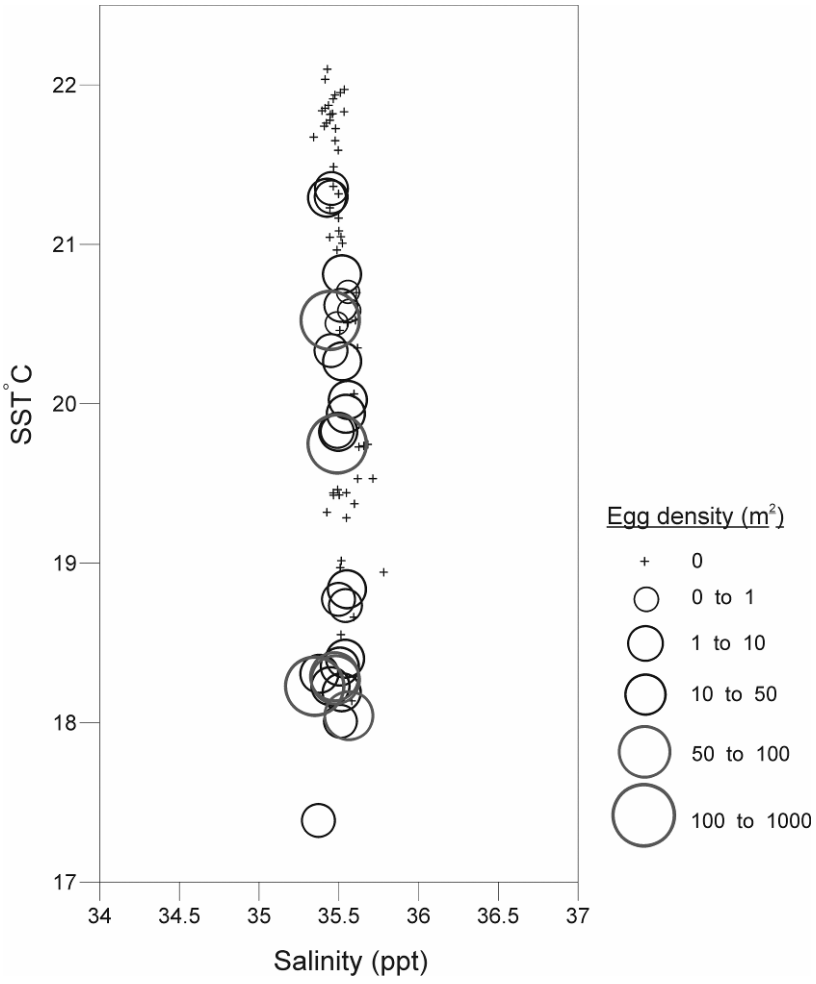

Figure 5. Relationship between egg density, sea-surface temperature and salinity.

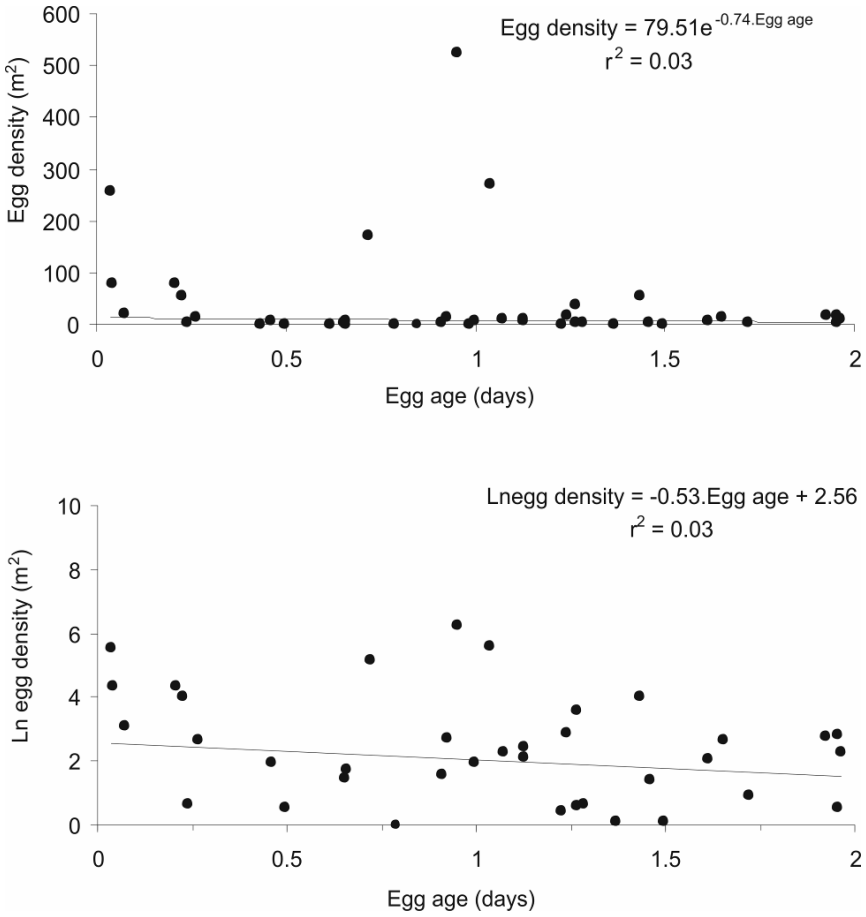

Figure 6. Fits of egg density and age data using (A) exponential and (B) log-linear versions of the egg mortality model.

3.5 Adult Reproductive Parameters

3.5.1 Mean female weight

The mean weight of mature females (*W*) collected from waters of southern NSW between November 2002 and July 2006 is shown in Figure 7. Mean estimates for each month ranged from 33.6 g in February to 85.46 g in December. The overall mean female weight for NSW samples was 59.02 g.

Estimates of mean female weight obtained in Australian studies conducted between 1991 and 2006 are shown in Table 3. Estimates for each study ranged from 34.6 in WA in 1992 to 73.5 g in South Australia in 2005. The overall mean female weight for Australian samples was 51.35 g. Estimates of mean female weight in southern Queensland in 1997 and 1998 were 44.1 and 47.8 g, respectively.

Mean female weight is positively correlated with spawning biomass. For the purposes of this study it is important that female weight is not overestimated. On this basis, we consider that the overall mean for Australian samples (51.35 g) is the best estimate of female weight for spawning biomass estimation, rather than the overall value for the NSW samples. The mean weight of mature females for southern Queensland (45.97 g) is a suitable minimum estimate of this parameter. The overall mean female weight for NSW samples (59.02 g) is a suitable maximum estimate.

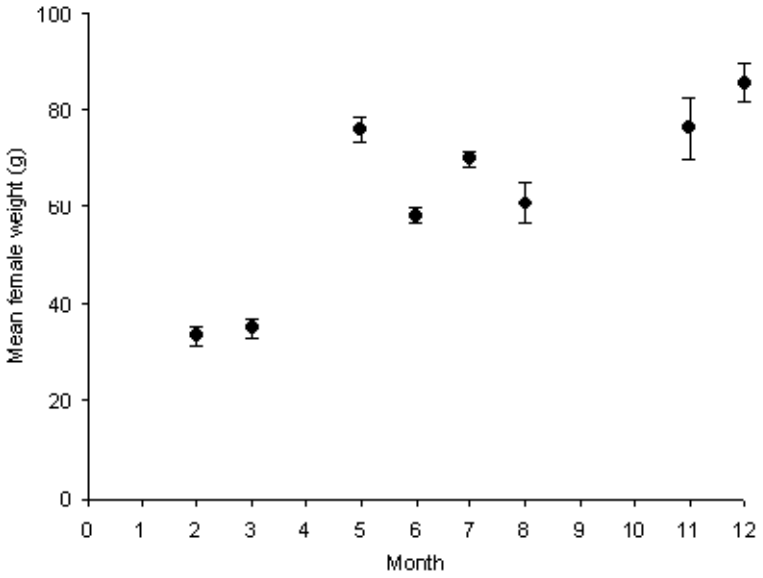

Figure 7. Mean female weight of *S. sagax* collected from waters of southern NSW during November 2002 and July 2006. Data for all years combined due to the small number of records available (n = 382).

Table 3. Sample details and adult reproductive parameters from previous Australian studies of *S. sagax*. W is mean female weight, *R* is mean sex ratio, *S* is mean spawning fraction and *F* is mean batch fecundity.

Location	Year	N	n	W	R	F	S	Reference
Western Australia	1991	10	253	39.8	0.58	11316	0.13	Fletcher *et al.* (1996)
Western Australia	1992	10	250	34.6	0.65	10950	0.09	Fletcher *et al.* (1996)
Queensland	1997	10	455	44.1	0.63	20268		Staunton-Smith and Ward 2000
Queensland	1998	11	688	47.84	0.64	20506	0.15	Staunton-Smith and Ward 2000
South Australia	1998	11	933	45.18	0.51	13615	0.14	Ward and McLeay (1998)
South Australia	1999	13	1563	52.28	0.47	15252	0.18	Ward and McLeay (1999)
South Australia	2000	15	2199	48.83	0.48	13650	0.16	Ward *et al.* (2000)
South Australia	2001	10	1394	51.9	0.56	17359	0.18	Ward *et al.* (2001b)
South Australia	2002	22	2823	62.42	0.59	18393	0.11	Ward *et al.* (2002)
South Australia	2003	5	414	53.48	0.52	15599	0.14	Ward *et al.* (2003a)
South Australia	2004	10	867	56.37	0.52	16699	0.15	Ward *et al.* (2004)
South Australia	2005	28	4688	73.5	0.5	22271	0.1	Ward *et al.* (2005)
South Australia	2006	19	2433	57.2	0.64	14290	0.13	Ward *et al.* (2006)
Total				51.35	0.56	16167	0.138	

3.5.2 Sex ratio

The overall sex ratio by weight (*R*) for mature *S. sagax* collected from southern NSW between November 2002 and July 2006 was 0.68 (Table 4). The sex ratio by number (i.e. number of females/total number of fish) was 0.66, suggesting that sampling may have been biased towards females. Other studies have shown that *S. sagax* samples obtained from commercial purse seine vessels can be biased towards females (Ward *et al.* 1998).

Estimates of mean sex ratio obtained in Australian studies conducted between 1991 and 2006 ranged from 0.47 in SA in 1999 to 0.65 in WA in 1992 (Table 4). The overall mean sex ratio for Australian samples was 0.56 g. Mean sex ratio estimates in southern Queensland in 1997 and 1998 were 0.63 and 0.64, respectively.

The estimate of sex ratio for NSW is higher than the values obtained in all other studies of *S. sagax* in Australia (Table 3, 4). As samples obtained from commercial purse seine vessels can be biased towards females and mature females generally weigh more than mature males, we consider that the mean of all Australian estimates of sex ratio (0.56) is the best estimate for calculating spawning biomass. The maximum and minimum sex ratio obtained in previous studies are used as the maximum (least conservative) and minimum value for estimating biomass in the present report.

Table 4. Mean sex ratio by weight and number of *S. sagax* collected from waters of southern NSW between November 2003 and July 2006. Data for all years combined due to the small number of records available (n = 582).

Sample Date	Female Weight (g)	No. Females	Male Weight (g)	No. Males	Sex Ratio (Weight)	Sex Ratio (Number)
10/11/2003	89.02	2	134.02	3	0.40	0.40
26/07/2004	2293.9	31	880	14	0.72	0.69
10/06/2005	985.1	14	349.5	6	0.74	0.70
19/06/2005	743.6	13	516.8	11	0.59	0.54
21/06/2005	1192.1	18	527.6	9	0.69	0.67
29/06/2005	1040.8	18	423.3	9	0.71	0.67
06/07/2005	1168.4	16	335.5	6	0.78	0.73
21/07/2005	1103.6	14	693.5	10	0.61	0.58
26/07/2005	1889.8	30	576.1	11	0.77	0.73
11/08/2005	790.1	13	320.2	5	0.71	0.72
21/11/2005	901.9	11	346.3	6	0.72	0.65
07/12/2005	1196.4	14	429.4	5	0.74	0.74
08/02/2006	470.4	14	644	20	0.42	0.41
06/03/2006	667.7	25	104.2	4	0.87	0.86
20/03/2006	530.5	20	56.7	2	0.90	0.91
31/03/2006	1191.1	23	232.4	6	0.84	0.79
23/05/2006	1518.3	20	631.1	9	0.71	0.69
06/06/2006	1021.1	20	571	10	0.64	0.67
19/06/2006	1921.4	33	1276.8	27	0.60	0.55
29/06/2006	870.6	18	481.7	12	0.64	0.60
03/07/2006	961.2	15	853.9	15	0.53	0.50
Total	22,547.0	382	10,384.0	200	0.68	0.66

3.5.3 Batch fecundity

No females with hydrated oocytes (i.e. suitable for estimating batch fecundity) were collected from NSW waters.

Estimates of mean batch fecundity (*F*) obtained in previous Australian studies ranged from 10,950 hydrated oocytes in WA in 1992 to 22,271 hydrated oocytes in SA in 2005 (Table 3). The overall mean batch fecundity for Australian samples was 16,167 hydrated oocytes. Estimates of mean batch fecundity in southern Queensland in 1997 and 1998 were 20,268 and 20,506 hydrated oocytes, respectively.

Batch fecundity data from previous Australia studies are shown in Table 3. Fig. 8 shows the relationship between mean batch fecundity and mean female weight (Batch fecundity = 353. Weight - 3019; $R^2 = 0.41$). Fish weight explained ~41% of the variation in estimates of mean batch fecundity. Using the best (51.35 g), minimum (45.97 g) and maximum (59.02 g) estimates of mean female weight identified above, we calculated best, minimum and maximum estimates of mean batch fecundity of 15,108, 13,208 and 17,815 hydrated oocytes, respectively.

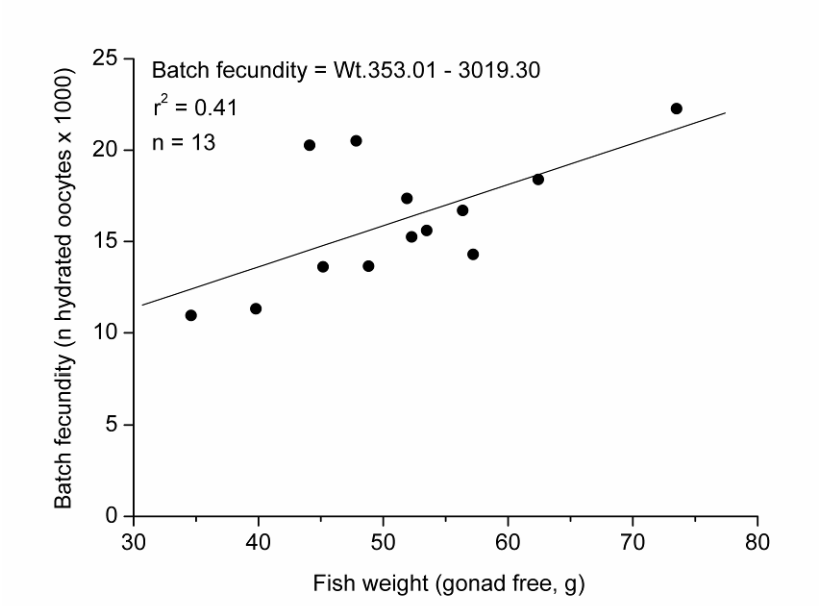

Figure 8. Linear regression of batch fecundity and female weight from previous Australian studies (Table 3).

