March 1996

FINAL REPORT TO FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

GRANT # 92/019

AN ICHTHYOPLANKTON BASED ANALYSIS OF THE SPAWNING DISTRIBUTION AND STOCK STRUCTURE OF TEMPERATE AUSTRALIAN FINFISH

BY B.D. BRUCE, C.A. SUTTON AND R.E. THRESHER

CSIRO
AUSTRALIA

DIVISION OF FISHERIES

CONTENTS

1. NON TECHNICAL SUMMARY

Knowlege of the structure of fished stocks is essential for effectively managing fisheries and ensuring their sustainable exploitation. Yet for the majority of quota species in the South East Fishery (SEF) this information is lacking. Several techniques can be employed to establish stock structure (eg genetic studies, otolith microchemistry, tagging) but each have their own biases and may not be appropriate for every species. This has been recently highlighted, for example, when comparing genetic and otolith microchemistry techniques for jackass morwong (FRDC Report 1991/32). An additional technique that has proved useful in overseas applications has been an analysis of the distribution and patterns of dispersal of eggs and larval stages. Such analyses can provide details of stock structure by identifying the number and location of spawning areas, timing of spawning and the pattern of mixing of larvae between different areas. Recent advances in the identification of larvae of southern Australian commercial fish species now allows us to apply this technique to SEF species.

In this study, the larval distribution of four SEF quota species (jackass morwong, blue warehou, spotted warehou and blue grenadier) were investigated based on plankton samples collected in south eastern Australian waters between 1992 and 1994. Details of larval age (from otolith microstructure) and distribution were combined with data on ocean currents (from concurrently collected temperature and salinity data, wind data, satellite tracked surface drifters and satellite images of sea surface temperature) to deduce advection pathways for larvae, likely source spawning and destination nursery areas and hence further details of stock structure.

1.1 JACKASS MORWONG.

Large numbers of jackass morwong larvae (6-30 mm in length) were captured in surface waters up to 250 km east of Tasmania (the limit of sampling) during autumn and early winter in 1992, 1993 and 1994. Jackass morwong larvae were found both north and south of a major frontal zone (Sub-tropical Convergence - STC) within water masses derived from the East Australian Current (EAC) and Sub-Antarctic Water (SAW). Back calculated spawning dates and inferred current patterns suggest that larvae from within each water mass originate from different spawning regions. There was a significant positive relationship between both larval age as well as size and distance offshore. Calculated larval advection rates matched data from satellite-tracked drifters suggesting a largely passive movement of larvae offshore within surface waters. Once offshore, satellite tracked drifters showed a complex pattern of movement but were generally retained within a few hundred km of the coast for periods up to 8 months, roughly equal to the pelagic larval duration of morwong.

Patterns of surface circulation as well as the seasonal variability in the movement of major water masses off the SE Australian coast suggest that jackass morwong stocks in south western Tasmania as well as southern NSW are self-recruiting, and that a region of mixed recruitment should exist covering eastern Tasmania and eastern Victoria. These circulation patterns provide mechanisms that account for the multiple stock scenario suggested by otolith microchemistry analyses (FIRTA Report 1991/32). Furthermore, the degree of population mixing suggested by these patterns undoubtedly accounts for the lack of distinct genetic differences throughout the SE Australian region. Whether stocks remain sufficiently distinct to be managed separately remains unresolved. However, the correspondence between recruitment patterns predicted from larval advection and those from otolith microchemistry suggest that the latter technique may be useful in quantifying the extent of mixing between jackass morwong stocks in SE Australia.

1.2 BLUE GRENADIER

Blue grenadier larvae were located, for the first time, in waters off southern NSW and eastern Victoria. This data further supports the presence of a second spawning area for the species in south eastern Australia. Based on the age of larvae and current patterns, this spawning area is most likely located off north east Tasmania or eastern Bass Strait as originally hypothesised during a previous CSIRO study (FIRTA Report 1984/63). Neither the exact location, annual regularity nor the magnitude of this spawning event can yet be determined and these questions provide potential areas for future research.

1.3 SPOTTED AND BLUE WAREHOUS

The identity of spotted and blue warehou larvae was established for the first time during this study. The distribution of larvae of both species suggest widespread spawning activity throughout the SEF. A complex pattern of mixing of larvae between regions suggests that the current strategy for managing both species as single respective stocks is appropriate.

2. BACKGROUND

Detailed information on stock structure is essential for effectively managing fisheries, ensuring their sustainable exploitation and interpreting changes in the characteristics of resources. Yet, for most species in southern Australian waters, including most of those that constitute the SEF, there is not enough information to determine stock structure (Tilzey, 1994).

Information on stock structure can be derived from a number of different sources, including results of tagging studies, genetics, analysis of parasite distributions and analysis of otolith chemistry. However each has its own different bias and one technique is unlikely to provide universally unambiguous results. In these situations, combinations of independent techniques can provide the best interpretations. Recent discussions regarding the stock structure of orange roughy demonstrate that the most compelling and least ambiguous evidence of stock structure is knowledge of the location and number of discrete spawning grounds for each species (or evidence of continuous spawning, where a single, broadly distributed stock exists). Such an approach is also widely used overseas; North Atlantic cod and herring stocks, as examples, are defined less on genetic and tagging studies as on evidence from demersal trawling and plankton samples of well defined, discrete spawning grounds for each stock.

Information on the location and number of spawning areas is also extremely valuable in two other contexts. First, where species can be shown to aggregate for spawning and the location of those aggregations determined, such aggregations can form the focus of a targeted fishery. A case in point is Blue Grenadier. Second, determining the biomass of trawled fish species is extremely difficult, for which reason CSIRO has pioneered, in Australia, the development and application of egg production and acoustic methods of biomass estimation (e.g. blue grenadier and orange roughy surveys). These techniques can be applied only when the location and duration of spawning aggregations have first been established. However. for most of Australia's temperate fish stocks, we lack even this basic biological information.

Spawning grounds can be located in two ways, by trawling for adults and noting areas of running ripe individuals (which is how many of the North Atlantic herring grounds were discovered) or by egg and larval (ichthyoplankton) surveys. The former is extremely expensive and difficult to apply to species which (1) largely inhabit un-trawlable grounds, (2) aggregate to spawn (and hence could easily be missed), and (3) spawn over relatively short periods (and hence could be missed because sampling was not done often enough or at exactly the correct time). By comparison, locating spawning grounds from ichthyoplankton studies is relatively more simple logistically, since larvae disperse away from even small spawning grounds (increasing the size of the target area and hence the likelihood of locating the ground) and, in

temperate regions, develop in the plankton for periods of, usually, several months (e.g., Whiting, Blue Grenadier, Jackass Morwong), increasing the likelihood of finding evidence of a spawning ground even with a relatively coarse spacing of samples in time. Recent successful applications of this approach include CSIRO and MAF (New Zealand) studies on Blue Grenadier and studies by Western Australian Fisheries on pilchards.

This study represents an initial analysis of larval distribution for three main species within the SEF (jackass morwong, blue warehou and spotted warehou) for which there was essentially no previous information on early life history . We have also re-examined evidence of a second spawning area for blue grenadier in light of new information on larval distribution. The long term goal of documenting such information is to provide a synthesis of early life history data for southern Australian commercial fish species from which spawning areas, patterns of larval dispersal and probable stock structure can be inferred.

3. PROJECT DETAILS

3.1 OBJECTIVES

The original objectives of this study were:

To determine the distribution of spawning activities for major commercial finfish species in SE Australian waters (mainly the SEF),

To obtain, opportunistically, samples of larvae from elsewhere in temperate Australian waters for preliminary evaluation of spawning by key species in areas outside the SEF,

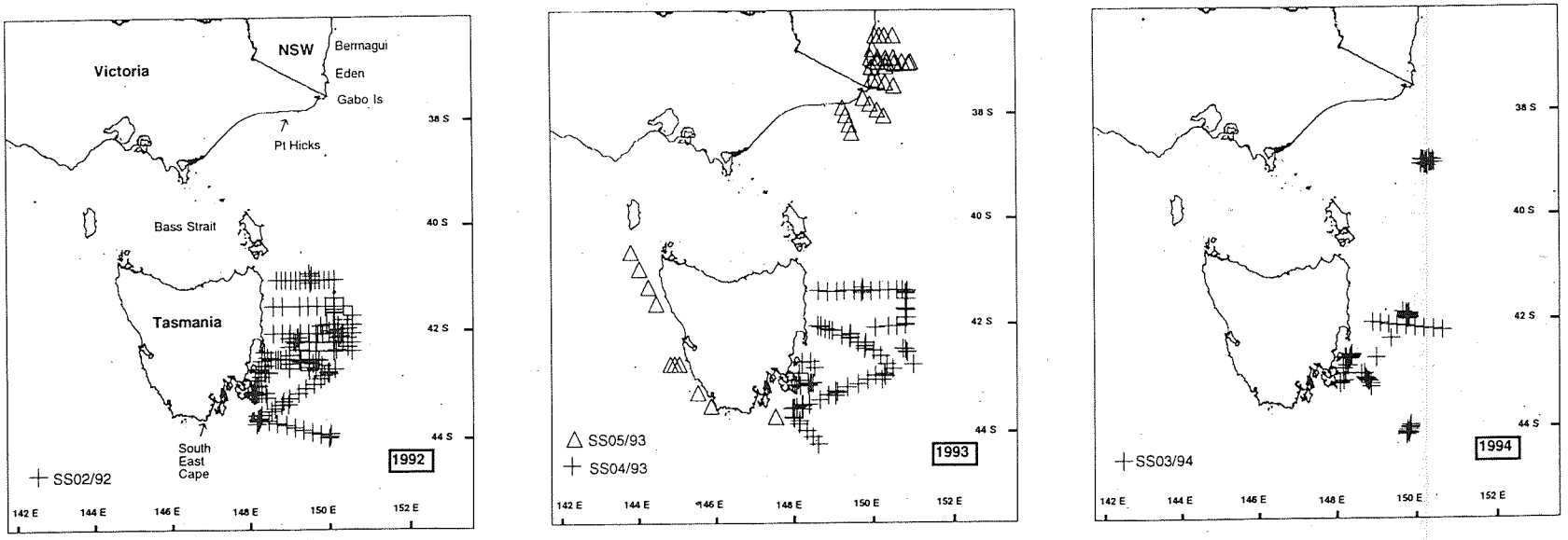
To develop genetic techniques for identification of eggs and larvae of commercial species, and to use genetic and conventional techniques to extend our knowlege of the taxonomy of commercial finfish species,

To trial the application of microprobe techniques on larvae to assess its use as a means of measuring the spread of individuals from spawning areas and to measure the mixing rate of stocks, and

To apply a range of sampling techniques (e.g. neuston tows, very deep plankton samplers) to determine the distributions of larvae of commercial species that are not common in conventional plankton tows.

After discussion with both FRDC and industry groups regarding the level of both financial and logistic support, these original objectives were scaled back to target specific commercial fish groups and reduce the length of the project to 1

Figure 1. The study area showing locations of sampling stations.



year. The revised objectives covering this study were:

- To synthesise available data on larval distribution of jackass morwong, blue warehous and spotted warehous in south eastern Australian waters
- To determine the main advection pathways of these larvae and linkages between spawning and nursery areas
- To re-examine the distribution and advection pathways of blue grenadier larvae for evidence of multiple spawning areas.
- To use these data to infer likely spawning areas and stock structure for these species in southeastern Australian waters.

These objectives remain in step with our original approach and long term goal of synthesising early life history information for commercial species in southern Australia.

3.2 REPORT SCOPE AND FORMAT

This study focuses on larvae of selected commercial finfish species collected during a series of cruises in south east Australian waters between 1992 and 1995. Sampling locations and cruise details are given in Figure 1. Three groups were examined in detail; jackass morwong, warehous (blue and spotted) and blue grenadier. For each, larval distribution, advection pathways and adult spawning patterns (as inferred from otolith microstructure) are examined in turn.

4. TECHNICAL RESULTS

4.1 JACKASS MORWONG

4.1.1 INTRODUCTION

The jackass morwong *Nemadactylus macropterus* (Cheilodactylidae) is a commercially important temperate ground fish common in coastal and continental shelf waters of southern Australia and New Zealand (Last *et al.* 1983, Ayling and Cox 1982). Despite a number of studies, the stock structure of the species remains contentious (Thresher *et al.* 1994). Genetic analyses suggest little population sub-structuring across southern Australia, but a distinct separation between Australia and New Zealand (Richardson, 1982; Elliott and Ward, 1994; Grewe *et al.* 1994). Otolith microchemistry analyses, however, suggest a far more complex stock structure with up to four distinct groupings within southern Australia and a link between southern and western Tasmanian populations and those of the South Island of New Zealand. This discrepancy