3.5.4 Spawning fraction

No data are available for spawning fraction (*S*) of *S. sagax* in NSW waters.

Estimates of mean spawning fraction from previous Australian studies ranged from 0.09 for WA in 1992 to 0.18 for SA in 2001 (Table 3). The overall estimate of mean spawning fraction for Australian samples was 0.14. The estimate of mean spawning fraction in southern Queensland in 1998 was 0.15.

We consider the mean of all Australian estimates of spawning fraction (0.14) to be the best estimate for biomass estimation. Similarly, we consider that the minimum and maximum estimates of spawning fraction for biomass estimation are the extreme values obtained in other Australian studies (i.e. 0.18 and 0.09, respectively).

3.6 Spawning Biomass

Parameters used for calculating three estimates of spawning biomass are listed in Table 5. The best estimate of spawning biomass for the total spawning area was 28,809 t. The minimum and maximum estimates of spawning biomass were 9.161 and 58,673 t, respectively.

Table 5. Minimum, best and maximum estimates of each parameter and the spawning biomass of sardine off the east coast in July 2004. The rationale for choosing the minimum, best and maximum is explained in the results section for each parameter.

DEPM Parameter	Minimum	Best	Maximum
P_o	35.63	69.96	79.51
A	8643	9363	9422
W	45.97	51.35	59.02
R	0.65	0.56	0.47
F	13208	15108	17815
S	0.18	0.138	0.09
Spawning biomass	9,161	28,809	58,673

3.7 Sensitivity Analysis

The relative sensitivity of estimates of spawning biomass to variations in estimates of each parameter is shown in Figure 9. Most biomass estimates range between 25,000 and 35,000 t. The only biomass estimates outside that range were those calculated using: 1) the estimate of P_0 obtained using the methods of McGarvey and Kinloch (2001), which produced spawning biomass estimates of approximately half those obtained using the conventional approaches (i.e. 15,000 t); and 2) the minimum and maximum estimate of spawning fraction, which produced spawning biomass estimates of ~22,000 t and ~44,000 t, respectively. The method of McGarvey and Kinloch (2001) was developed specifically for situations where estimates of egg age are unavailable and provides conservative estimates of mean daily egg production. The estimate of spawning fraction (0.09) that produced the spawning biomass estimate of 44,000 t is unusually low, and may reflect spawning levels outside the main spawning season and be the result of collecting adult samples the commercial fleet. These sensitivity analyses suggest that there is a high probability that the spawning biomass of *S. sagax* in the area between Bundaberg and Newcastle in July 2004 was within the range of 25,000 to 35,000 t.

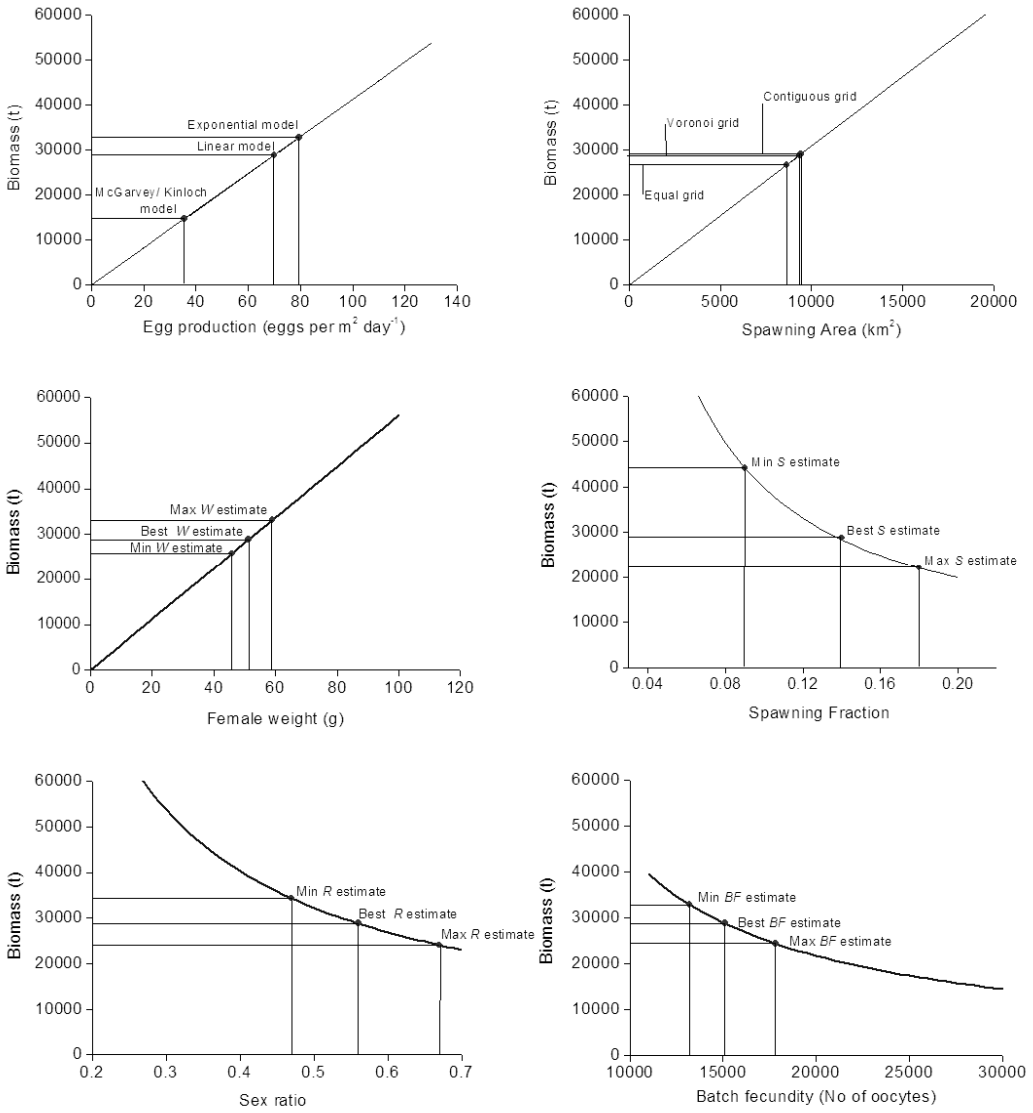

Figure 9. Sensitivity of estimates of *S. sagax* spawning biomass to variations in adult parameters, spawning area and mean daily egg production.

4. Discussion

The levels of egg abundance recorded during the survey in July 2004 are comparable to those obtained in Australian studies of *S. sagax* conducted during the main spawning season. For example, estimates of mean daily egg production recorded during the main spawning season in South Australia between 1998 and 2006 ranged from 53.66 eggs.m^{-2} in 1999 (immediately after the 1998 mortality event) to 132.17 eggs.m^{-2} in 2004 (Rogers and Ward 2005). Lower egg densities are usually recorded outside the main spawning season (e.g. Ward and Staunton-Smith 2002). This finding suggests that the July 2004 survey coincided with a period of significant spawning activity by *S. sagax* in northern NSW and that the survey results are suitable for use in an application of the DEPM.

S. sagax eggs occur in waters of southern Queensland between July and November, and the peak of the spawning season often occurs during September when SST fall below 22°C (Staunton-Smith and Ward 2000; Ward and Staunton-Smith 2002; Ward *et al.* 2003b). Data provided in the present study show that SST at many sites located in shelf waters of northern NSW fall below 22°C as early as July (Fig. 3, 4). This finding provides further evidence that the July 2004 survey may have coincided with the main spawning season of *S. sagax* in northern NSW. It is worth noting that Ward *et al.* (2003b) provided evidence to suggest that *S. sagax* migrate northwards into southern Queensland during late winter and early spring to spawn. On the basis of data provided in the present study, the hypothesis that the spawning aggregation that occurs in northern NSW during early winter moves northward into southern Queensland to spawn during late winter and early spring warrants investigation.

The wide distribution of *S. sagax* eggs in waters of northern NSW also suggests that the survey was conducted during the main spawning season. Although few eggs were collected from sites located north of Cape Byron, significant numbers were obtained from sites in the southern part of the sampling area. This finding suggests that the entire spawning area may not have been sampled during the survey. If this interpretation is correct, the estimates of spawning area (and hence spawning biomass) provided in this study may be negatively biased (i.e. conservative) and thus provide a sound basis for precautionary management.

The similarity of the estimates of spawning area obtained using the three methods suggest that the sampling design for the survey was adequate for the purposes of this study. However,

increasing the number of stations sampled would have provided more robust estimates of spawning area and mean daily egg production (e.g. (Lo *et al.* 1996; Lo *et al.* 2001). The estimate of spawning area obtained using uniform grid squares may be negatively biased as the survey did not cover the entire shelf. Estimates of spawning area obtained using both contiguous or VNN grids were suitable for estimating spawning biomass.

The linear version of the exponential mortality model method, including the application of the bias correction factor of Picquelle and Stauffer (1985), provides unbiased estimates of mean daily egg production. It is the internationally accepted method for estimating this parameter in applications of the DEPM (e.g. Stratoudakis *et al.* 2006), and on this basis, the value calculated using this model is clearly the best estimate. The method of McGarvey and Kinloch (2001) was developed specifically for situations where estimates of egg age are unavailable and provides conservative estimates of egg production in those cases. Although, this is not directly relevant to this study, and temperature egg development keys are available for *S. sagax* in Australian waters, the estimate obtained using this method was used as an estimate of minimum mean daily egg production in the sensitivity analyses.

As the FRDC-funded study of blue mackerel did not aim to provide an estimate of the spawning biomass of *S. sagax* off northern NSW, no adult samples were collected during the July survey. Adult data from southern NSW were not suitable for estimating adult reproductive parameters. Hence, the only option for calculating a best estimate of the spawning biomass off eastern Australia for July 2004 was to use historical data collected in other Australian studies. This approach introduced additional uncertainty into the estimates of spawning biomass, which is mitigated by the relatively narrow range of estimates of these parameters that have been obtained in these studies and the relative insensitivity of the DEPM model to variation in the estimates of adult parameters.

Our sensitivity analyses showed that variations in spawning area, female weight, sex ratio and batch fecundity had relatively minor effects on the estimates of spawning biomass. All estimates of spawning biomass obtained by varying these parameters to reflect the extreme values estimated in the 13 previous applications of the DEPM to *S. sagax* in Australia were within the range of 25,000 to 35,000 t. Other studies have shown that estimates of spawning biomass are relatively insensitive to variations in female weight, sex ratio and batch fecundity. The relative

insensitivity of our estimate of spawning biomass to variations in spawning area reflects (i) the similarity of our three estimates of spawning area; (ii) the strong correlation between spawning area and spawning biomass; and (iii) the suitability of spawning area as an index of spawning biomass (Gaughan *et al.* 2004).

Estimates of spawning fraction that reflected the extreme values obtained in the previous Australian studies produced estimates of spawning biomass between ~22,000 and ~44,000 t. However, the estimate of spawning fraction (0.09) that produced the high biomass estimate is unusually low and may reflect the fact that samples were obtained from commercial catches, which often under sample actively spawning fish (Ward *et al.* 1998). Our egg survey was conducted during the main spawning season so it is unlikely that the estimate of spawning fraction would have been less than 0.10. Studies conducted in Australia and overseas suggest that the spawning fraction of *S. sagax* during the main spawning season is relatively stable (Table 1, Appendix 1) and that 0.14 is a conservative and suitable 'best' estimate of this parameter. As indicated by Hunter and Lo (1997), the use of historical data to estimate adult parameters can introduce bises but is preferable to attempting to manage fisheries in the absence of scientific information.

The estimate of spawning biomass obtained using the mean daily egg production estimate calculated using method the McGarvey and Kinloch (2001) was ~15,000 t, which reflects the conservative nature of estimates obtained using this method (see discussion above).

Estimates of spawning biomass presented in this report should be treated with caution. Statistical uncertainty associated with the best estimate could not be calculated in the normal manner due to the lack of adult reproductive data collected during the ichthyoplankton survey. However, we suggest that our estimates of minimum and maximum spawning biomass can be viewed as being analogous to confidence limits – it seems unlikely that the true spawning biomass would lie outside the range of 9,000 to 59,000 t. Our sensitivity analyses also suggest that there is a high probability that the spawning biomass of *S. sagax* in the area between Bundaberg and Newcastle in July 2004 was within the range of 25,000 to 35,000 t. We also consider that the best estimate of spawning biomass (i.e. ~29,000 t) is conservative and provides a preliminary basis for precautionary management because: 1) the estimate of spawning area on which it is based may be conservative; 2) the estimate of mean daily egg production is robust; 3) the estimate of spawning

biomass is relatively insensitive to variations in spawning area, mean size, sex ratio and batch fecundity and 4) the estimate of spawning fraction is conservative relative to the findings of previous studies.

The best estimate of spawning biomass provided in the present report (i.e. ~29,000 t) is similar to the two conservative estimates of spawning biomass of ~25,000 t provided for southern Queensland by Staunton Smith and Ward (2000). Future management of *S. sagax* off eastern Australia would be enhanced by studies designed to determine whether (or not) the spawning aggregation that occurs in northern NSW during early winter migrates into southern Queensland during late winter to spawn. Nevertheless, it is clear that *S. sagax* in northern NSW and southern Queensland belong to the same stock and that future management arrangements should reflect this linkage.

Results provided in this report provide a useful basis for planning future assessment and management of *S. sagax* off NSW. Importantly, the estimates of spawning biomass provide a context for assessing the suitability of recent catch levels. The highest annual catch of ~1,800 t is ~6.2% of the best estimate of spawning biomass, and 3.3 and 14.9% of the maximum and minimum estimates of spawning biomass, respectively (Table 6). Exploitation rates (catch/spawning biomass) of less than 20% are generally considered to be sustainable for small pelagic fisheries (e.g. Rogers and Ward 2005). Hence, current fishing levels appear to be sustainable at broad spatial scales. We consider that, in the short term at least, catches could be retained at or below this level (~1,800 t) with relatively low risk to the sustainability of the stock and only a limited need for ongoing assessment (see below).

If catches were to rise significantly above this level, e.g. to 2,500 t or ~8.7% of the best estimate of spawning biomass (i.e. 4.5 to 20.7% of the maximum and minimum estimates of spawning biomass, respectively) we suggest that additional ongoing assessment, ideally involving application of the DEPM, would be required. Before catches of ~3,500 t, or ~12.1% of the best estimate of spawning biomass (i.e. 6.3 to 29.0% of the maximum and minimum estimates of spawning biomass, respectively), could be considered it would be necessary to implement a significant assessment program, ideally involving annual application of the DEPM.

The ichthyoplankton survey on which this study was based was conducted in July 2004. The abundance of small pelagic fishes is known to fluctuate between years. For this reason, a DEPM study of the *S. sagax* population off eastern Australia should be conducted within the next 3–5 years, especially if recent levels of fishing activity are maintained or increased. Ichthyoplankton surveys conducted in any future studies should be conducted in the peak spawning season (i.e. around July) and should extend further south and further offshore than the survey area in the present study to ensure that the entire spawning area is sampled. Future ichthyoplankton surveys should also involve the collection of representative samples of spawning adults to provide a basis for estimating the reproductive parameters that in this study could only be estimated on the basis of information provided in previous Australian studies.