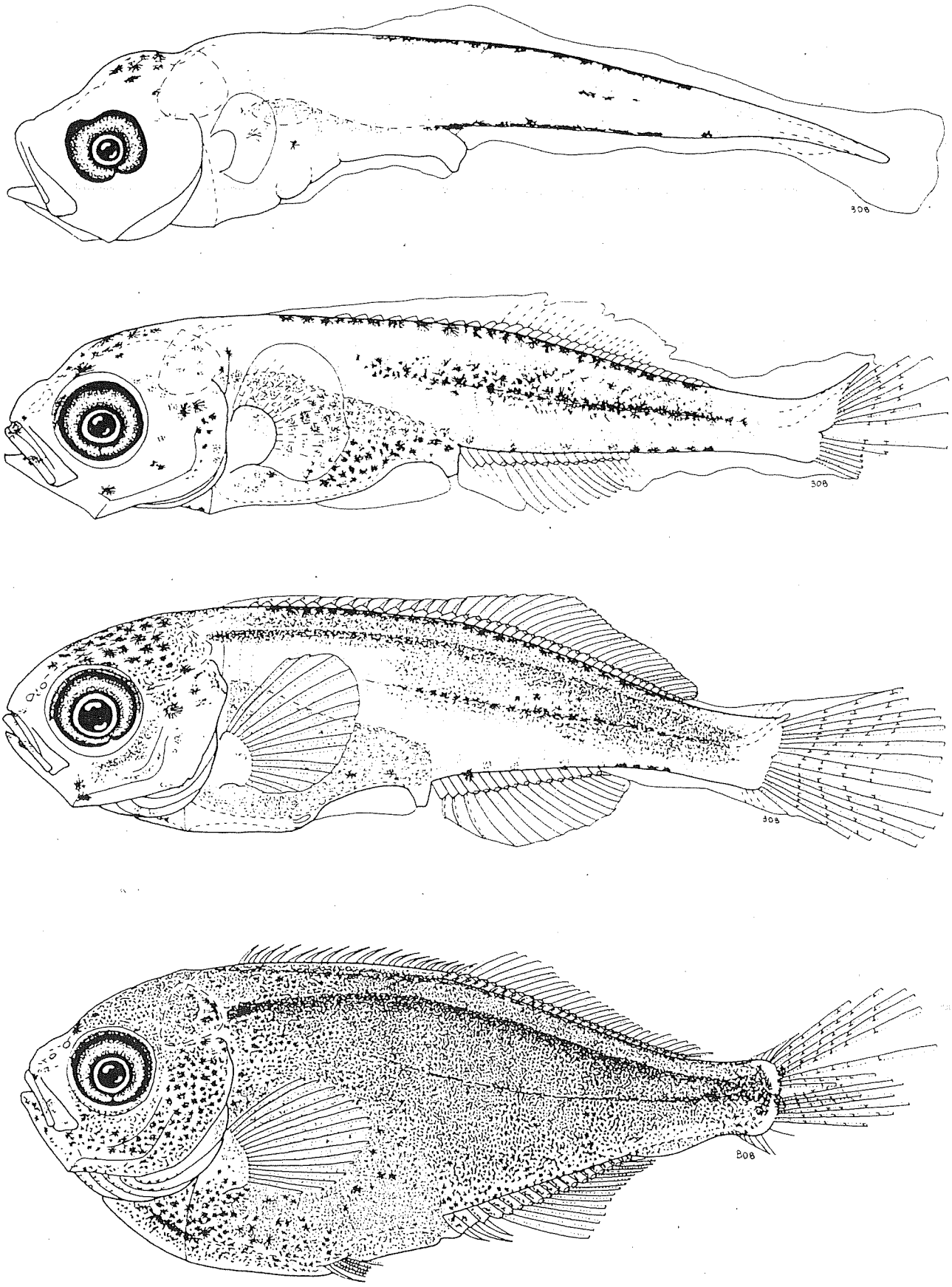


Figure 2. Larval development of jackass morwong (*N. macropterus*) larvae. (A) 4.2 mm; (B) 7.1 mm; (C) 9.2 mm; (D) 19.2 mm.

has been ascribed to the relative sensitivities of the two techniques to mixing rates between stocks (Thresher *et al.* 1994; Elliott and Ward, 1994). The multiple stock scenario for jackass morwong in southern Australia is consistent with observed regional declines in abundance (Thresher *et al.* 1994) and work in New Zealand where three geographically discrete populations have been identified (Gauldie and Nathan, 1977). It does, however, suggest regional self-recruiting populations which seems at odds with the species' extended offshore early life history (Vooren, 1972, 1975; Tong and Saito, 1977), that implies a high potential for larval mixing and dispersal.

Major nursery areas for jackass morwong are located in southern Tasmania and Bass Strait (Tilzey *et al.* 1990), thus when a study of zooplankton in waters offshore of this region commenced in 1992 (Young *et al.* in press) we began a series of collections of jackass morwong larvae. Our purpose here is to examine, in detail, the distribution of jackass morwong larvae and identify advection processes in order in order to further clarify the stock structure of the species in south eastern Australia.

4.1.2 LARVAL IDENTIFICATION

Morwong larvae are initially elongate, moderately pigmented with melanophores concentrated over dorsal, ventral and lateral midlines and have 34-36 myomeres (Brownell, 1979; Okiyama, 1988; Bruce, 1989). Postflexion larvae are heavily pigmented and become strongly, laterally compressed with a sharp ventral keel extending from isthmus to anus as well as below the caudal peduncle (Bruce, 1989). Larvae >5.5 mm BL were identified as jackass morwong by their anal fin count of III, 14–15. Larvae <5.5 mm were identified based on assembling a size series and following the development of pigment (see Bruce, in press for details).

4.1.3 BRIEF DESCRIPTION OF JACKASS MORWONG LARVAE

Figure 2.

Morphology

Body elongate, round in cross section in preflexion larvae (BD 18%–19%), moderate in flexion (BD 23%–27%), rapidly increasing from moderate to deep in postflexion (BD 24%–41%) and becoming strongly, laterally compressed. Head moderate (HL 23%–32%) with a small to moderate mouth reaching to below the anterior edge of eye. Gut long (PAL 52%–59%) and coiled but not compact. Gas bladder large, extending posteriorly from above the pectoral fin base 2/3 distance to anus when inflated. No gap between anus and anal fin. No head spines. Prominent ventral keel extending posteriorly from isthmus to

pelvic fin in larvae >9.1 mm and on caudal peduncle (>11.0 mm). Persistent preanal finfold between pelvic fin and anus in larvae <11.4 mm, gradually thickening to form extension of ventral keel.

Size at	
Hatching	<2.9–3.2 mm
Notochord flexion	5.2–7.1 mm
Settlement	60.0–80.0 mm
Formation of scales	9.1–12.5 mm
Formation of fins:	
Anal	4.6–12.4 mm
Dorsal	4.6–12.4 mm
Caudal	6.4–7.2 mm
Pelvic	6.4–12.4 mm
Pectoral	6.4–12.4 mm

Pigmentation

Preflexion and flexion larvae are moderately pigmented, becoming heavily pigmented during postflexion. External: Scattered stellate melanophores dorsally on head, extending between eyes and towards nape by 7.0 mm. Small scattered melanophores over snout, becoming less prominent and contracting to tip of upper jaw during flexion. Single prominent melanophores over urohyal by 4.6 mm; lower jaw below anterior margin of eye by 5.0 mm and at angle of lower jaw by 7.0 mm. Scattered melanophores added over preoperculum and operculum during flexion and postflexion. Melanophores (2–5) develop along ventral midline anterior to cleithral symphysis and bases of branchiostegal rays during flexion. Dense melanistic shield anterio-dorsally around orbit by 7.0 mm, extending over upper half of eye by 10.0 mm. Initially, a row of single stellate melanophores along dorsal midline of trunk and tail. This expands to form a paired series in larvae >5.0 mm and extends from nape to caudal peduncle in postflexion. Eight to ten melanophores on ventral midline of tail. Small melanophores along lateral midline of tail, expanding dorsally and ventrally by 5.2 mm and extending anteriorly and posteriorly during postflexion. Row of prominent melanophores on trunk above lateral midline by 8.1 mm, extending anteriorly to below nape and posteriorly to caudal peduncle forming a solid band of pigment by 9.1 mm. Scattered melanophores coalesce over trunk and tail to form an evenly pigmented zone above lateral midline by 9.0 mm and similarly below lateral midline on tail by 11.0 mm. Single melanophores on anterior margins of anal fin ray bases and scattered over ventral keels by 19.3

mm. Internal: Pigment above gut and gas bladder, on nape and scattered over otic capsule. Anterior-most 5–7 melanophores on ventral midline of tail overlain by musculature during flexion.

4.1.4 METHODS

(a) Samples examined

Jackass morwong larvae were sorted from samples collected off the east coast of Tasmania during three in May/June of 1992, 1993 and 1994 (SS02/92, SS04/93, SS03/94 - Figure 1). Cruises were designed to study zooplankton and micronekton community dynamics within the region of a seasonal longline fishery for southern bluefin tuna (see Young et al in press for full sampling details). Larvae were collected using two net systems: a 1 m^2 (1000 µm) net towed at the surface adjacent to the vessel and a multiple opening closing EZ net. All samples from 1992 were fixed in a 10% unbuffered formaldehyde/ seawater solution. Samples from 1993 and 1994 were fixed in either 10% unbuffered formaldehyde/seawater or 95% ethanol. Some samples in 1993 and 1994 were rough sorted onboard and all observed morwong larvae were removed and stored in 95% ethanol, the remaining material and all other samples were fixed in a 10% unbuffered formaldehyde/seawater solution. The volume filtered during each plankton tow was calculated using calibrated General Oceanics flowmeters. Reported catch rates of larvae are standardised to number per 1000 m^3.

(b) Physical Oceanography

Three data sets were used to examine circulation patterns and water mass structure in the sampling region: cruise data (temperature and salinity profiles), satellite images and satellite tracked surface drifters. Each cruise sampled along a series of transects covering the dominant water masses: East Australian Current (EAC) T>15°C, Sub-Antarctic water (SAW) T< 15°C and the sub-tropical convergence (STC) $14 \leq T \geq 15$°C separating the two (Young *et al.* in press). On each transect, at intervals between 5 and 30 nm, temperature and salinity profiles to 1000 m were recorded using a Neil Brown CTD. These data were used to ground truth satellite images of the area. Historical satellite images (taken at three day intervals and corrected for cloud cover by C. Rathbone & J. Parslow, CSIRO Marine Laboratories, Hobart) were examined for the years 1990–1994 to assess the seasonal and interannual mobility of major physical features and to infer likely patterns of larval advection.

The trajectories of 10 satellite tracked drifters, released at various positions on the Tasmanian continental shelf between 1992 and 1994 (Cresswell *et al.* 1994),

were compared to the distribution of jackass morwong larvae and the position of large scale oceanographic features.

(c) Otolith analyses

Jackass morwong larvae were aged by examining otolith microstructure following the procedures of Brothers *et al.* (1976). Increment formation was assumed to be daily, based on the similarity of increment structure to that in species for which age validation has been previously documented (e.g. Jenkins, 1987 - green back flounder *Rhombosolea tapirina*; Thresher *et al.* 1989 - blue grenadier). Indirect evidence supporting this assumption was gained from the coincidence of back calculated spawning dates with the documented spawning period for jackass morwong.

Increment counts were taken from whole unprocessed otoliths mounted in a drop of lens immersion oil. Otoliths were examined under transmitted light at 1200-2500x using a Leitz orthoplan microscope fitted with a high resolution television camera (Ikegami CTC-6000) and linked to a high resolution monitor. Counts were made from a single sagitta and lapillus removed from one side of the head. Increment age was estimated by averaging counts from the sagitta and the lapillus (where counts from a respective otolith set did not differ by >5% for larvae ≤40 increments or 10% – larvae ≥41 increments). Otolith pairs not satisfying these criteria were rejected from subsequent analyses (4.2% rejected). Increment age (i.e. number of increments) was used in all calculations of growth rate and in back calculating spawning dates. Increment age differs from true age by the number of days between spawning and the formation of the first increment. The timing of first increment formation varies between species from prior to hatching (e.g. Radtke and Dean, 1982; Neilson and Green, 1985) to the commencement of exogenous feeding (e.g. Brothers *et al.* 1976; Thresher *et al.* 1989). No information exists regarding the time to first feeding in Jackass morwong, however, Robertson (1978) reported that yolk sac absorption was complete after "1 week" in larvae reared at 18-20°C. Thus reported ages may underestimate true age by up to 7 days. Use of increment age rather than true age has little influence on either the calculation of growth rates or rates of advection from otolith data, although it will result in a minor shift in back calculated spawning dates.

To examine whether could be separated by differences in growth patterns, increment widths were compared between larvae collected from different water masses (identified by satellite imagery and temperature/salinity characteristics at the time of sampling) for the 1994 data set. Twenty larvae of approximately the same age were selected from each area for analysis. Increment widths, radius to first increment and total otolith radius were measured on sagittae via an Apple MacIntosh computer linked to the ITC video system and using the program