Table 6. Estimates of exploitation rate (catch/spawning biomass) based on the maximum catch (1,800 t) and potential future catches of 2,500 and 3,500 t and the minimum, low, best, high and maximum estimates of spawning biomass presented in Table 5. Note that the low and high estimates of spawning biomass represent the likely range of the spawning biomass based on the sensitivity analyses shown in Figure 9.

	Exploitation Rates (%)				
Catch Level	Minimum SB (9,161)	Low SB (25,000)	Best SB (28,809)	High SB (35,000)	Maximum SB (58,673)
1800	19.6	7.2	6.2	5.1	3.1
2700	27.3	10.0	8.7	7.1	4.3
3600	38.2	14.0	12.1	10.0	6.0

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Appendix 1. Sample details and adult reproductive parameters from previous international studies of *S. sagax*.

Location	Year	N	n	W	R	F	S	Reference
California -North		1986	11	378	199.9	0.56	71382	0.04Scannell *et al.* (1996)
California -South	"	"	"		154.8	0.6	51743	0.19Scannell *et al.* (1996)
California		1987†	†		163.8	0.66	62289	0.13Lo *et al.* (1996)
California		1988†	†		166.3	0.49	61147	0.14Lo *et al.* (1996)
California		1994†	†		82.5	0.54	24282	0.07Lo *et al.* (1996)
California		1997	5	178	127.76	0.592	42003	0.133Lo and Macewicz (2004)
California		2001	2	16	79.08	0.677	22456	0.111Lo and Macewicz (2004)
California		2002	6	61	159.25	0.385	54403	0.174Lo and Macewicz (2004)
California		2004	17	574	166.99	0.618	55711	0.131Lo and Macewicz (2004)
South Africa		1972	636*		111.8		25700	Le Clus (1988)
South Africa		1973	6196*		120		32300	Le Clus (1988)
South Africa		1974	635*		128.8		32900	Le Clus (1988)
South Africa		1993	9248*					0.057Akkers *et al.* (1996)
South Africa		1994	18652*					0.095Akkers *et al.* (1996)
California		1946	13	1270	129		31800	MacGregor (1957) in Le Clus (1988)
Peru		1982†	91*		129		43400	Lo *et al.* 1986 in Le Clus (1988)
Chile		1983†	168*		100		25500	Retamales and Gonzalez (1983) in Alheit *et al.* (1993)
Chile		1989†	163*		100		32800	Oliva et al (1989) in Alheit *et al.* (1993)
Japan		1991	2	18	80.6		33900	Aoki (1996)

11. Draft Harvest Strategy for the Commonwealth Small Pelagic Fishery, including *Scomber australasicus* (February 2008)

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Objective: To evaluate potential harvest strategies for *Scomber australasicus* in southern Australia and provide preliminary estimates of the potential yields for each zone of the Commonwealth Small Pelagic Fishery.

Summary: At meetings of the Small Pelagic Fishery Resource Assessment Group (SPFRAG) in late 2007 and early 2008, a Draft Harvest Strategy was developed for submission to the AFMA Board in April 2008. The strategy applies to quota species prescribed under the draft SPF Plan, namely jack mackerels (*Trachurus declivis*, *T.murphyi*, *T.symmetricus*), blue mackerel (*Scomber australasicus*), redbait (*Emmelichthys nitidus*) throughout the entire SPF and to Australian sardine (*Sardinops sagax*) in Commonwealth waters adjacent to NSW. The SPF Harvest Strategy has adopted many of the features of the harvest strategy for the South Australian Sardine Fishery and drew heavily on the findings of the present study and the concurrent evaluation of the application of the DEPM to redbait off Tasmania (FRDC Project 2004/039). The Draft Harvest Strategy is tiered to accommodate growth of the fishery and the collection of additional information to support stock assessment. The tiered approach is underpinned by the need to balance risk with knowledge by establishing exploitation rates that are initially very conservative and which increase (but remain conservative) as additional information becomes available. The framework explicitly allows the level of investment research and assessment to be varied to match commercial interest in exploiting the resource. At Tier 3, Recommended Biological catches (RBCs) within a zone may not exceed 500 t and stock assessment is done biannually based only on catch and effort data from logbooks and/or observers. At Tier 2, RBCs are specified for each species within a zone based on all available information and stock assessments are done annually based on catch and effort data and age structure information. At Tier 1, RBCs are set as a proportion of the best estimate of spawning biomass obtained using the DEPM, with the maximum harvest rate increasing from 10 to 20% based on the frequency that the DEPM is applied (once every five years up to twice in three years).

The Draft Harvest Strategy for the SPF complies with the requirements prescribed under the Commonwealth Harvest Strategy Policy and Guidelines. The reliance of the Draft Harvest Strategy for the SPF on the DEPM provides clear evidence of the success of the current project in achieving it ambitious objectives. The version of the Draft Harvest Strategy that was completed by the SPFRAG in February 2008 is not reproduced here (under the direction of AFMA) as it is being further refined by AFMA prior to this report going to press. The Tier 2 RBCs for each species in zone will be determined at the meeting of SPFRAG and SPF MAC on 31 March and 1 April 2008, respectively.

12. General Discussion

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This study builds on previous investments by FRDC, government agencies (e.g. Fisheries WA, SARDI Aquatic Sciences) and the Australian fishing industry, in the use of the DEPM to underpin stock assessment of small pelagic fishes in temperate Australia (e.g. Fletcher *et al.* 1996; Ward *et al.* 1998; Ward et al. 2001). Importantly, the results of the study show that the DEPM is a potentially suitable tool for ongoing stock assessment of the *S. australasicus* component of the SPF. It also identifies research that is needed to improve the effectiveness of this technique. The success of the project in demonstrably improving the management of Australia's Commonwealth fisheries is evidenced by the Draft Harvest Strategy for the SPF, which identifies the DEPM as the fishery-independent stock assessment method that will underpin future management of that fishery (Chapter 11). A copy of the Draft Harvest Strategy for the SPF (as of February 2008) is included in this report.

As well as achieving the primary aim of adapting the DEPM for stock assessment of *S. australasicus* in temperate Australia, this study stimulated a Ph.D. study of the stock structure of this species, which added significant value to the initial investments by FRDC and AFMA. Chapter 3 outlines the results of the pilot study that identified the approaches that should be taken to determining the stock structure of *S. australasicus* using genetics, parasitology and otolith microchemistry. This study established protocols for determining variability within and among putative stocks of this species in temperate and sub-tropical Australian waters. Preliminary results suggest that the stock of *S. australasicus* off eastern Australia is separate from the stock or stocks west of Bass Strait, which is an important finding for future management of the SPF.

Other additional information that is provided in this report, and which was beyond the scope of work outlined in the original proposal (Chapter 1), is the information on the distribution of the eggs and larvae of other pelagic fishes that is provided in Chapter 9. This information is

important because it suggests that the DEPM may also be suitable for stock assessment of other SPF species, including *Trachurus* spp. and Australian sardine (*Sardinops sagax*) off NSW. However, before the DEPM could be applied to *Trachurus* spp. a reliable and cost-effective genetic technique for identifying eggs would need to be developed. In addition, it would be necessary to: 1) estimate adult reproductive parameters; 2) determine the rates of degeneration of post-ovulatory follicles; and 3) develop a temperature-egg development key.

The synthesis of fisheries data from all jurisdictions that is provided in Chapter 2 of this report shows that the increase in the Australian TAC of *S. australasicus,* which has been predicted over the last decade, has not yet eventuated. Industry members of the SPFMAC and RAG suggest that the lack of growth reflects the absence of suitably priced markets for this species, rather than the size of the resource. The data presented in this report suggests that the total commercial catch of blue mackerel remains at approximately 1,000 t, most of which is taken in the NSW Ocean Haul Fishery and the SPF. However, more recently catches of up approximately 1,500 t have been taken from the Great Australian Bight, and the potential for further expansion of this component of the fishery looms as a real possibility. The delays experienced obtaining the data we needed to prepare Chapter 2 highlighted the ongoing difficulties associated with collating fisheries data across all Australian jurisdictions. This problem should be resolved before a significant fishery for *S. australasicus* is established.

Recreational fishers catch significant numbers of *S. australasicus* (e.g. 720,814 in 2000), especially in waters off NSW, WA and SA. Our results suggest that off NSW, the annual recreational harvest of *S. australasicus* ranges between 60.5 and 107 t, which is 12–20% of the mean annual commercial harvest off NSW. There is considerable spatial and seasonal overlap between the activities of commercial and recreational fishers targeting *S. australasicus* off NSW. Spatial and/or seasonal management arrangements may be needed to alleviate conflict between these sectors. These arrangements should be established whether or not a large commercial fishery develops off eastern Australia. SPFMAC/RAG could assess the suitability of establishing a working group to address this issue.

The principle reason that the DEPM is suitable for stock assessment of *S. australasicus* is that this species is a serial spawner with indeterminate fecundity, which means that reliable estimates of daily fecundity can be obtained from estimates of female weight, sex ratio, spawning fraction and batch fecundity. In this study, we developed reliable estimates of these adult reproductive

parameters for waters off southern Australia, but not for waters off eastern Australia. Identifying locations/methods for obtaining large samples of mature fish from waters off southern Queensland and northern NSW during the spawning season is a high priority for future research on this species. Rates of degeneration of post-ovulatory follicles must also be determined to support the calculation of robust estimates of spawning fraction.

The descriptions of the pelagic eggs of *S. australasicus* provided in this study are critical for the future application of the DEPM. Molecular analyses showed that middle and late stage eggs can be identified with a high degree of confidence. However, significant uncertainty remains regarding the identification of the early stage eggs. Future use of the DEPM for stock assessment of *S. australasicus* must involve the application of molecular techniques to validate the identity of early stage eggs. Hence, the highest priority for future research on *S. australasicus* eggs is to develop a cost-effective and efficient molecular method for identifying early stage eggs. It is also important that an egg development-temperature key is developed to support the estimation of egg production. It is critical that in future surveys the contents of one cod-end of the bongo net are fixed in ethanol solution (to facilitate genetic identification) and the contents of other cod-end are fixed in formalin solution (to facilitate morphological identification and staging).

The surveys conducted off southern and eastern Australia provided valuable information on the timing and location of spawning by *S. australasicus*. However, due to the uncertainty regarding the identification of early stage eggs, only eggs that could be identified with a high degree of confidence were included in our analyses. The main spawning season of *S. australasicus* occurs during summer and early autumn off southern Australia and during late winter and early spring off eastern Australia. The location of spawning off southern Australia appears to vary between years. The western GAB may be an important spawning area that was not sampled intensively during the present study. The main spawning ground of *S. australasicus* off eastern Australia is in shelf waters of southern Qld and northern NSW. Future DEPM surveys off southern Australia will be logistically challenging due to the large and variable area over which *S. australasicus* spawns in this region. In contrast, applications of the DEPM off eastern Australia may be more tractable due to the comparatively smaller size of the spawning area.

Future DEPM surveys should use bongo nets rather than CalVET nets to estimate egg production and spawning area. The voronoi natural neighbour and contiguous gridding methods that were used in this study are suitable for estimating spawning area. More reliable estimates of

mean daily egg production will be obtained if an egg development-temperature key is established for *S. australasicus*. Estimates of female weight (452 g), sex ratio (0.46), batch fecundity (52,182 eggs), and spawning fraction (0.14) for southern Australia appear to be robust. Estimates of spawning biomass for eastern Australian should be viewed with caution as they are based on estimates of adult reproductive parameters for southern Australia. Our estimates of spawning biomass in the areas surveyed off southern and eastern Australia lie within the range of 45,000-70,000 t and 20,000-60,000 t, respectively. These estimates are considered to be conservative as they are based on negatively biased estimates of egg production and spawning area

The DEPM is a potentially suitable tool for assessing Australia's stocks of *S. australasicus*. However, some technical refinements are required to maximize the reliability of the estimates of spawning biomass that are obtained using this method. The highest immediate priorities for additional research are: 1) estimating the adult reproductive parameters of *S. australasicus* in eastern Australia; 2) determining the rates of degeneration of post-ovulatory follicles; 3) developing a temperature-egg development keys for this species; and 4) developing cost-effective and reliable genetic techniques for identifying early stage eggs. These refinements should occur before the DEPM is used for ongoing stock assessment to support the new Harvest Strategy for the SPF.

13. Benefits

The most important benefit of this project is that it has underpinned the development of the Harvest Strategy for the *S. australasicus* component of the SPF by a establishing fishery-independent method that will be used in future assessment of the fishery. Chapter 11 clearly documents the role that this project has played in the development of the Harvest Strategy for the SPF. A copy of the new Harvest Strategy for the SPF will be included in the final report for this project.

It is also significant that the development of this harvest strategy and stock assessment method builds on previous investments by FRDC, government agencies (e.g. Fisheries WA, SARDI Aquatic Sciences) and the Australian fishing industry in the development of stock assessments for small pelagic fishes in temperate Australia (e.g. Fletcher *et al.* 1996; Ward *et al.* 1998; Ward et al. 2001). For example, this stock assessment method builds on the research conducted by Fletcher *et al.* (1996); Ward *et al.* (1998), and Staunton Smith and Ward (2000) in developing the application of the DEPM. Similarly, the harvest strategy for the SPF builds on the management systems that have been established for the SA Sardine Fishery.

The project has also provided benefits to AFMA and other agencies responsible for the management of Australia's fisheries for small pelagic fishes (e.g. NSW DPI) beyond those identified in the original proposal. For example, by establishing protocols for determining variability within and among putative stocks of *S. australasicus* in Australian waters, the project will assist future studies of stock structure of other small pelagic fishes. Perhaps even more importantly information from the Ph.D. study of the stock structure of *S. australasicus,* that was conducted in conjunction with this project (at no additional cost to FRDC or AFMA), will contribute significantly to future management of the SPF (which under the Commonwealth Harvest Strategy Policy must be stock based).

Similarly, the information on the distribution of the eggs and larvae of other pelagic fishes that is provided in Chapter 9 is beyond the scope of benefits identified in the original proposal, but will assist the Harvest Strategy that is being developed for *S. australasicus* to be adopted for other SPF species. This additional information has already been used to provide NSW DPI with preliminary information on the sardine stock and fishery off NSW.

This study also showed that the annual recreational harvest of *S. australasicus* of NSW comprises up to 20% of the mean annual harvest of the commercial sector, and that there is considerable spatial and seasonal overlap in the activities of these sectors. However, the involvement of representatives of both recreational and commercial fishers on the steering group for this study appears to have helped reduce conflict between these groups. The relationships developed during this project could assist the establishment of spatial and/or seasonal management arrangements that may be needed to alleviate future allocation disputes between these sectors.

This study provides biological and ecological information on *S. australasicus,* which will be critical for the future application of the DEPM to this species (e.g. egg descriptions, reproductive information). Similarly, the information provided on the timing and location of spawning by *S. australasicus* off eastern Australia is critical to ensuring that future applications of the DEPM provide robust estimates of biomass. In addition, the project provides specific information (e.g. sampling design and methods, preservation techniques, etc) on how to optimise future surveys. It is also significant that the project clearly identifies the additional research that is needed to improve future applications of the DEPM to estimates of spawning biomass for *S. australasicus*.