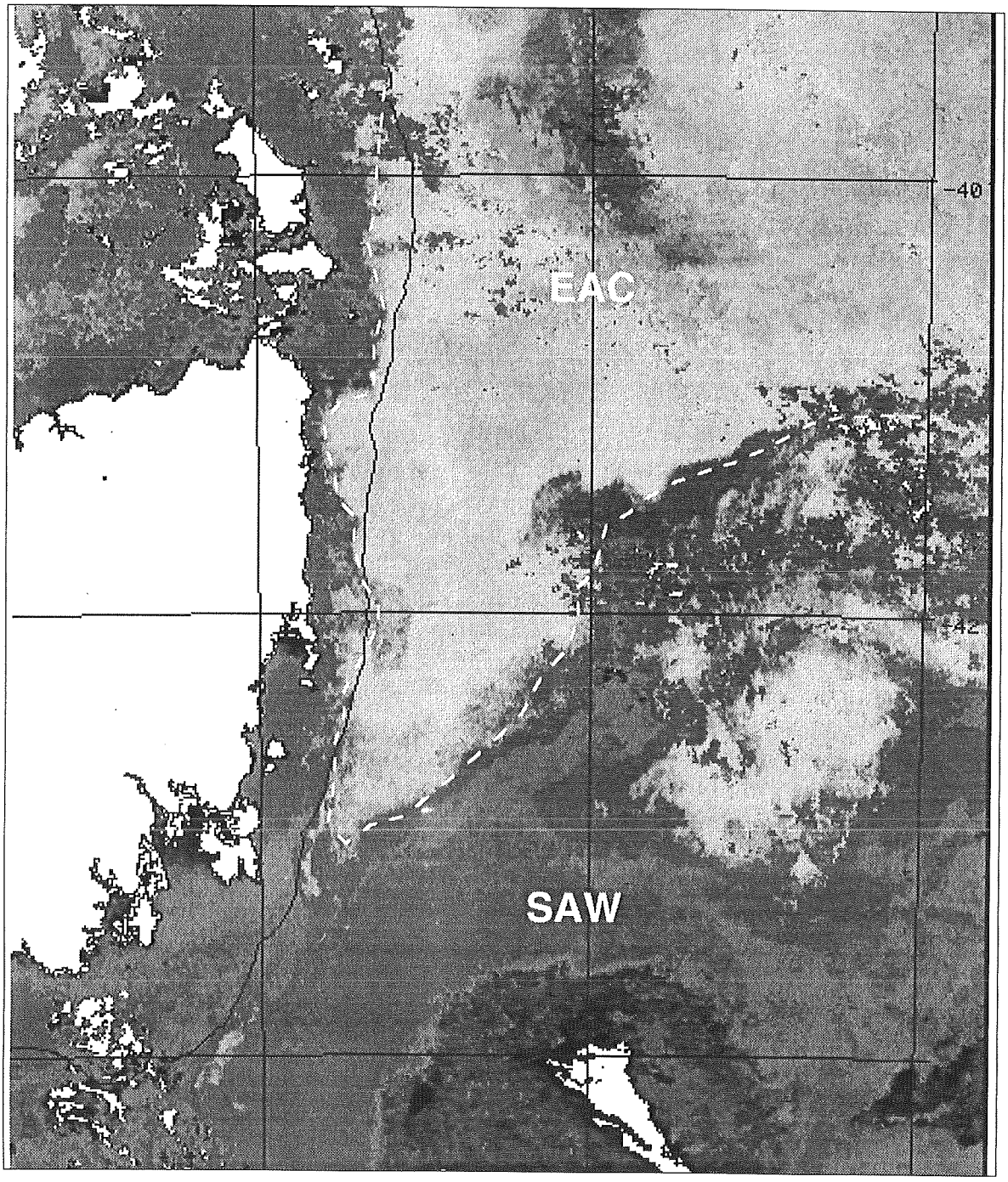


Figure 3a. 1992 satellite image of sea surface temperature at the time of sampling jackass morwong larvae off SE Australia. Frontal zone (STC) separating EAC and SAW marked as dotted line.

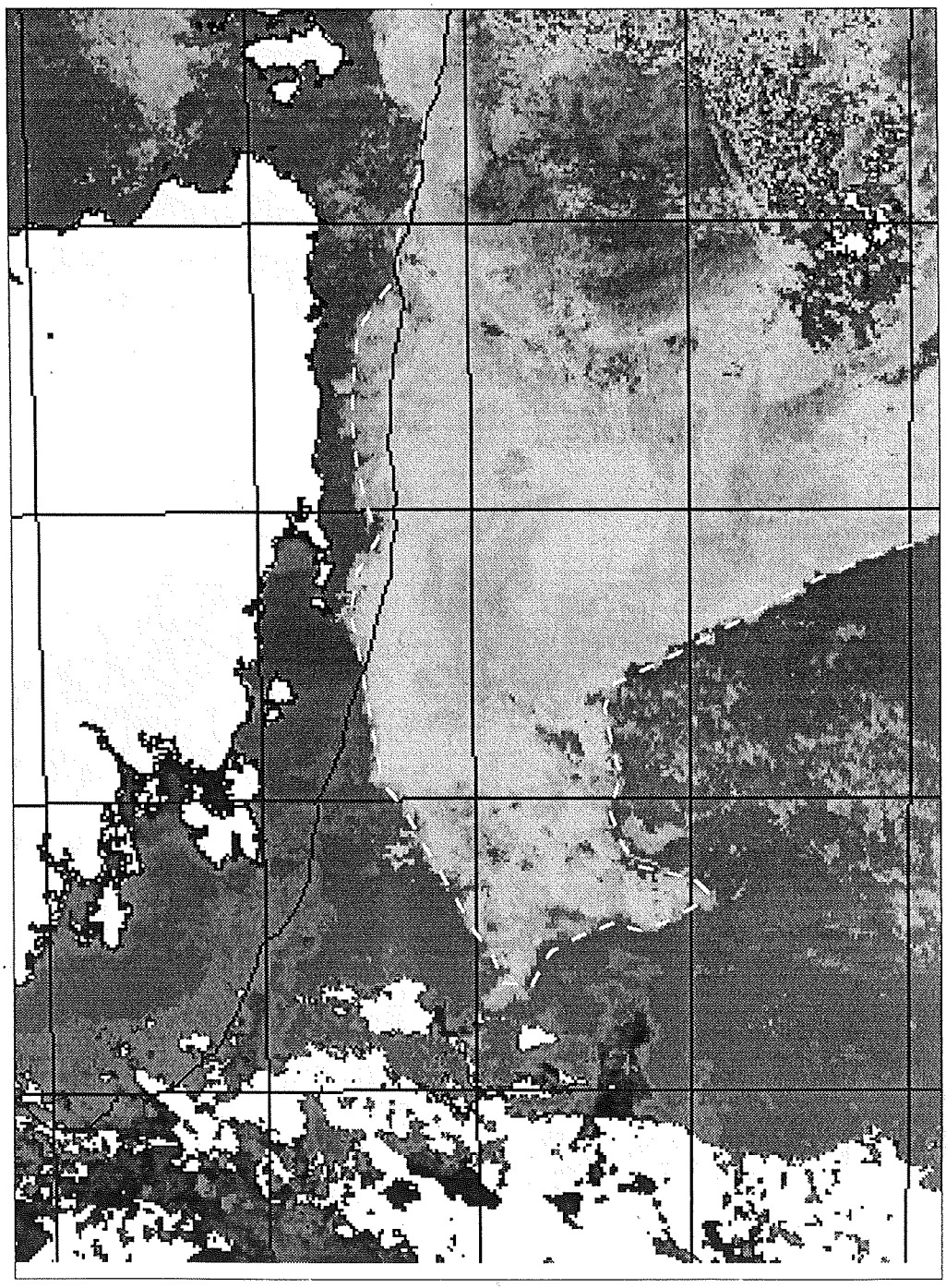


Figure 3b. 1993 satellite image of sea surface temperature at the time of sampling jackass morwong larvae off SE Australia. Frontal zone (STC) separating EAC and SAW marked as dotted line.

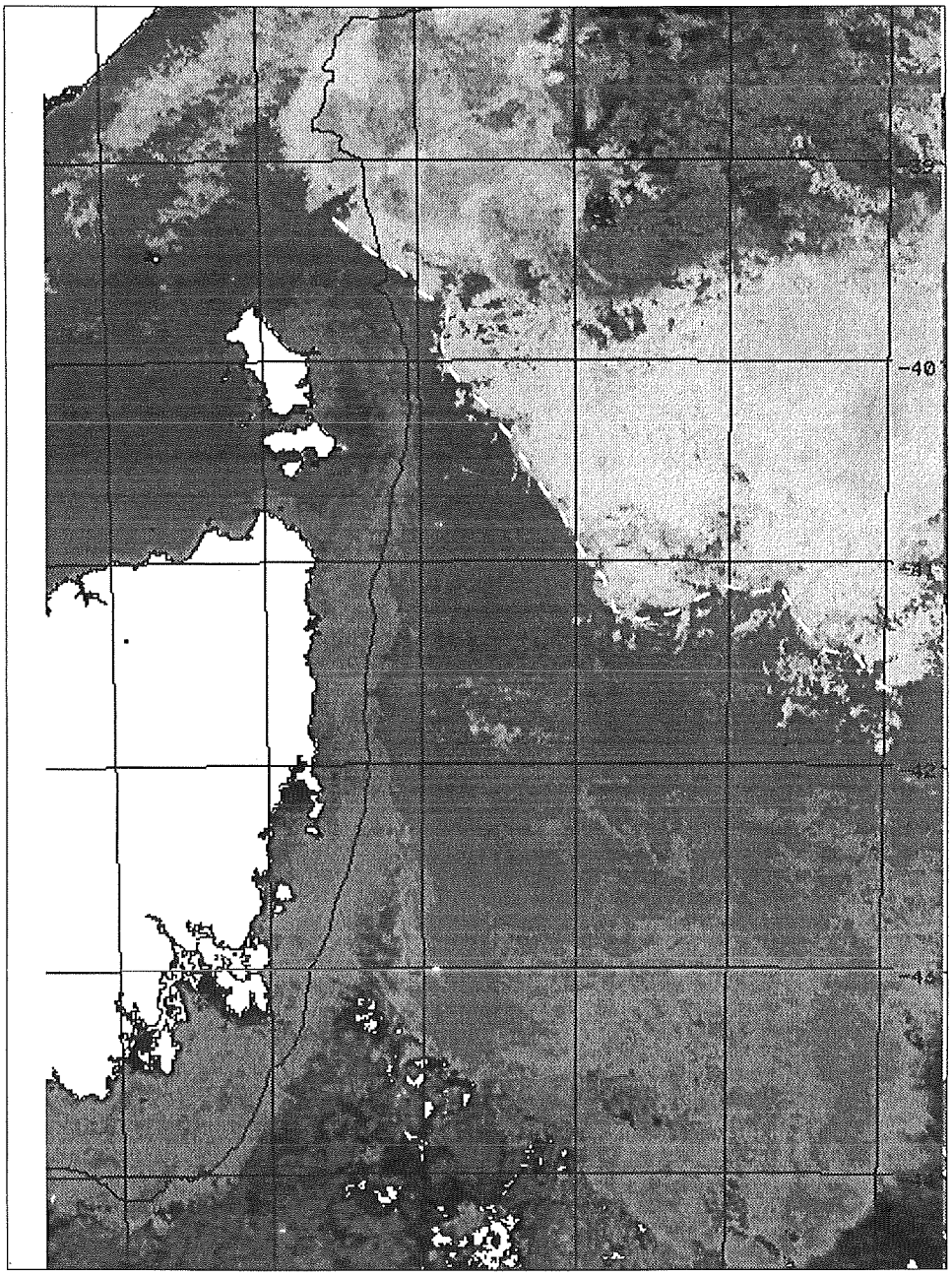


Figure 3c. 1994 satellite image of sea surface temperature at the time of sampling jackass morwong larvae off SE Australia. Frontal zone (STC) separating EAC and SAW marked as dotted line.

Bony Parts (Brittnacher and Botsford 1994). Sagittae were roughly elliptical in shape with an anterior rostrum. Increment width measurements were taken from unprepared otoliths along a transect 17 degrees ventrally to a line passing from the primordium through the tip of the rostrum. This transect was chosen on the basis of consistent increment clarity. Ages of larvae analysed ranged from 29–42 increments. Otoliths were read and processed "blind" without knowlege of the location of capture. Width comparisons were made between the same increment number rather than increments layed down on the same day (ie the width of the first increment was compared across all specimens irrespective of total age, then the second and so on). This was necessary to avoid confounding effects of ontogenetic differences in increment widths.

4.1.5 RESULTS

(a) Physical Oceanography

The physical and biological oceanography of the study region during 1992 - 1994 has been described in detail by Young *et al.* (in press). Briefly, in 1992, the EAC extended southwards in a broad wedge, bounded by the shelf break, to approximately 43^0S (Figure 3*a*). The STC, separating cooler SAW to the south, extended along a NE/SW axis and was characterised by a change in surface temperature of approximately 2°C over a distance of 20 nm. A cell of warm water, probably of EAC origin, was located between 150–152°E and 42–43°S. In 1993, the EAC was located slightly further offshore and extended further south than in 1992 (Figure 3*b*). The STC was much broader and less intense with a surface temperature gradient of 2°C over a distance of some 100 nm. In 1994, EAC water was located even further offshore and only extended to approximately 42°S during the period of sampling (Figure 3*c*). The STC was well defined with a surface temperature gradient of approximately 4°C over 50 nm.

Vertical profiles in all three years identified EAC water within the sampling region as a relatively shallow (0–150 m) tongue overlying cooler SAW (Young *et al.* in press).

(b) Distribution of larvae

A total of 2,432 jackass morwong larvae (5.9–25.4 mm) were recorded. Jackass morwong larvae were caught only in surface tows or in the EZ net where the net was open at the surface. No jackass morwong larvae were recorded from oblique tows nor subsurface strata sampled with opening closing gear.