14. Further Development

The highest immediate priorities for additional research to support the application of the DEPM for *S. australasicus* are: 1) developing cost-effective and reliable genetic techniques for identifying early stage eggs; 2) developing a temperature-egg development keys for this species; 3) estimating the adult reproductive parameters of *S. australasicus* in eastern Australia; and 4) determining the rates of degeneration of post-ovulatory follicles. These refinements should occur before the DEPM is used for ongoing stock assessment to support the new Harvest Strategy for the SPF. The report provides detailed recommendations on the timing, location and methods that should be applied in future DEPM surveys for *S. australasicus*.

15. Planned outcomes

The main outcome for this project is the establishment of a stock assessment method and harvest strategy for the *S. australasicus* component of the SPF. Information on stock structure provided in the Ph.D. study may also affect future management arrangements for this fishery. This study has also provided information that will assist the development of stock assessment methods and harvest strategies for other SPF species and sardine off NSW.

16. Appendices

16.1 Intellectual Property

No applications for patents were made during the course of this project.

16.2 Staff

Name	Position	Organisation	Address
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16.3 Original Proposal

FRDC R&D FUNDING APPLICATION

- ApplicationID: macker

PART A ADMINISTRATIVE SUMMARY

A1 PROJECT TITLE

Development and evaluation of egg-based stock assessment methods for blue mackerel, Scomber australasicus, in southern Australia.

A2 APPLICANT

The contact information provided at A2 to A5 will be made public through the FRDC contacts database.

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A6 PLANNED START AND END DATE

Start Date	1/07/2002
End Date	30/06/2005

A7 PROJECT BUDGET SUMMARY

Contribution by the FRDC (C1 - C4)

Year	Salaries	Travel	**Operating**	**Capital**	Total
02/03	210,176	34,902	**86,600**	**-**	331,678
03/04	216,671	36,352	**82,000**	**-**	335,023
04/05	190,645	27,896	**72,600**	**-**	291,141
Total	617,492	99,150	**241,200**	**-**	957,842

Contribution by the Applicant (C5)

Year	Salaries	Travel	**Operating**	**Capital**	Total
02/03	21,500	-	**198,000**	**-**	219,500
03/04	22,000	-	**200,000**	**-**	222,000
04/05	22,500	-	**200,000**	**-**	222,500
Total	66,000	-	**598,000**	**-**	664,000

Contribution by Other Sources (C6)

Year	Salaries	Travel	**Operating**	**Capital**	Total
02/03	121,282	3,000	**70,800**	**270,000**	465,082
03/04	124,560	3,000	**70,800**	**332,500**	530,860
04/05	123,850	3,000	**70,800**	**330,000**	527,650
Total	369,692	9,000	**212,400**	**932,500**	1,523,592
Budget Total	1,053,184	108,150	**1,051,600**	**932,500**	3,145,434

A8 SPECIAL PROJECT BUDGET CONSIDERATIONS

Include information that impacts on the project budget, but may not be made clear in Part C, eg, estimates of income from the sale of publications.

The total budget and level of funding requested from FRDC for this project are high. This because the stock assessment component of the project involves collaboration of research agencies in all the southern Australian states and because conducting the fishery-independent surveys on which the success of this project depends is inherently expensive.

The total cost of the project is also increased by the inclusion of the recreational survey off NSW, a change which was made in response to advice from the FRDC Board. This approach has proven useful as the total cost of this combined proposal ($0.958M) is approximately 19.2% lower than the combined cost of the two separate initial proposals ($1.186M).

The high cost of the project is justified by the high level of community support for this type of study, which is reflected in the high level of media attention that has been given to the social and ecological implications of expansion of the commercial fishery for blue mackerel. The flow of benefits is also spread across six jurisdiction, i.e. the Commonwealth and
the five southern states.

As indicated by the reviewers "the project is tackling an issue where there is a real need" (Reviewer 1) and "this proposal is significant as it will allow knowledge to catch up with investment and in this sense will be addressing institutional/political failure" (Reviewer 2).

The large contributions of AFMA, SARDI, AMC, TAFI and NSW Fisheries reflect the high importance that these agencies and their clients assign to this project. The large contribution of SARDI in particular, (e.g. provision of RV Ngerin at marginal cost; provision of Dr Ward's salary; payment of office costs and general consumables) reflects this agencies goal of developing its already considerable research capacity in the area of stock assessment of small pelagic fishes.

Objective 8 aims to estimate the levels of usage by three components of the NSW recreational sector. That objective will be undertaken only if augmentative funding is obtained from the NSW Recreational Fishing (Saltwater) Trust. If additional funding is not obtained, this objective and associated funding will be deleted from the project.

A9 EXTERNAL REVIEW

The FRDC reserves the right to engage external consultants to review applications. Applicants should advise the FRDC separately 'in-confidence' of any information in the application that they do not wish to be sent to a reviewer, and any potential reviewers they do not wish to be engaged.

No

A10 CERTIFICATION

The Applicant and the Principal Investigator warrant that all information contained in and forming part of this R&D Application to the FRDC is complete, accurate and provided in good faith at the date submitted to the FRDC and that any changes to circumstances will be notified to the FRDC as soon as possible. They also warrant that the Principal Investigator, key research staff and research agency funding inputs will be available for the duration of the project.

Signed for and on behalf of the Applicant

(Print Name and Position) (Signature and Date)

Signed by the Principal Investigator

(Print Name and Position) (Signature and Date)

A11 TIME BOX (Applicable to applicant organisations with less than 20 employees)

PART B PROJECT DESCRIPTION

The Project Description should provide all the information necessary to enable the R&D Application to be fully evaluated

B1 PROJECT IDENTIFICATION

FRDC Programs	Natural Resources Sustainability
Stategies	Fisheries and ecosystems management
	Interactions between fish and their ecosystems
	Effects of fishing activities on fish and their ecosystems
	Stock assessment methods
	Fish biology
	MACKEREL — Blue

B2 BACKGROUND

DEVELOPMENT OF THE PROPOSAL

Blue mackerel (Scomber australasicus Cuvier, 1832), is an important element of the pelagic ecosystems off southern Australia and is a key prey species for a large range of predatory fishes, including premier recreational species, such as tunas and billfishes.

For several decades small-scale fisheries in New South Wales, Victoria, Tasmainia, South Australia and Western Australia have supplied local markets with blue mackerel for bait and human consumption. Significant quantities of blue mackerel have also been taken as by-catch in purse-seining and mid-water trawling operations conducted in these states, e.g. up to 1200 tonnes per annum was taken off Tasmania in the 1980s (P.J. Ward et al. 2001).

Over the last few years there has been increasing pressure to expand the commercial fisheries for blue mackerel, with commercial operators claiming that stocks are under-exploited and capable of supporting large and valuable industries. Currently, target fishing for blue mackerel is being conducted off southern NSW and is planned for eastern Tasmania, the Great Australian Bight and southern Western Australia (P.J. Ward et al. 2001; Mr A Bodsworth AFMA pers. comm.).

Facilities to process blue mackerel for a range of purposes, including export markets for human consumption, have been established recently in southern NSW and Tasmania at considerable cost to both commercial proponents and the Commonwealth and State Governments, e.g. as part of the Eden Regional Adjustment Package (see Attachment 1).

Recreational fishers commonly use blue mackerel as bait, especially for the large predatory fishes that commonly feed on this species. Peak representative groups such as Recfish Australia, as well as game fishing associations (e.g. Game Fishing Association of Australia - GFAA), have strongly opposed the expansion of the commercial fisheries for blue mackerel due to the lack of scientific information on population sizes and the potential effects on the abundance, distribution and availability of sportsfish species (see Attachments 2, 3 4).

Serious concerns have been expressed regarding the potential effects of localised depletion on the availability of gamefish on key recreational fishing grounds, such as those off Port Stephens and the south coast of NSW, and the difficulties of establishing suitable Total Allowable Catches (TACs) for a species that is thought to undergo large interannual fluctuations in abundance (Dr Julian Pepperell, pers. comm.).

As a precautionary response to current lack of knowledge on fisheries biology and population sizes of blue mackerel and other temperate mackerels, AFMA recently reduced the purse-seine trigger TAC in several zones of the Jack Mackerel Fishery, from 5000 to 2500 tonnes (see Attachment 5) and from 2000 to 1000 tonnes for the mid-water trawl sector (Fig. 1). These reductions have heightened the concerns of commercial fishers regarding the security of their access to this resource and have impeded investment in the industry (Mr Andre Remoy, commercial fisher and processor, pers comm.).

AFMA recently commissioned the BRS to undertake a desktop investigation and analysis of information

available on biology and fisheries for blue mackerel and related species (P.J. Ward et al. 2001). The BRS report concluded that biological and ecological data for blue mackerel were sparse and did not provide an appropriate basis for determining suitable commercial harvest levels or the potential effects of industrial fishing on other components of the ecosystem.

This lack of information is a significant impediment to the establishment of management arrangements that fully satisfy either the core objectives or guiding principles of Australia's National Strategy for Ecologically Sustainable Development or the Standing Committee on Fisheries and Aquaculture's guidelines for ecologically sustainable fisheries. Lack of information is also impeding efforts by the Commonwealth and State Governments to develop and implement best-practice management plans for the mackerel fisheries of southern Australia.

On 12 July 2001, a meeting was held between representatives of AFMA, BRS, AMC and SARDI to discuss options for addressing the paucity of data available on blue mackerel and related species. Prior to the meeting, the Tasmanian and South Australian researchers had conducted discussions with scientists in NSW Fisheries, MAFRI and Fisheries WA regarding the priorities for mackerel research in their state.

Participants in the meeting unanimously supported the findings of the BRS study and confirmed that the lack of biological information was impairing management efficiency, particularly the ability to determine harvest levels that will ensure that objectives of ecologically sustainable development are achieved. Participants agreed that a greater understanding of blue mackerel and its role in Australia's temperate marine ecosystems was essential for the development of effective management arrangements across jurisdictions.

It was also emphasised that the future work should be designed explicitly to build on and synthesise results of previous projects such as Stewart et al. (1998, 1999), Stewart and Ferrell (2001), and P.J. Ward et al. (2001).

B2 BACKGROUND Continued

AFMA indicated in principle support for the provision of significant funding (in the order of $55000 per annum) for the period 1 July 2002 to 30 June 2005 to (i) support the state monitoring and research programs and (ii) leverage additional funds from FRDC to support national collaborative investigation of blue mackerel stocks. This proposal has been developed on the understanding that AFMA will contribute approximately $55000 per annum to support the project. Dr Bruce Wallner (AFMA) recently provided Dr Patrick Hone with verbal confirmation that this support would be forthcoming.

A preliminary research proposal involving SARDI, TAFI, NSW Fisheries, AMC, Fisheries WA and BRS was submitted to COMFRAB, TASFRAB and SAFRAB. The project was ranked as a high priority for funding by TASFRAB and SAFRAB and was supported strongly by COMFRAB - which indicated it would rank the proposal in January when the full proposal was available (letters from the FRABS are attached).

The proposal was evaluated by the FRDC Board in March 2002. The Principal Investigator received a letter from Dr Patrick Hone on 11 March 2002 that indicated a revised application should be submitted by 28 March and should (i) focus on one key species, such as blue mackerel and (ii) include an analysis of the recreational harvest of blue mackerel off NSW, with Dr Michael Lowry (NSW Fisheries) as the Co-investigator responsible for that section of the project. The comments of four reviewers were also provided.

Copies of Dr Hone's letter and the reviewers comments are attached to this revised version of the proposal.

RATIONALE FOR PROJECT

The current proposal is modelled largely on FRDC projects 94/029 (Ward et al. 1998), 95/043 and 98/130 (Staunton Smith and Ward 2000), which (i) investigated the fisheries biology (age, growth and reproduction) and (ii) established quantitative stock assessment procedures for the pilchard (Sardinops sagax) in southern and eastern Australia. The stock assessment techniques developed in those projects are now undertaken annually in South Australia and funded by the participants in the SA pilchard fishery. As a result of these assessments, the TAC for the South Australian fishery has increased from 3500 tonnes in 1995 - a level that was established (like the current mackerel quotas) in the absence of quantitative information on the size of the stock - to 17700 tonnes in 2002, which is based on a conservative estimate of the spawning biomass of pilchard in South Australia during 2001 (Ward et al. 2001). The TAC for 2002 was established on the basis of an exploitation of 12.5% of the conservative estimate of minimum spawning biomass, which is less than half of the internationally recognised standard for sustainable use of cluepoid stocks (25-30%), and has been established specifically to account for the ecological importance of pilchards in temperate marine ecosystems.

FRDC project 94/029 also included a review of stock assessment methods for small pelagic fishes. That study concluded that classical fishery models that rely on fishery-dependent data are inappropriate for new and developing fisheries and that their usual reliance on CPUE data renders them unsuitable for schooling pelagic fishes, such as clupeoids and blue mackerel. The value of hydroacoustic and visual (i.e. aerial) methods is also impeded by temporal and spatial variation in schooling behaviour, and difficulties identifying the species and size composition of schools. As a result, aerial surveys may provide useful

qualitative information on the distribution of mackerel off southern Australia (P.J. Ward et al. 2001), but will not provide the quantitative estimates of stock abundance required to establish appropriate TACs (see Morrison et al. 2001). In contrast, egg production surveys are used routinely to provide estimates of mackerel abundance in the northern Atlantic Ocean and elsewhere (see Borchers et al. 1997; P.J. Ward et al. 2001) and appear to provide the only potentially useful alternative for obtaining quantitative estimates of the spawning biomass of mackerels in southern Australia. As shown by FRDC project 94/029, and the subsequent development of the South Australian pilchard fishery, egg production methods can provide conservative estimates of spawning biomass within a few years of implementation and can thus facilitate the precautionary development of fisheries for small pelagic species.

Positive egg identification is a pre-requisite for the reliable application of egg-based stock assessment methods (Ward et al. 1998). Information on egg stages/ages is also useful, although conservative estimates of egg production can be obtained by ignoring egg mortality and estimating intial egg production from the abundance of Stage I eggs only (e.g. Borchers et al. 1997). Eggs of blue mackerel have not been formally described. Information required to stage/age eggs and estimate levels of egg mortality and initial egg production is not available.

The BRS review (P.J. Ward et al. 2001) concluded that additional studies of age and growth are needed to ensure that the fishery for blue mackerel in southern Australia is developed in a precautionary manner. FRDC has funded several investigations of the age and growth of mackerels. For example, FRDC project 95/151 (Stewart et al. 1998) provided information on the age and size composition of commercial and recreational catches of blue mackerel off the NSW coast. The project proposed herein does not aim to replicate that study but will extend the results by providing (i) a comprehensive analysis of the patterns of age and growth of blue mackerel throughout most of its Australian range and (ii) a detailed analysis of the age-specific spatial and temporal patterns of distribution and abundance in the catches of commerical and recreational fishers as well as samples of adult/spawning fishing obtained using fishery-independent methods.

Methods for obtaining representative samples of adult fishes and for estimating batch fecundity and

B2 BACKGROUND Continued

spawning fraction are prerequisites for the application of egg based stock assessment methods (Ward et al. 1998). However, information on the reproductive biology of blue mackerel in southern Australia is sparse. Blue mackerel in the GAB reach sexual maturity at ~28 cm, and may spawn in summer-autumn (Stevens et al. 1984). Blue mackerel are thought to spawn in spring off NSW and during summer off Tasmania. No estimates of batch fecundity or spawning fraction are available; mainly due to the absence of methods for sampling spawning adults.