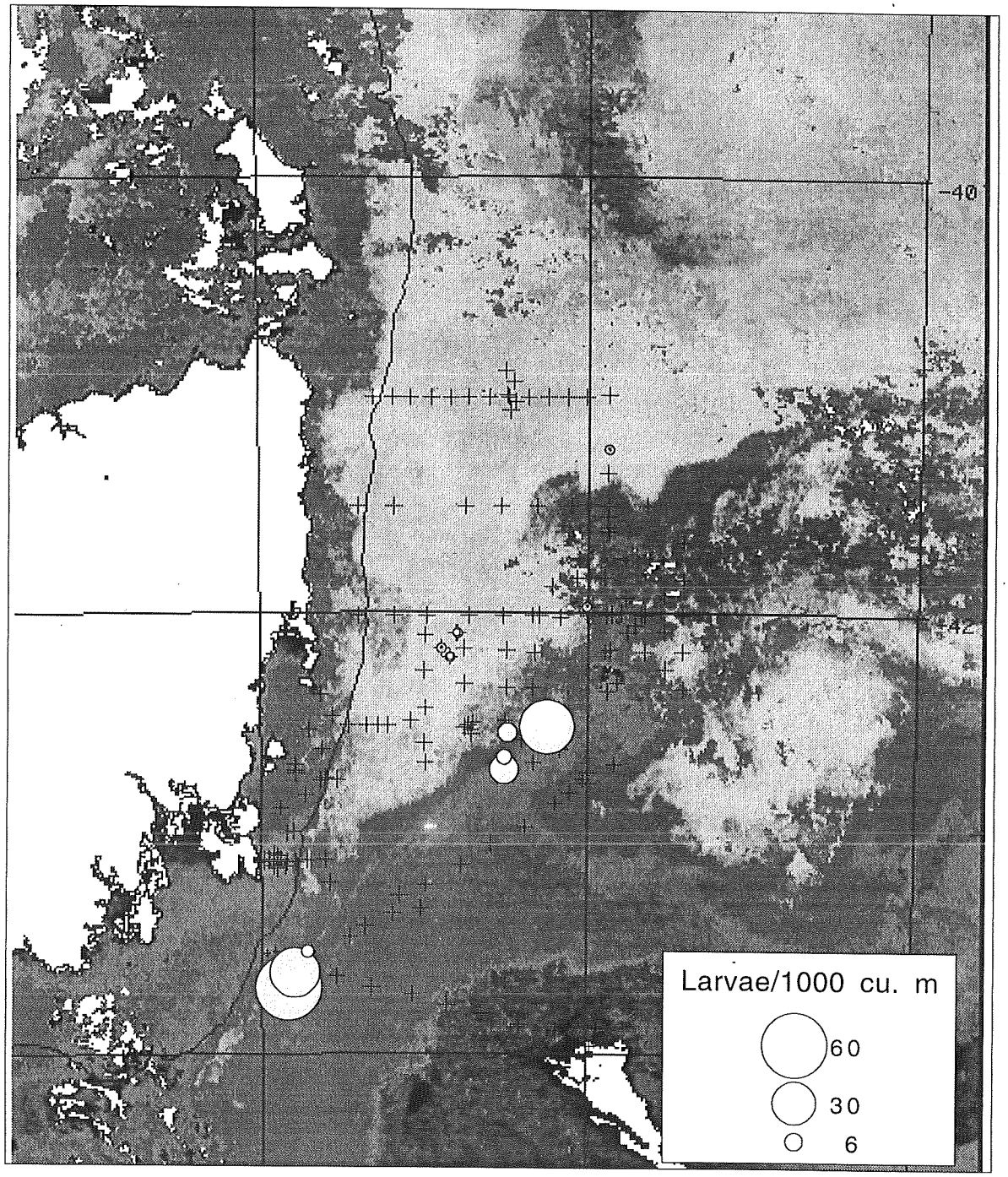


Figure 4a. Distribution of jackass morwong larvae off SE Australia in 1992.

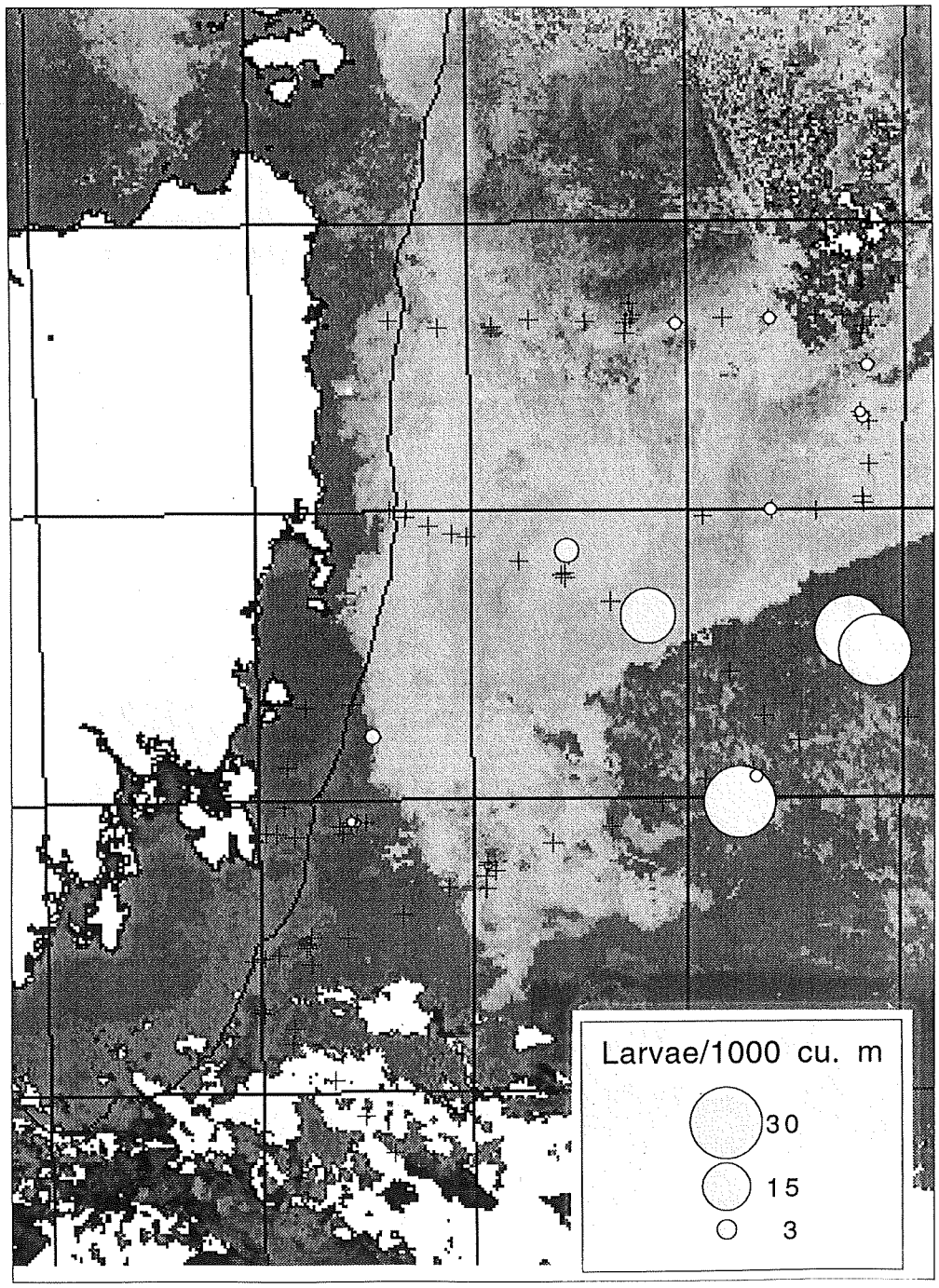


Figure 4b. Distribution of jackass morwong larvae off SE Australia in 1993.