Accurate information on the location of spawning is essential for the application of egg-based stock assessment methods (Ward et al. 1998). Few data are available on the location of spawning and/or distribution and abundance of eggs and larvae of blue mackerel. However, eggs tentatively identified as blue mackerel have been obtained in egg surveys conducted during summer-autumn in shelf waters of South Australia, mainly from sites located near the edge of the continental shelf.

Data from congeneric species in other ecosystems (e.g. Scomber scombrus in the Northeastern Atlantic) suggest that blue mackerel may also spawn mainly at the shelf break. Preliminary experiments conducted by SARDI have shown that mature mackerel can be caught using a gill net and underwater lights. The major development that will be required in this study is to establish the techniques to deploy the gillnet and lights to depths of 200+ metres.

Information on levels of usage by recreational fishers that will obtained by synthesising the existing data on the trailer boat sector and data collected from surveys of the charter and game fishing sectors will provide a sound basis for developing equitable resource sharing arrangments for blue mackerel resources off NSW.

The information on age and growth will provide information required to develop a fishery-dependent method for monitoring the status if the stock.

The development and evaluation of egg-based stock assessment methods for blue mackerel off temperate Australia will provide a mechanisms for estimating and monitoring the the size and of one of the potentially most valuable and under-exploited fisheries resources remaining in Australian waters.

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B2 BACKGROUND Continued

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B3 NEED

Stock assessment methods need to be developed for blue mackerel for a range of economic, ecological, social and legislative/administrative reasons.

Perhaps most importantly, the large and valuable international markets for members of the genus Scomber, in conjunction with the apparently large stocks of blue mackerel off southern Australia, suggest that a commercial fishery for this species could generate significant export earnings. Furthermore, as the economic potential of this industry is well known, significant amounts of private and public funds have been invested trying to develop fisheries and processing facilities for this species. To date, the development of these industries has been impeded by the absence of the information required to establish appropriate TACs. In fact, trigger TACs in Commonwealth waters were halved recently as a precautionary response to scientific uncertainty regarding sustainable harvest levels.

Blue mackerel is also prized as bait by recreational anglers and reliable estimates of the quantities taken by this sector is needed to determine the total impacts of fishing and to make informed decisions about resource sharing amongst stakeholders (see Attachments 1-5). The need for data from the recreational sector is most pressing off the NSW coast.

There is also significant concern among recreational anglers that sustained commercial fishing for blue mackerel may affect the local abundance and availability of sportsfishes, such as tuna and billfishes. Australia's recreational and charter fisheries for these sportfishes are economically important and provide a significant source of income for many regional communities (e.g. Port Stephens and southern NSW). If stocks of blue mackerels are not as large as commercial fishers claim, then the concerns of recreational fishers may be valid and further development of the commercial fisheries could potentially impact on the distribution, abundance and availability of sportfishes and the viability of the recreational and charter fisheries which they support.

Similarly, the removal of large quantities of a key prey species could adversely affect populations of other marine predators, including marine mammals and seabirds.

The species that prey on blue mackerel have considerable social and ecological significance. As a result, there is strong public pressure for Commonwealth and State governments to conduct research and develop management arrangements that will ensure that commercial harvesting of blue mackerel is ecologically sustainable. Commonwealth and state legislation, policies and strategies also require government agencies to ensure that the harvesting of fisheries resources not only provides maximum economic and social benefits to the Australian community, but also minimise impacts on other components of the ecosystem.

In the cost recovery frameworks in which most fisheries management and research agencies currently operate, acquiring funds to conduct research in support of small and developing (albeit potentially valuable) fisheries is problematic. The augmentative funding requested in this proposal is needed to ensure that the harvest strategies that are developed for blue mackerel off southern Australia reflect the social significance of the species as well as the size and potential economic value of the resource, and take into account the potential ecological effects of the expansion of the commercial sector.

The major impediment to the development of southern Australia's commercial mackerel fisheries is the lack of quantitative information required to establish appropriate TACs. The most cost- and time-effective option for obtaining this information is to apply egg-based stock assessment methodologies, such as the Daily Egg Production Method (T.M. Ward et al. 1998, 2001; P. Ward et al. 2001). This project will (i) develop the methods for sampling adults and identifying and staging eggs that are required to apply egg-based stock assessment methods to blue mackerel and (ii) use the Daily Egg Production Method to calculate conservative estimates of minimum spawning biomass of blue mackerel off southeastern Australia.

B4 OBJECTIVES

1 To synthesise information available on the fisheries for blue mackerel in southern Australia. (Note that information on the biology of blue mackerel will be reviewed as part of the objectives that deal specifically with age and growth, reproductive biology, stock assessment, etc.).

2 To describe the spatial and temporal patterns of age and growth, and compare the age structure of commercial and recreational catches and fishery-independent samples of blue mackerel taken from throughout southern Australia.

3 To estimate the critical adult reproductive parameters for blue mackerel, especially spawning fractions and batch fecundities, in southeastern Australia.

4 To establish methods and criteria for identifying and staging the eggs and larvae of blue

5 To estimate the size of the spawning areas and levels of egg production of blue mackerel off south-eastern Australia (northern NSW to the central Great Australian Bight).

6 To develop and evaluate methods for estimating the spawning biomass of blue mackerel in southern Australia.

7 To evaluate potential harvest strategies for blue mackerel in southern Australia and provide preliminary estimates of the potential yields for each zone of the Commonwealth fishery.

8 To estimate the number, size frequency and total weight of blue mackerel taken by recreational (charter, gamefish and trailer-boat) fishers off the NSW coast.

B5 OUTPUTS & EXTENSION

The FRDC's share of intellectual property and hence project income, based on the relative values of contributions in Part C of this application or unless otherwise justified, will be 30.45%

FRDC's and SARDI's share of the intellectual property will be 25% and 15% respectively. TAFI, AMC, NSW Fisheries, Fisheries WA, MAFRI and AFMA will each have a 10% share.

The primary output of this project will be the conservative estimates of minimum spawning biomass and other relevant fisheries information (e.g. spatial and temporal patterns in the age structure of commercial catches) that are required to facilitate the ecologically sustainable development and sound management of Australia's blue mackerel resources.

The project will also provide information on the age structure of the population that will be needed to monitor and assess the future status of the fisheries for this species in southern Australia.

The project will also provide information on the number, size frequency and total weight of blue mackerel taken by recreational fishers off NSW that is required to make informed decisions regarding the allocation of this resource among the commercial and recreational sectors.

A steering committee will be established that will include scientists involved in the project as well representatives of key stakeholder groups including fisheries managers (e.g. AFMA), recreational fishing groups (e.g. RecFish Australia), gamefishing associations (e.g. GFAA), commercial fishers (e.g. Ocean Fresh) and a representative of FRDC. This committee will be responsible for coordinating the project and ensuring that findings are extended effectively to key stakeholder groups.

Several members of the steering committee are also members of the Commonwealth Small Pelagic Research and Assessment Team (SPRAT) and the Small Pelagic Working Group. These members will submit reports documenting the findings of the project to each of these groups. Members of the steering committee will also inform members of the other committees of the progress of the project. Information provided by this study is likely to form the basis of stock assessment advice provided by the SPRAT to the Small Pelagic Working Group and to AFMA.

Copies of reports, articles and papers resulting from the study will be sent directly to key stakeholder groups.

Stock assessment and other information will also be extended to commercial and recreational fishing communities through articles in popular magazines, presentations at workshops and through press releases by relevant government agencies.

At the end of the project, workshops will be conducted in each state to provide individual stakeholders with an opportunity to discuss and comment on the findings. Researchers will provide presentations at these workshops which describe the results of the project using non-scientific terms.

Information on the history and current status of the mackerel fisheries in southern Australia, patterns of age and growth, and the size and distribution of stocks will be stored in databases and made available to other scientists through the publication of scientific papers. The publication of peer reviewed papers is important as it provides fisheries managers and other stakeholders with an increased level of confidence in the advice provided by research scientists.

The results of the proposed project will (of course) also be disseminated using the full range of information exchange measures routinely employed by the organisations at which the investigators work, and which have been developed specifically to satisfy the needs of clients including other scientists, commercial and recreational fishers, fisheries managers, conservation agencies and groups, and other interest groups.

B6 PLANNED OUTCOMES

Beneficiaries of this work include AFMA, NSW Fisheries, PIRSA, DPIWE Tasmania, Fisheries WA, Fisheries Victoria, Environment Australia, State and Commonwealth commercial fishers, recreational fishers, including charter, game and trailer boat fishers.

The involvement of representatives of stakeholder groups as members of the steering committee will help to provide these groups with ownership of the findings of the project and facilitate extension. It is also envisaged that the committee will provide an opportunity for dialogue between stakeholders that may help to develop innovative strategies for overcoming disputes over allocation and conflicts between the users of mackerel resources.

Information provided to AFMA and the state management agencies will facilitate the ecologically sustainable development and sound management of blue mackerel resources, and provide a basis for making allocation decisions. This will benefit commercial and recreational fishers and the entire Australian community by ensuring that the blue mackerel resources of southern Australia are harvested in a manner that is ecologically sustainable and provides maximum economic and social benefits to the Australian community.

Similarly, information on the history and status of the fisheries and the spatial and temporal patterns in the age composition of the population and commercial and recreational catches will provide information required to develop an age-structured stock assessment model and further enhance the management of the fisheries. This information will also provide a basis for using fishery information to monitor the status of the stock(s).

Articles in recreational and commerical fishing magazines and workshops in each state will make results of the project accessable to the broader community, who have shown a strong interest in the management of blue mackerel resources (see Attachments).

Reports, papers in peer reviewed journals and presentations at conferences will be used to communicate the findings

B7 FLOW OF BENEFITS

Fishery (including aquaculture) Managed by:	Commercial Sector	Recreational Sector	**Traditional Fishing (by Aboriginal & Torres Strait Islander people) Sector**
NSW	15	12.5	**0**
SA	10	5	**0**
Tas	5	2.5	**0**
Vic	2.5	2.5	**0**
WA	2.5	2.5	**0**
Australian Fisheries Management Authority			
AFMA - South East (trawl and non-trawl)	7.5	0	**0**
AFMA - Eastern Tuna and Billfish	7.5	5	**0**
AFMA - Southern Bluefin Tuna	7.5	5	**0**
AFMA - Great Australian Bight Trawl	7.5	0	**0**
Total	65	35	**0**

Summary Flow of Benefits

Sub Total Commercial Sector	65
Sub Total Recreational Sector	35
Sub Total Traditional Fishing Sector	0
Summary Flow of Benefits	100

B8 INDUSTRY AND MANAGEMENT CONSULTATION

The project was designed to address issues identified independently as priorities by BRS, AFMA, PIRSA, SARDI, TAFI, and NSW Fisheries and was developed collaboratively by these agencies.

The proposal is consistent with the small pelagic (baitfish) research priorities listed by NSW Ministerial Advisory Council on Recreational Fishing. The NSW Baitfish Working Group, with representatives from commercial fisheries, recreational fisheries, AFMA, NSW Fisheries, has also identified recreational use of baitfish as a priority and has provided in principle support for this proposal.

This need for this type of research project has also been indentified by recreational and commercial fishers (see Attachments 1-5).

Comments on drafts of the proposal provided by Dr Julian Pepperell and Mr Graham Pike have been incoporated into the project. A letter of support from Recfish Australia was forwarded to FRDC in early December. The Game Fishermens Association of Australia sent a letter endorsing the project to FRDC early in December. Dr Pepperell and Mr Pike will be members of the steering committee for the project, and have indicated there willingness (and enthusiasm) to participate.

Commercial fishers and processors with interests in Tasmanian, NSW and GAB stocks (e.g. Mr Angus Nichols, Ocean Fresh) have expressed their support for this type of project in several meetings with AFMA and the Principal Investigator, and have indicated that they will send letters of support directly to FRDC.

The approach taken in the proposed project reflects the recommendations made in the BRS report on mackerels and was refined at meetings in Canberra on 12 July and 12 November 2001 involving representatives of BRS, AFMA, AMC, SARDI, TAFI and NSW Fisheries.

The project was supported by COMFRAB, SAFRAB and TASFRAB and incorporates advice and suggestions provided by these groups. Letters of support from COMFRAB and TASFRAB are attached. SAFRAB, which ranked the project as a high priority, will forward their letter of support directly to FRDC.

The proposal was evaluated favourably by the FRDC Board in March 2002. In response to comments by the Board forwarded to the Principal Investigator by Dr Patrick Hone the proposal was revised to focus on blue mackerel and expanded to include an analysis of the recreational harvest of blue mackerel off NSW.

B9 METHODS

A timeline for the project is attached to the proposal (Table 1).

1. HISTORY AND STATUS OF BLUE MACKEREL FISHERIES IN SOUTHERN AUSTRALIA.
Historical information, catch/effort information and size frequency data for the commercial and recreational fisheries for blue mackerel in southern Australia will be synthesised by SARDI.

2. PATTERNS OF AGE AND GROWTH, AND THE AGE STRUCTURE OF COMMERCIAL CATCHES.
Commercial catch sampling programs will be established and/or continued and extended in NSW, Victoria, Tasmania, SA and WA. Monthly samples will be collected from commerical and recreational fisheries in each state using a combination of port-based and on-board catch sampling. Samples will also be collected using fishery-independent methods. On-board catch sampling will also provide information about bycatch species. A standard approach will be utilized to collect and report fishery information.

TAFI will sample the purse-seine and pair-trawl fisheries. NSW Fisheries will sample the inshore fishery and the offshore fishery and obtain samples from catches taken by tuna fishers for bait. SARDI will collect samples from trawlers in the GAB and from inshore marine scale-fishers. Where necessary, additional samples will be obtained using fishery-independent sampling methods (see method 3).

Existing data and biological samples (especially otoliths) will be forwarded to SARDI for collation, analysis and reporting. Age determination protocols developed in previous FRDC studies (e.g. 95/151) will be reassessed (if required) and applied to all new and existing samples (Stewart et al. 1998, 1999; Stewart and Ferrell 2001).

Information obtained will be used to describe the spatial and temporal patterns of age and growth, and the age structures of the commercial catches and fishery-independent samples collected from each region. Spatial and temporal variations in important reproductive parameters such as age at 50% maturity will also be examined.

3. ADULT REPRODUCTIVE PARAMETERS
(a) Developing the fishery-independent sampling technique
Preliminary experiments conducted by SARDI have shown that mature blue mackerel can be caught using a gill net and underwater lights (see Staunton Smith and Ward 2000; Ward et al. 2001a). The major development that will be required is to establish the techniques for deploying and retrieving the gillnet and lights from depths of 200+ metres and testing the methodology off NSW, Victoria, Tasmania and SA.

Field trials will be conducted in South Australia during the first six months of the project (i.e. prior to the first spawning season). SARDI will then coordinate sampling of adult blue mackerel off NSW, Victoria, Tasmania and SA during the peak spawning season in each area. Adult sampling will be conducted in conjunction with the egg surveys (See methods section 5).

(b) Estimating adult reproductive parameters

Standard reproductive information (sex ratios, gonad stages, GSIs, etc.) will be determined from (existing and newly collected) samples of adult fish obtained from the commercial fisheries (see Ward and Staunton Smith 2002). This information will help to ensure that egg surveys and fishery-independent adult sampling is conducted during the peak spawning season in each location.

Samples of adult fish obtained using the fishery-independent sampling techniques will be used to obtain estimates of critical adult reproductive parameters, such as mean female weight, sex ratio (by weight), spawning fraction and batch fecundity. Reproductive analyses will be undertaken by SARDI. Standard histological techniques (i.e. those routinely applied to pilchards in South Australia) will be used (e.g. Ward et al. 1998; Ward et al. 2001a). Estimates of spawning fraction will be obtained from the proportion of females containing post-ovulatory follicles of various ages (Hunter and Macewicz 1985). Batch fecundity will be determined using the gravimetric method of Hunter et al. (1985).

4. IDENTIFYING AND STAGING EGGS

Eggs of blue mackerel will be identified and staged under a stereomicroscope and identified using standard techniques. If necessary, scanning electron microscopy will also be used to identify characteristics that can be used to distinguish eggs of blue mackerel from those of similar species. Initially, eggs will be identified using the description of eggs of the closely related Scomber japonicus (Okiyama 1988). However, detailed descriptions, illustrations and photographs of each development stage of blue mackerel will be developed during the course of the project.

Eggs of blue mackerel will be hatched under a range of temperature regimes in the AMC's aquaculture farm facilities at Beauty Point (Tasmania) and SARDI (Aquatic Sciences). Data obtained will be used to construct a temperature-dependent age model. This model will provide the estimates of the age of egg stages that is required for the application of egg production methodologies.

5. LOCATION AND EXTENT OF THE SPAWNING AREA

B9 METHODS Continued

Each year, ichthyoplankton surveys of up to 20 days duration will be conducted the along the shelf break off NSW to eastern Tasmania and South Australia and southern Victoria. Surveys will be timed to coincide with the peak spawning seasons blue mackerel off NSW (spring), eastern Tasmania (summer) and southern Victoria and South Australia (summer). Information on reproductive periodicity obtained from commercial catch and fishery-independent samples will be used to ensure that surveys coincide with the peak spawning seasons.

During the first year of the study the surveys will be extensive and designed to identify major spawning areas. Transects and sites will thus be widely spaced, e.g. 10-20 km and 5-15 km respectively, and the survey will cover as much of the area surrounding the shelf break as possible. During the second and third years the surveys will be more intensive and designed to more precise estimates of egg abundance and egg production. Transects and sites will be closer together (5-10 km and <5 km respectively); the survey area may be reduced; and a stratified design, with increased sampling intensity in key spawning areas, may be employed. If deemed appropriate, the surveys may be conducted in two phases with the first phase covering a large area and the second more intensive phase focusing on spawning "hotspots".

Ichthyoplankton surveys of waters along the shelf break will be conducted from the FTV Bluefin in NSW during spring, and eastern Tasmanian during summer. Similar surveys will be conducted from the RV Ngerin in South Australian and southern Vistorian waters during summer. In NSW, vessels provided by members of the Game Fishing Association of Australia may also be used.

During the first year samples will be collected using large bongo nets (length 3m diameter ~600 mm; mesh 300 microns) towed obliquely through the water column from the maximum permissible depth to the surface for a period of 10-15 minutes. During the second and third years, smaller bongo nets (diameter ~255 mm; mesh 300 micron) will be towed vertically from 10 metres above the seabed to the surface. A flowmeter fitted to the mouth of each net will be used to estimate the volume of water filtered during each tow. Samples will be fixed in a 10% formalin-seawater solution (see Ward et al. 2001 a, b).

All fish eggs and larvae will be removed from each sample. All blue mackerel eggs and larvae will be identified and counted (Neira et al. 1998). Samples will be made available to students and other researchers (e.g. Mr Barry Bruce, CSIRO) to provide information on the distribution and abundance of the eggs and larvae of other species.

Standard oceanographic parameters, such as temperature, salinity, dissolved oxygen and density of chlorophyll-a, will also be recorded at each site by attaching a CTD with a profiling fluorometer below the plankton net. Surface data will be compared with information provided on satellite images (SST and chlorophyll-a) obtained from CSIRO.

A relational database will be established to incorporate the egg and larval data sets. Data will be made available to the ongoing CSIRO project that is synthesising existing data on the early life history of southern Australian finfish (FRDC 98/103).

Patterns of egg and larval distribution will be mapped using Mapinfo® and Surfer® and correlated with environmental variables using standard statistical techniques (e.g Multi-dimmensional scaling, Principal Components Analysis; Canonical Correspondence Analysis). Estimates of initial egg production will be obtained by regressing the densities of eggs against their age (as per Ward et al. 1998, 2001). Estimates of spawning area will be calculated by determining the proportion of the spawning area that contains day-1 eggs.

6. STOCK ASSESSMENT

This section will evaluate the suitability of using egg production methods for estimating the spawning biomass of blue mackerel off southern Australia. If these techniques are shown to be suitable, preliminary estimates of the minimum spawning biomass of blue mackerel off NSW, eastern Tasmania and South Australia will be developed using the daily egg production method (DEPM).

The DEPM provides an estimate of the biomass of adult fishes that release batches of pelagic eggs throughout the spawning season, and has ben applied to pelagic fishes that some of the world's largest fisheries (see Ward et al. 1998). It relies on the premise that spawning biomass can be calculated from estimates of the number of eggs produced per day in the spawning area (daily egg production) and the number of eggs produced per unit mass of population (daily fecundity).

The spawning biomass (B) of each species in each location will be calculated according to the equation:

$$B = (P.A.W)/(R.F.S)$$

where P is mean daily egg production, A is the spawning area, W is the mean weight of mature females, R is the sex ratio (proportion of females by weight), F is the mean batch fecundity and S is the mean spawning fraction (Lasker 1985; Parker 1985; Alheit 1993).

The 95% confidence intervals for the estimate of each parameter except spawning area will be calculated

B9 METHODS Continued

from 10000 bootstrapped estimates using the percentile method. The 95% confidence intervals of spawning biomass will be estimated using the percentile method and by calculating the spawning biomass 10000 times using the 10000 bootstrapped estimates of each parameter.

7. EVALUATION OF HARVEST STRATEGIES

Issues that need to be considered when establishing harvest strategies for ecologically significant species such as blue mackerel will be reviewed. This section will extend the reviews conducted in FRDC project 94/029 (Ward et al. 1998) by focusing on blue mackerel rather than pilchards and by providing additional information for the ecosystems off the east coast of Tasmania and NSW. It will also discuss options for using estimates of spawning biomass to establish harvest strategies and appropriate biological indicators and reference points for developing mackerel fisheries. In addition, the section will provide preliminary estimates of the potential yields of these fisheries and provide assessments of the levels of ongoing research that may be required to support each fishery.

8. SURVEY OF RECREATIONAL FISHERS

NSW Fisheries works closely with the recreational gamefish sector through the Gamefish Tagging Program (GTP), Gamefish Tournament Monitoring Program (GTMP) and Charter Boat Monitoring Program (CMP) as part of an integrated approach in the assessment of the recreational catch and effort associated with the principal gamefish species. A comprehensive survey of the trailer boat sector was completed (Steffe et al FRDC 94/053), however information on baitfish collected during that study has not been analysed. The use of existing data and sampling programs will provide a cost effective and an efficient means of developing estimates of use of blue mackerel by recreational fishers.

The proposed project will (i) use existing data to estimate the number of blue mackerel taken in the trailer boat fishery and (ii) collect data required to estimate the numbers of blue mackerel taken by the gamefish and charter sectors. A sampling program that will be conducted in conjunction with fishers will provide the information on the size frequency of the catch that is required to convert estimates of numbers caught into estimates of total catch by weight for each sector.

(a) Size frequency of catches

Recreational anglers are reluctant measure the fish landed for bait as additional handling can increase mortality and defeat the purpose of collecting live bait. Measuring fish retained at the end of a fishing day is biased by the selection of larger baitfish over a fishing day, potentially resulting in underestimates of the catch (Stewart et al. 1998). Independent sampling is required to obtain the unbiased weight frequency information that is needed to convert estimates of the numbers of fish caught into estimates of the total weight of the catch.

Estimates of size frequency of catches will be obtained opportunistically throughout the course of the project as part of the surveys of the charter and gamefishing sectors. Information will be used to detect seasonal and regional differences in weight frequencies and to calculate more reliable estimates of the weight of the total recreational harvest. This section of the study will be conducted during each year of the three year project.

Otoliths, gonads and collection data will be sent to SARDI for analysis.

(b) Trailer boat sector

FRDC funded a three year survey of recreational fishing in NSW (Steffe et al FRDC 94/053). The objectives of the survey were to estimate the effort and catch of recreational fishers in NSW nearshore waters, and to compare the estimated recreational harvest to the commercial catch. In excess of 10,600 interviews with fishing parties were conducted at major NSW ports over a two year period. The survey specifically asked all participants to specify the number and species of fish used for bait. This data has yet to be analysed and will used to obtain an estimate of the number of blue mackerel taken by the trailer boat sector. These estimates of the number of fish taken will be used in conjunction with the estimates of size frequency to estimate the total catch of the trailer boat sector. This section of the study will be the focus of the first year of the three year project.

(c) Charter boat sector

The charter logbook program came into effect 13 November 2000. The program is mandatory and requires all licensed charter vessels in NSW waters to record detailed catch and effort information. The existing logbook design will be modified to include data on the baitfish catch, especially blue mackerel. Information will be stratified by endorsement type (estuarine, gamefish, bottom fishing) date, location and length of trip.

This information will be used in conjunction with the estimates of size frequency to estimate the total catch of blue mackerel by the charter sector. This section of the study will be the focus of the second year of the three year project.

Game Fishing Sector

The gamefish tournament monitoring program currently provides catch and effort data for target species associated with specific tournaments. Fifteen ports are monitored in the region between Coffs Harbour and

B9 METHODS Continued

Bermagui. The choice of tournaments sampled provides a good latitudinal range with high participation rates.

Tournaments monitored by the program operate a self-imposed mandatory radio reporting system, which requires competing boats to report their location and details of fish captures at regular intervals during a fishing day. The data received is considered to be of high quality as it is collected regularly throughout the day and is not subject to the same degree of recall bias and rounding error as end of day interviews.

This system will be modified so that participants are also required to report on the number of blue mackerel landed. Information gained from scheduled reports will be compared with the information from post fishing interviews to indicate the level of concurrence and compliance between reporting methods.

Independent sampling at each tournament will provide the weight frequency information that can be used to estimate total weight of the catch at each tournament. Clubs associated with tournaments that are not monitored by the program will provide effort information required to estimate the total quantity of blue mackerel taken by the club based gamefish sector. This section of the study will be the focus of the third year of the three year project.

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B9 METHODS Continued

B10 RISK ANALYSIS

THREAT

Significant fishing is not conducted for one or more of the species in one or more of the regions.

CONTINGENCY

The fishery independent techniques that have been developed for catching adult fishes will be used to collect monthly samples. Resources that would be applied to catch sampling will be used to conduct the fishery independent sampling program. In addition, alternative sources of blue mackerel will be accessed, this species being also taken as by-catch of other commercial fishing operations, eg gillnets, beach seines, demersal trawls etc.

THREAT

A fishery-independent method for obtaining representative samples of (spawning) adult blue mackerel cannot be developed.

CONTINGENCY

Preliminary fishing trials have already indicated that multi-panel gillnets with a range of mesh sizes employed in association with lights are effective in catching blue mackerel, although further refinement of the technique is required. In the event that the method cannot be applied satisfactorily conservative estimates of spawning fraction and batch fecundity will be derived from information available for other similar species, and will be applied to estimates of spawning area and egg production obtained during the second spawning season to provide a conservative estimate of spawning biomass. This approach was taken initially in Project # 94/029 (Ward et al. 1998) and provided useful first estimates of biomass. Under these circumstances the project would not continue into the third year.

THREAT

Data on egg stage/age relationship cannot be obtained.

CONTINGENCY

Conservative estimates of initial egg production will be obtained by ignoring egg mortality and using estimates of the abundance of day-1 eggs only.

THREAT

One or more of the recreational surveys cannot be conducted.

CONTINGENCY

The use of existing data and programs to derive estimates of baitfish usage minimises the risks associated with this aspect of the project as many of the logistic and fishery based variables are known. The existing programs can be regarded as pilot studies, which have established the links with the user groups and developed the knowledge based which have been used to minimise risk associated with this aspect of the current project.

B11 PERFORMANCE INDICATORS

The overall success of this project will be measured by:

Collation of existing information on the fisheries, including the comprehensive analysis of archived otolith collections;

Publication of a popular article that documents the history and status of the blue mackerel fisheries of southern Australia;

Publication of a scientific paper that describes and compares the spatial and temporal patterns in the age composition of the catches of blue mackerel in the commercial fisheries off southern Australia;

Delineation of the spatial and temporal spawning patterns of blue mackerel off New South Wales, Tasmania and South Australia;

Estimation of key adult reproductive parameters including spawning fraction and batch fecundity;

Provision of conservative estimates of spawning biomass and their acceptance by resource managers and key stakeholder groups;

Publication of a paper that describes and compares the spawning biomasses of blue mackerel off New South Wales, Tasmania and South Australia;

Acceptance and implementation of the techniques developed in this study for the routine assessment of spawning stock biomass for the blue mackerel fisheries;

provision of estimated the quantities (total numbers and weight) of blue mackerel harvested each sector of the NSW recreational fishery.

Provision of resource managers with information required to make decisions relating to resource sharing among sectors.

Dissemination of above information to managers, industry and other stakeholders through reports, workshops and public meetings.

B12 MILESTONES

30/12/2002	Staff appointed. First meeting of steering committee completed. Stakeholder groups informed that project is underway through short articles in recreational and commercial fishing magazines. Commenced synthesis of existing fisheries data. Commenced analysis of archived otolith collections. Commenced catch sampling program.Trialed fishery-independent sampling methods. Conducted egg survey off NSW coast. Established section on baitfish usage into Charter Logbook Program. Collated data on baitfish usage by trailer boat sector. Begun collection of samples for estimating size frequency. A timeline for the project is attached to the proposal (Table 1).
30/06/2003	Completed synthesis of existing fisheries data. Submitted popular article describing blue mackerel fisheries of southern Australia. Completed analysis of archived otolith collections. Continuing catch sampling program. Established ageing protocol and histological procedures. Development of fishery-independent sampling methods continuing. Conducted egg surveys off Tasmania and South Australia. Developed laboratory techniques for estimating spawning fraction and batch fecundity. Calculated preliminary estimate of total catch of blue mackerel by trailer boat fishers off NSW.
30/12/2003	Second meeting of steering committee completed. Catch sampling program and analysis of otoliths continuing. Development of fishery-independent sampling methods continuing. Descriptions of developmental stages of blue mackerel eggs completed. Conducted second egg survey off NSW. Developed and described laboratory techniques for estimating spawning fraction and batch fecundity. Survey of charter
30/06/2004	Continuing catch sampling program and otolith analysis. Developed, described and evaluated fishery-independent sampling method. Continuing work on establishing temperature development key. Conducted second egg surveys off Tasmania and South Australia. Described distribution of eggs and larvae off NSW coast. Developed estimates of spawning fraction and batch fecundity. Developed preliminary estimates of spawning biomass. Provided reports to AFMA and state management agencies. Third meeting of steering committee conducted. Survey of charter sector completed.
30/12/2004	Completed egg development keys. Conducted final egg survey off NSW. Completed analyses of otoliths collected during first 18 months of project. Completed preliminary comparison of age structure of commercial and recreational catches and fishery independent samples in each state. Survey of game fishing tournaments underway. Calculations of preliminary conservative estimates of spawning biomass for each zone completed. Developing draft report discussing potential harvest strategies for the fisheries.
30/06/2005	Completed final egg surveys off Tasmania and South Australia. Provided conservative estimates of spawning biomass for all zones. Completed report to management agencies discussing potential harvest strategies and yields for the fisheries. Paper on age structure of catch submitted to journal. Estimates of catch by charter and trailer boat sectors completed. Completed survey of gamefishing tournamments. Final meeting of steering committee completed. Conducted workshops with stakeholders.

B13 OTHER RELATED PROJECTS

FRDC project 94/029 investigated the fisheries biology and established quantitative stock assessment procedures for the pilchard (Sardinops sagax) in southern Australia. This proposed project will build on the outcomes of that study.

FRDC project 95/151 provided information on the age and size composition of commercial and recreational catches of blue mackerel and yellowtail scad off the NSW coast. The proposed project further develops the findings of that study and was developed in response to recommendations in the final report.

BRS conducted a review (P.J. Ward et al. 2001) of mackerel stocks and fisheries. The proposed project was designed to address research priorities that it identified.

Information on the reproductive biology of mackerels in southern Australia is provided by Webb (1976), Maxwell (1979), Stevens et al. (1984), Marshall et al. (1993), Jordan et al. (1995). The proposed study builds on the information provided in those papers and reports.

FRDC Project 96/116 (Neira et al., 2000) provided information on the early life-history and recruitment commercially important species in coastal waters of western South Australia and eastern Victoria. Data from the proposed study will complement those obtained in this project.

The collection of new material, together with specimens already collected and identified from the Victorian coast (FRDC 96/116), will be used in the near future to produce a revised and more complete version of the book "Larvae of Temperate Australian Fishes" (Neira et al., 1998; FRDC Project 94/129).

FRDC Project 98/103 aimed at collating the existing data on the early life history of southern Australian finfish. The database currently being assembled in that project will be enhanced by larval fish data obtained during the proposed research project.

Some information on the usage of baitfish in southern and eastern Australia is provided in Dixon et al. (1996). FRDC Project 94/053 provided the raw estimates of number of baitfish used by the trailerboat sector of the NSW coast. The proposed project will aggregate and analyse this existing data to provide estimates of blue mackerel taken by this sector.

NSW Fisheries supports research to monitor each of the components of the gamefish sector, and works closely with the club and non-club sectors through the Gamefish Tournament Monitoring Program (GTMP) and the Gamefish Tagging Program (GTP). Charter fishing is regulated by a plan of management, which is supported by the Fisheries Management (General) Amendment (Charter Fishing Boats) Regulation 2000. Licence conditions require charter operators to complete logbooks and monthly reconciliation, which will detail the time spent fishing, species caught and numbers retained.

Information from the gamefish monitoring, charter boat monitoring and commercial catch records will be

complemented by information flowing from the National Survey of Recreational and Indigenous Fishing. This survey will provide estimates of the total catch of all sectors of the recreational fishery. It is anticipated that this broad-based study will provide a greater understanding of all participants (club and non-club anglers) of the east coast recreational gamefish fishery. Data generated from the tournament monitoring database will assist the national survey by providing more precise and accurate estimates of the total catch of gamefishers.

B14 FACILITIES

SARDI has offices, laboratories, computer network, library and research vessel (RV Ngerin) required to conduct modern marine research. Agency can also provide easy access to high level statistical advice – Dr Yongshun Xiao, Dr Rick McGarvey).

Similarly, TAFI has offices, laboratories, and computer facilities appropriate for this project.

AMC has laboratory space and fish processing facilities, office space, administrative support, computer network, workshop, library facilities and the 35 m stern trawler FTV Bluefin, which is fully equipped with a range of fish sampling gear (trawl nets, plankton nets, etc) and instruments to measure a range of environmental variables.

The Cronulla Fisheries Centre (CFC) has office and laboratory facilities, mainframe computing facilities, a database infrastructure to handle the large volumes of data that will result from the recreational component of the project. The CFC has a fleet of vehicles and boats available for travel and use throughout the survey. Members and representatives of the GFAA have indicated their willingness to provide access to vessels

B15 STAFF

Name	Position	Qualifications	**Time**
Dr Dan Gaughan (Fisheries WA)	Senior Scientist	Ph.D.	**5**
Dr Francisco Neira (AMC)	Program Leader	Ph.D.	**20**
Dr Jeremy Lyle (AMC)	Program Leader - Finfish Assessment	Ph.D.	**10**
Dr Julian Pepperell	Consultant Scientist	Ph.D.	**5**
Dr Kimberely Smith (NSW Fisheries)	Fisheries Scientist	Ph.D.	**15**
Dr Michael Lowry (NSW Fisheries)	Senior Scientist	Ph.D.	**50**
Dr Sandy Morison (MAFRI)	Senior Scientist	Ph.D.	**5**
Dr Tim Ward (SARDI)	Program Leader	Ph.D.	**30**
Mr Andy Bodsworth (AFMA)	Fisheries Manager	B.Sc.	**10**
Mr Angus Nicholls	Ocean Fresh	Commerical Rep	**5**
Mr Graham Pike	Recfish Australia	Recreational Rep	**5**
Project Scientist TBA (SARDI)	Senior Scientist	Ph.D. (or equivalent experience)	**100**
Tech TBA (Fisheries WA)	Technician	B. Sc. (Hons)	**25**
Tech TBA (MAFRI)	Technician	B. Sc. (Hons)	**25**
Tech TBA (NSW Fisheries)	Technician	B.Sc. (Hons)	**60**
Tech TBA (SARDI)	Technician	B.Sc. (Hons)	**100**
Tech TBA (TAFI/AMC)	Technician	B.Sc. (Hons)	**60**EDITION : 11

PART C PROJECT BUDGET

The budget should be a realistic estimate of costs, and include provisions for a maximum of three percent annual price increase.
All cost estimates are to be GST exclusive. GST will be covered in the Project Agreement.
The FRDC will normally only fund (C1 to C4) the marginal costs of undertaking R&D projects. The FRDC will not fund items regarded as essential to the operation of the applicant's research facility.

Budget items for C1 to C4 must be assigned to a milestone.
C1 to C4 refer only to the funds being requested from the FRDC.

C1 PROJECT STAFF

Milestone Date	Name	Position	**Salary**	**On Costs**
30/12/2002	Tech TBA (TAFI/AMC)	Technician	**11,192**	**4,141**
	Tech TBA (MAFRI)	Technician	**4,600**	**1,380**
	Tech TBA (SARDI)	Technician	**17,749**	**5,325**
	Dr Francisco Neira	Program Leader	**3,578**	**1,073**
	Project Scientist (SARDI)	Senior Scientist	**6,850**	**2,055**
	Tech TBA (NSW Fisheries)	Technician	**5,286**	**4,969**
	Tech TBA (Fisheries WA)	Technician	**4,500**	**1,350**
	Dr Michael Lowry (NSW Fisheries)	Senior Scientist	**16,000**	**15,040**
30/06/2003	Tech TBA (SARDI)	Technician	**17,749**	**5,325**
	Tech TBA (TAFI/AMC)	Technician	**11,192**	**4,141**
	Tech TBA (MAFRI)	Technician	**4,600**	**1,380**
	Tech TBA (NSW Fisheries)	Technician	**5,286**	**4,969**
	Project Scientist TBA (SARDI)	Senior Scientist	**6,850**	**2,055**
	Tech TBA (Fisheries WA)	Technician	**4,500**	**1,350**
	Dr Michael Lowry (NSW Fisheries)	Senior Scientist	**16,000**	**15,040**
	Dr Francisco Neira (AMC)	Program Leader	**3,578**	**1,073**
30/12/2003	Project Scientist TBA (SARDI)	Senior Scientist	**7,055**	**2,117**
	Dr Francisco Neira (AMC)	Program Leader	**3,685**	**1,106**
	Tech TBA (MAFRI)	Technician	**4,738**	**1,421**
	Tech TBA (NSW Fisheries)	Technician	**5,444**	**5,117**
	Dr Michael Lowry (NSW Fisheries)	Senior Scientist	**16,480**	**15,491**
	Tech TBA (TAFI/AMC)	Technician	**11,599**	**4,292**
	Tech TBA (Fisheries WA)	Technician	**4,635**	**1,391**
	Tech TBA (SARDI)	Technician	**18,281**	**5,484**
30/06/2004	Dr Francisco Neira (AMC)	Program Leader	**3,685**	**1,106**
	Dr Michael Lowry (NSW Fisheries)	Senior Scientist	**16,480**	**15,491**
	Tech TBA (MAFRI)	Technician	**4,738**	**1,421**
	Tech TBA (NSW Fisheries)	Technician	**5,444**	**5,117**
	Project Scientist TBA (SARDI)	Senior Scientist	**7,055**	**2,117**
	Tech TBA (Fisheries WA)	Technician	**4,635**	**1,391**

	Tech TBA (TAFI/AMC)	Technician	**11,599**	**4,292**
	Tech TBA (SARDI)	Technician	**18,281**	**5,484**
30/12/2004	Tech TBA (NSW Fisheries)	Technician	**5,607**	**5,271**
	Tech TBA (TAFI/AMC)	Technician	**12,231**	**4,525**
	Tech TBA (MAFRI)	Technician	**4,738**	**1,421**
	Tech TBA (Fisheries WA)	Technician	**4,774**	**1,432**
	Dr Michael Lowry (NSW Fisheries)	Senior Scientist	**16,974**	**15,956**
	Dr Francisco Neira (AMC)	Program Leader	**3,795**	**1,139**
	Project Scientist TBA (SARDI)	Senior Scientist	**7,267**	**2,180**
	Tech TBA (SARDI)	Technician	**18,829**	**5,649**

C1 PROJECT STAFF Continued

30/06/2005	Tech TBA (Fisheries WA)	Technician	**4,774**	**1,432**
	Tech TBA (NSW Fisheries)	Technician	**5,607**	**5,271**
	Tech TBA (MAFRI)	Technician	**4,738**	**1,421**
	Project Scientist TBA (SARDI)	Senior Scientist	**7,267**	**2,180**
	Dr Francisco Neira (AMC)	Program Leader	**3,795**	**1,139**
	Tech TBA (TAFI/AMC)	Technician	**12,231**	**4,525**
	Tech TBA (SARDI)	Technician	**18,829**	**5,649**
Total Salaries			**414,800**	**202,692**

C1 PROJECT STAFF JUSTIFICATION

Milestone Date	Name	Justification
30/12/2002	Dr Francisco Neira	10% of salary. Additional 10% of salary contributed by AMC. Supervise egg development experiments. Participate in surveys off NSW and Tasmania. Liase with SARDI. Participate in steering committee meetings.
	Dr Michael Lowry (NSW Fisheries)	50% of salary. Conduct survey of baitfish usage by recreational fishers in NSW.
	Project Scientist (SARDI)	25% of salary. Other 75% paid by AFMA contribution. Supervise sampling program and laboratory work in SA. Supervise otolith reading. partipate in surveys in all states. Supervise sorting of egg samples. Analyse and interpret data. Assist Dr Ward in preparation of reports and papers.
	Tech TBA (Fisheries WA)	25% of salary. Collect samples and conduct preliminary laboratory work (remove and preserve otoliths and gonads) in WA. Send samples to SARDI.
	Tech TBA (MAFRI)	25% of salary. Conduct sampling and preliminary laboratory analyses (removal and preservation of otoliths and gonads) in Victoria. Send samples and data to SARDI.
	Tech TBA (NSW Fisheries)	35% of salary. Oncosts also cover provision of facilities. Collect samples and conduct preliminary laboratory work (eg removal and preservation of gonads and otoliths) in NSW. Forward samples and data to SARDI. Participate in surveys off NSW. Collect samples for recreational component of study.
	Tech TBA (SARDI)	100% of salary. Collect samples in SA. Participate in surveys in all states. Read otoliths from all states. Data
	Tech TBA (TAFI/AMC)	60% of salary. Conduct catch sampling and preliminary laboratory work (eg removal and preservation of gonads and otoliths) in Tasmania. Forward samples and data to SARDI. Participate in egg rearing experiments and surveys off Tasmania.
30/06/2003	Dr Francisco Neira (AMC)	As per milestone for 30/12/2002
	Dr Michael Lowry (NSW Fisheries)	As per milestone for 30/12/2002

	Project Scientist TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (Fisheries WA)	As per milestone for 30/12/2002
	Tech TBA (MAFRI)	As per milestone for 30/12/2002
	Tech TBA (NSW Fisheries)	As per milestone for 30/12/2002
	Tech TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (TAFI/AMC)	As per milestone for 30/12/2002
30/12/2003	Dr Francisco Neira (AMC)	As per milestone for 30/12/2002
	Dr Michael Lowry (NSW Fisheries)	As per milestone for 30/12/2002
	Project Scientist TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (Fisheries WA)	As per milestone for 30/12/2002
	Tech TBA (MAFRI)	As per milestone for 30/12/2002
	Tech TBA (NSW Fisheries)	As per milestone for 30/12/2002
	Tech TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (TAFI/AMC)	As per milestone for 30/12/2002
30/06/2004	Dr Francisco Neira (AMC)	As per milestone for 30/12/2002

C1 PROJECT STAFF JUSTIFICATION Continued

	Dr Michael Lowry (NSW Fisheries)	As per milestone for 30/12/2002
	Project Scientist TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (Fisheries WA)	As per milestone for 30/12/2002
	Tech TBA (MAFRI)	As per milestone for 30/12/2002
	Tech TBA (NSW Fisheries)	As per milestone for 30/12/2002
	Tech TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (TAFI/AMC)	As per milestone for 30/12/2002
30/12/2004	Dr Francisco Neira (AMC)	As per milestone for 30/12/2002
	Dr Michael Lowry (NSW Fisheries)	As per milestone for 30/12/2002
	Project Scientist TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (Fisheries WA)	As per milestone for 30/12/2002
	Tech TBA (MAFRI)	As per milestone for 30/12/2002
	Tech TBA (NSW Fisheries)	As per milestone for 30/12/2002
	Tech TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (TAFI/AMC)	As per milestone for 30/12/2002
30/06/2005	Dr Francisco Neira (AMC)	As per milestone for 30/12/2002
	Project Scientist TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (Fisheries WA)	As per milestone for 30/12/2002
	Tech TBA (MAFRI)	As per milestone for 30/12/2002
	Tech TBA (NSW Fisheries)	As per milestone for 30/12/2002
	Tech TBA (SARDI)	As per milestone for 30/12/2002
	Tech TBA (TAFI/AMC)	As per milestone for 30/12/2002

C2 TRAVEL

Year	Fares	Allowances	**Accommodation**	**Other**	Description
30/12/2002	-	4,896	**-**	**-**	
	1,800	3,600	**100**	**-**	
	920	80	**120**	**-**	
	6,600	250	**250**	**-**	
30/06/2003	950	60	**120**	**-**	
	1,800	3,600	**240**	**-**	
	900	3,600	**120**	**-**	
	-	4,896	**-**	**-**	
30/12/2003	6,600	250	**250**	**-**	
	-	4,896	**-**	**-**	
	800	400	**300**	**-**	
	1,840	3,600	**240**	**-**	
30/06/2004	900	3,600	**-**	**120**	
	1,740	120	**160**	**-**	
	1,800	3,600	**-**	**240**	
	-	4,896	**-**	**-**	
30/12/2004	-	4,896	**-**	**-**	
	6,600	250	**250**	**-**	
	1,800	3,600	**240**	**-**	
30/06/2005	900	3,600	**120**	**-**	
	1,800	3,600	**240**	**-**	
Total Travel	37,750	58,290	**2,750**	**360**	

C2 TRAVEL JUSTIFICATION

Milestone Date	Justification
30/12/2002	Costs of attending gamefishing tournaments and liasing with charter boat operators in NSW. Travel costs, seagoing allowance and victualling for three technical staff involved in NSW egg surveys. Dr Tim Ward to travel to NSW to participate in surveys Mr Graham Pike (Recfish), Dr Julian Pepperell (GFAA), Mr Angus Nicholls (Ocean Freshh), Commerical fishing rep, Dr Jeremy Lyle (TAFI), Dr Francisco Neira (AMC), Dr Kim Smith (NSW Fisheries), Dr Michael Lowry (NSW Fisheries), Dr Sandy Morison (MAFRI), Dr Dan Gaughan (Fisheries WA) and Dr Tim Ward (SARDI) to partipate in steering committee meeting in ACT.
30/06/2003	Dr Tim Ward to travel to Tasmania to participate in surveys Seagoing allowance and victualling for three technical staff involved in SA egg Seagoing allowance and victualling for three technical staff involved in SA egg Costs of attending gamefishing tournaments and liasing with charter boat operators in NSW.
30/12/2003	Mr Graham Pike (Recfish), Dr Julian Pepperell (GFAA), Mr Angus Nicholls (Ocean Freshh), Commerical fishing rep, Dr Jeremy Lyle (TAFI), Dr Francisco Neira (AMC), Dr Kim Smith (NSW Fisheries), Dr Michael Lowry (NSW Fisheries), Dr Sandy Morison (MAFRI), Dr Dan Gaughan (Fisheries WA) and Dr Tim Ward (SARDI) to partipate in steering committee meeting in ACT. Costs of attending gamefishing tournaments and liasing with charter boat operators in NSW. Travel and other costs of involving Julian Peperell in NSW surveys. Travel costs and seagoing allowance and victualling for three technical staff involved in NSW egg surveys.
30/06/2004	Travel costs, seagoing allowance and victualling for three technical staff involved in South Australian egg surveys. Staff to travel to Tasmania to participate in surveys Travel costs, seagoing allowance and victualling for three technical staff involved in Tasmanian egg surveys. Costs of attending gamefishing tournaments and liasing with charter boat operators in NSW.
30/12/2004	Costs of attending gamefishing tournaments and liasing with charter boat operators in NSW. Mr Graham Pike (Recfish), Dr Julian Pepperell (GFAA), Mr Angus Nicholls (Ocean Freshh), Commerical fishing rep, Dr Jeremy Lyle (TAFI), Dr Francisco Neira (AMC), Dr Kim Smith (NSW Fisheries), Dr Michael Lowry (NSW Fisheries), Dr Sandy Morison

	(MAFRI), Dr Dan Gaughan (Fisheries WA) and Dr Tim Ward (SARDI) to partipate in steering committee meeting in ACT.
	Travel costs and seagoing allowance and victualling for three technical staff involved in egg NSW surveys.
30/06/2005	Travel and seagoing allowance and victualling for three technical staff involved in South Australian egg surveys.
	Travel and seagoing allowance and victualling for three technical staff involved in Tasmanian egg surveys.

C3 OPERATING

Milestone Date	Description	Amount
30/12/2002	Surveys off NSW coast.	20,000
	SARDI Institute Levy	8,000
	Nets and adult sampling equipment	3,000
	Transport otoliths and samples interstate.	2,000
	Histology	1,800
	Laboratory consumables	1,500
	Consumables for recreational survey	700
30/06/2003	Surveys off SA coast.	21,000
	Surveys off Tasmania coast.	16,000
	SARDI Institute Levy	8,000
	Histology	1,800
	Transport of otoliths and gonad samples interstate.	1,200
	Laboratory consumables	1,000
	Consumables for recreational survey	600
30/12/2003	Surveys of NSW coast.	20,000
	SARDI Institute Levy	8,000
	Histology	1,800
	Transport of otoliths and gonad samples interstate.	1,200
	Laboratory consumables	1,000
	Consumables for recreational survey	600
30/06/2004	Surveys off SA coast.	21,000
	Surveys off Tasmania coast.	16,000
	SARDI Institute Levy	8,000
	Histology	1,800
	Transport of otoliths and gonad samples interstate.	1,200
	Laboratory consumables	800
	Consumables for recreational survey	600
30/12/2004	Surveys of NSW coast.	20,000
	SARDI Institute Levy	8,000
	Histology	1,800
	Laboratory consumables	1,200
	Transport of otoliths and gonad samples interstate.	1,200
	Consumables for recreational survey	600
30/06/2005	Surveys of SA coast	21,000
	SARDI Institute Levy	8,000
	Workshops in each state and Canberra to extend findings to stakeholders.	5,000

	Histology	1,800
	Surveys off Tasmania coast.	1,600
	Laboratory consumables	1,200
	Transport of otoliths and gonad samples interstate.	1,200
Total Operating		241,200

C3 OPERATING JUSTIFICATION

Milestone Date	Description	Justification
30/12/2002	Surveys off NSW coast.	Costs of using FTV Bluefin to conduct surveys off NSW (10 days @ $2000 per day).
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Nets and adult sampling equipment	For collecting samples.
	Transport otoliths and samples interstate.	Needed to collate existing data and samples and develop comprehensive description of age structure of commerical catches. Allows each state to specialise in techniques for ageing one species.
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Laboratory consumables	Needed for removal and fixing of otoliths and gonads, and processing otoliths at SARDI
	Consumables for recreational survey	Wet weather gear, data sheets, tackle, bait, gratuities, etc.
30/06/2003	Surveys off SA coast.	Less than marginal cost (fuel) of using Ngerin for 14 days @ $1500 per day.
	Surveys off Tasmania coast.	Marginal cost (fuel) of using Bluefin for 10 days @ $1600 per day.
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Transport of otoliths and gonad	Needed to transport samples to SARDI for

	samples interstate.	analysis.
	Laboratory consumables	Needed for removal and fixing of otoliths and gonads, and processing otoliths at SARDI
	Consumables for recreational survey	Wet weather gear, data sheets, tackle, bait, gratuities, etc.
30/12/2003	Surveys of NSW coast.	Costs of using RV Bluefin to conduct surveys(10 days @ $2000 per day).
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Transport of otoliths and gonad samples interstate.	Needed to transport samples to SARDI for analysis.
	Laboratory consumables	Needed for removal and fixing of otoliths and

C3 OPERATING JUSTIFICATION Continued

	Consumables for recreational survey	Wet weather gear, data sheets, tackle, bait, gratuities, etc.
30/06/2004	Surveys off SA coast.	Less than marginal cost (fuel) of using Ngerin for 14 days @ $1600 per day.
	Surveys off Tasmania coast.	Marginal cost (fuel) of using Bluefin for 10 days @ $1600 per day.
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Transport of otoliths and gonad samples interstate.	Needed to transport samples to SARDI for analysis.
	Laboratory consumables	Needed for removal and fixing of otoliths and gonads, and processing otoliths at SARDI
	Consumables for recreational survey	Wet weather gear, data sheets, tackle, bait, gratuities, etc.
30/12/2004	Surveys of NSW coast.	Costs of using Bluefin to conduct surveys(10 days @ $2000 per day).
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Laboratory consumables	Needed for removal and fixing of otoliths and gonads, and processing otoliths at SARDI
	Transport of otoliths and gonad samples interstate.	Needed to transport samples to SARDI for analysis.
	Consumables for recreational survey	Wet weather gear, data sheets, tackle, bait,

		gratuities, etc.
30/06/2005	Surveys of SA coast	Marginal cost (fuel) of using Ngerin for 15 days @ $1500 per day.
	SARDI Institute Levy	20% SARDI salaries. Marginal cost increase to SARDI of the staff appointment and associated operations and administration. Provision of facilities - not the cost of operating. Includes: HR, phones, photocopier machine, lab use, office use, IT support, OHS&W, general accounting, facility
	Workshops in each state and Canberra to extend findings to stakeholders.	Needed to ensure extension of results to stakeholders.
	Histology	Costs of conducting histology on reproductive samples obtained from each state.
	Surveys off Tasmania coast.	Marginal cost (fuel) of using Bluefin for 10 days @ $1600 per day.
	Laboratory consumables	Needed for removal and fixing of otoliths and gonads, and processing otoliths at SARDI

C3 OPERATING JUSTIFICATION Continued

	Transport of otoliths and gonad samples interstate.	Needed to transport samples to SARDI for analysis.

C4 CAPITAL

Milestone Date	Description	Amount

C4 CAPITAL JUSTIFICATION

Milestone Date	Description	Justification

C1 to C4 MILESTONE COST SUMMARY

Milestone Date	Salaries	Travel	**Operating**	**Capital**	Total
30/12/2002	105,088	18,616	**37,000**	**-**	160,704
30/06/2003	105,088	16,286	**49,600**	**-**	170,974
30/12/2003	108,335	19,176	**32,600**	**-**	160,111
30/06/2004	108,335	17,176	**49,400**	**-**	174,911
30/12/2004	111,788	17,636	**32,800**	**-**	162,224
30/06/2005	78,858	10,260	**39,800**	**-**	128,918
Total	617,492	99,150	**241,200**	**-**	957,842

C5 CONTRIBUTION BY APPLICANT

Year	Salaries	Travel	**Operating**	**Capital**
02/03	21,500	-	**198,000**	**-**
03/04	22,000	-	**200,000**	**-**
04/05	22,500	-	**200,000**	**-**
Total Contribution	66,000	-	**598,000**	**-**

C5 CONTRIBUTION BY APPLICANT JUSTIFICATION

Year	Justification
02/03	25% Dr Tim Ward's salary ($21500). Real costs of providing Ngerin $52500(15 days @ $3500 per day). Other facilities $114000 (1.0 X total SARDI salaries). Office and general consumables $10000 (e.g. computer connnection fee, fuel for vehicle, etc.). The high contribution SARDI is making to this projectreflects an investment towards SARDI's intention of further developing capacity as research provider in this area.
03/04	25% Dr Tim Ward's salary ($22000). Real costs of providing Ngerin $52500(15 days @ $3500 per day). Other facilities $115500 (1.0 X total SARDI salaries). Office and general consumables

$10000 (e.g. computer connnection fee, fuel for vehicle, etc.). The high contribution SARDI is making to this projectreflects an investment towards SARDI's intention of further developing capacity as research provider in this area.

04/05 25% Dr Tim Ward's salary ($22500). Real costs of providing Ngerin $52500(15 days @ $3500 per day). Other facilities $117000 (1.0 X total SARDI salaries). Office and general consumables $10000 (e.g. computer connnection fee, fuel for vehicle, etc.). The high contribution SARDI is making to this projectreflects an investment towards SARDI's intention of further developing capacity as research provider in this area.

C6 CONTRIBUTION BY OTHER SOURCES

Year	Contributor	Salaries		**Travel**	**Operating**	Capital
02/03	AFMA	63,000		**-**	**-**	5,000
	AMC	9,282		**-**	**70,000**	50,000
	Fisheries WA	1,000		**-**	**-**	15,000
	MAFRI	1,000		**-**	**-**	15,000
	NSW Fisheries	26,000		**-**	**-**	80,000
	Ocean Fresh	4,000		**3,000**	**-**	-
	RecFish Australia	5,000		**-**	**-**	-
	TAFI	12,000		**-**	**800**	105,000
03/04	TAFI	12,000		**-**	**800**	105,000
	RecFish Australia	5,000		**-**	**-**	-
	Ocean Fresh	4,000		**3,000**	**-**	-
	NSW Fisheries	27,000		**-**	**-**	82,500
	MAFRI	1,000		**-**	**-**	15,000
	Fisheries WA	1,000		**-**	**-**	15,000
	GFAA	2,000		**-**	**-**	60,000
	AMC	9,560		**-**	**70,000**	50,000
	AFMA	63,000		**-**	**-**	5,000
04/05	AFMA	63,000		**-**	**-**	5,000
	AMC	9,850		**-**	**70,000**	50,000
	GFAA	2,000		**-**	**-**	60,000
	Fisheries WA	1,000		**-**	**-**	15,000
	MAFRI	1,000		**-**	**-**	15,000
	NSW Fisheries	26,000		**-**	**-**	80,000
	Ocean Fresh	4,000		**3,000**	**-**	-
	RecFish Australia	5,000		**-**	**-**	-
	TAFI	12,000		**-**	**800**	105,000
Total Contributions		369,692	9,000		**212,400**	**932,500**

C6 CONTRIBUTION BY OTHER SOURCES JUSTIFICATION

Year	Contributor	Justification
02/03	AFMA	Cash contribution of $55000 to be used for salaries by state agencies. 10% of Dr Andy Bodsworth's salary ($8000). Meeting facilites.
	AMC	10% of Dr Francisco Neira's salary. Infrastructure. Nets and consumables. Real costs of providing Bluefin.
	Fisheries WA	2.5% of Dr Dan Gaughan's time. Infrastucture. Nets and consumables.
	MAFRI	2.5% of Mr Sandy Morison's time. Infrastucture. Nets and consumables.
	NSW Fisheries	25% Dr Kimberley Smith's salary. Infrastructure.
	Ocean Fresh	Costs of Mr Angus Nicholl's participation in steering committee.
	RecFish Australia	Mr Graham Pike's particpation in project.
	TAFI	Contribution of 10% of Dr Lyle's salary ($10000), technicians salary ($2500) and allowances for technicians ($800). Provision of infrastructure.
03/04	TAFI	Contribution of 10% of Dr Lyle's salary ($5000), technicians salary ($2500) and allowances for technicians ($800). Provision of infrastructure.
	RecFish Australia	Mr Graham Pike's particpation in project.
	Ocean Fresh	Costs of Mr Angus Nicholl's participation in steering committee.
	NSW Fisheries	25% Dr Kimberley Smith's salary. Infrastructure.
	MAFRI	2.5% of Mr Sandy Morison's time. Infrastucture. Nets and consumables.
	Fisheries WA	2.5% of Dr Dan Gaughan's time. Infrastucture. Nets and consumables.
	GFAA	Access to vessels to conduct surveys of NSW.
	AMC	10% of Dr Francisco Neira's salary. Infrastructure. Nets and consumables. Real costs of providing Bluefin.
	AFMA	Cash contribution of $55000 to be used for salaries by state agencies. 10% of Mr Andy Bodsworth's salary ($8000). Meeting facilities.
04/05	AFMA	Cash contribution of $55000 to be used for salaries by state agencies. 10% of Dr Andy Bodsworth's salary ($8000). Meeting facilites.
	AMC	10% of Dr Francisco Neira's salary. Infrastructure. Nets and consumables. Real costs of providing Bluefin.
	GFAA	Access to vessels to conduct surveys of NSW.

Fisheries WA	2.5% of Dr Dan Gaughan's time. Infrastucture. Nets and consumables.
MAFRI	2.5% of Mr Sandy Morison's time. Infrastucture. Nets and consumables.
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RecFish Australia	Mr Graham Pike's particpation in project.
TAFI	Contribution of 10% of Dr Lyle's salary ($10000), technicians salary ($2500) and allowances for technicians ($800). Provision of infrastructure.