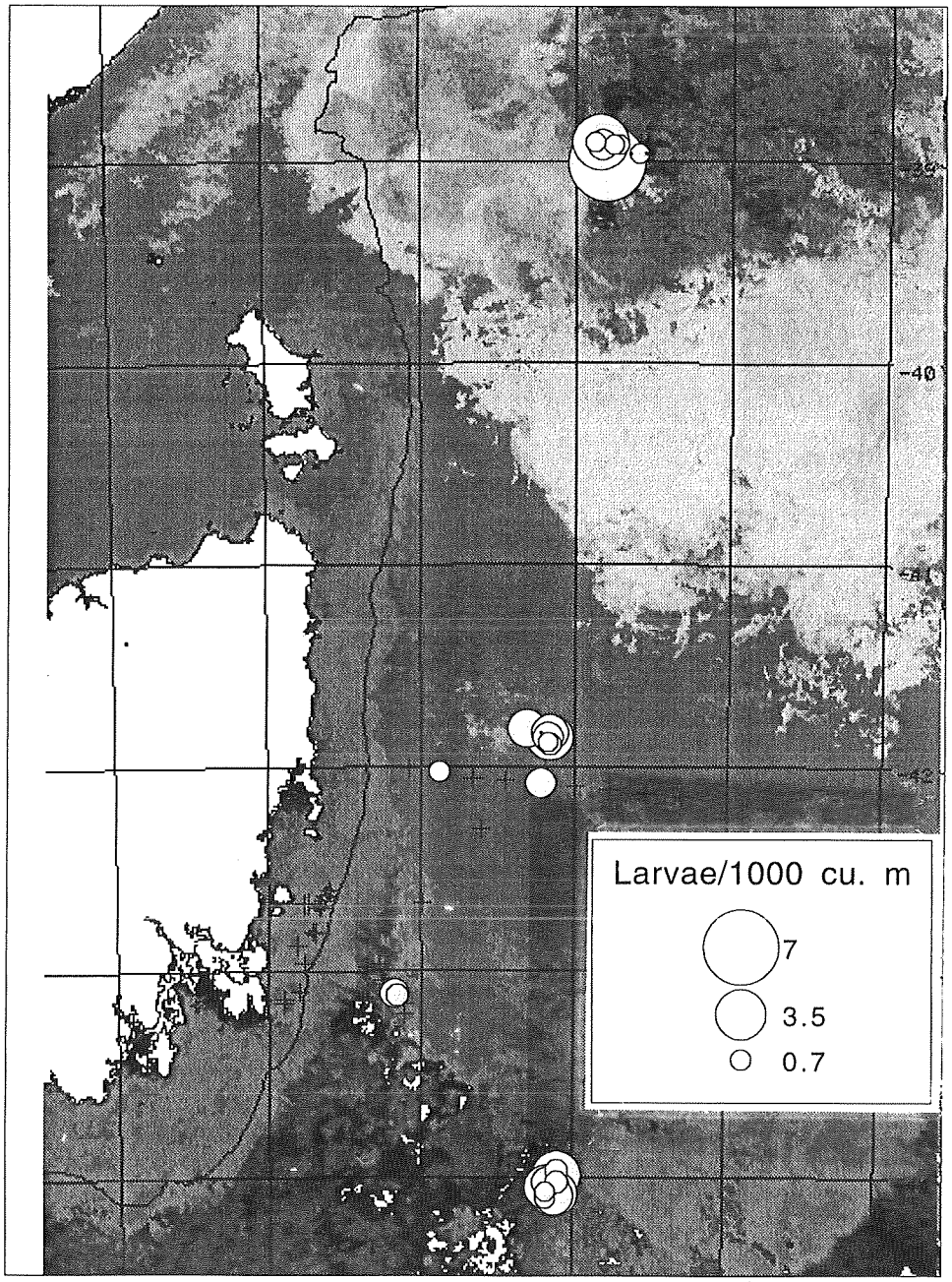


Figure 4c. Distribution of jackass morwong larvae off SE Australia in 1994.

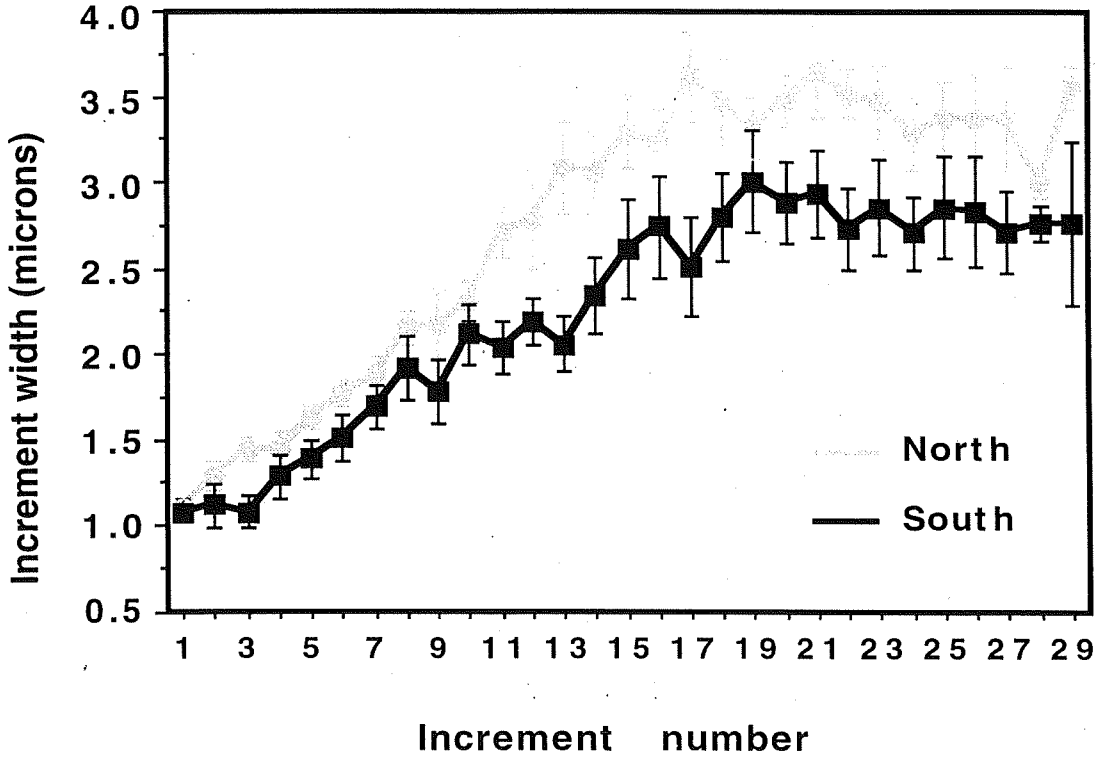


Figure 5. Otolith increment widths of 40 jackass morwong larvae collected in 1994. Bars = 1 standard deviation. North = larvae collected north of STC within EAC. South = larvae collected south of STC within SAW.

Jackass morwong larvae were widely distributed in all three years and were recorded up to 250 km offshore (the limit of sampling). Larvae were predominantly distributed in cooler waters south of the major frontal zone. Larvae were less abundant north of the frontal zone in 1992 and 1993 (Figure 4 *a+b*). Sampling was extended further north in 1994 than previous years and extended across a second frontal zone and into a warm core eddy of the EAC. Samples at these northern stations also contained significant numbers of jackass morwong larvae (Figure 4*c*).

(c) Otolith analyses

Jackass morwong larvae had a series of unambiguous bipartite increments extending from a central core to the edge in both sagitta and lapilli. The first increment was regularly located at 10.0–13.2 µm from the primordium in sagitta (mean 11.7, sd=1.08, n=10) and 10.0–14.4 µm (mean 12.7, sd=1.56, n=10) in lapilli.

Sagittal increments increased steadily in width from approximately 1 µm at increment 1 to approximately 3 µm by increment 17–18 (6–8 mm total length) in wild caught larvae. This length corresponds to the size at notochord flexion (Bruce in press). Increment width remained relatively constant thereafter (Figure 5).

Increment widths varied significantly between larvae from different water masses (Figure 5). Larvae north of the major frontal zone had significantly wider increments than for those south of the zone (t=10.336, p<0.0001). Both northern and southern caught larvae had the same pattern of increasing growth rate for the first 17-19 increments.

Spawning dates were calculated for larvae aged from 1993 and 1994 samples. The timing of spawning was consistent between years. In 1993, spawning was recorded on 49 days over a 66 d period between 17 March and 21 May (Figure 6). A peak in spawning dates occurred in mid to late April. In 1994, spawning was recorded on 34 days over a 54 d period between 16 March and 8 May (Figure 7). Insufficient specimens were available to delineate a peak in back calculated spawning dates for the 1994 set.

Back calculated spawning dates varied with location of capture. There was a tendency in both years for larvae north of the front to have been spawned later than those south (Figures 6+7). In 1993, back calculated spawning dates from larvae south of the front were recorded on 45 d over a 62d period from 17 March to 18 May, with a peak around the 19 April. North of the front, spawning dates were recorded on 16 d over a 37 d period from 14 April to 21 May, with a peak around 30 April. In 1994, back calculated spawning dates from larvae

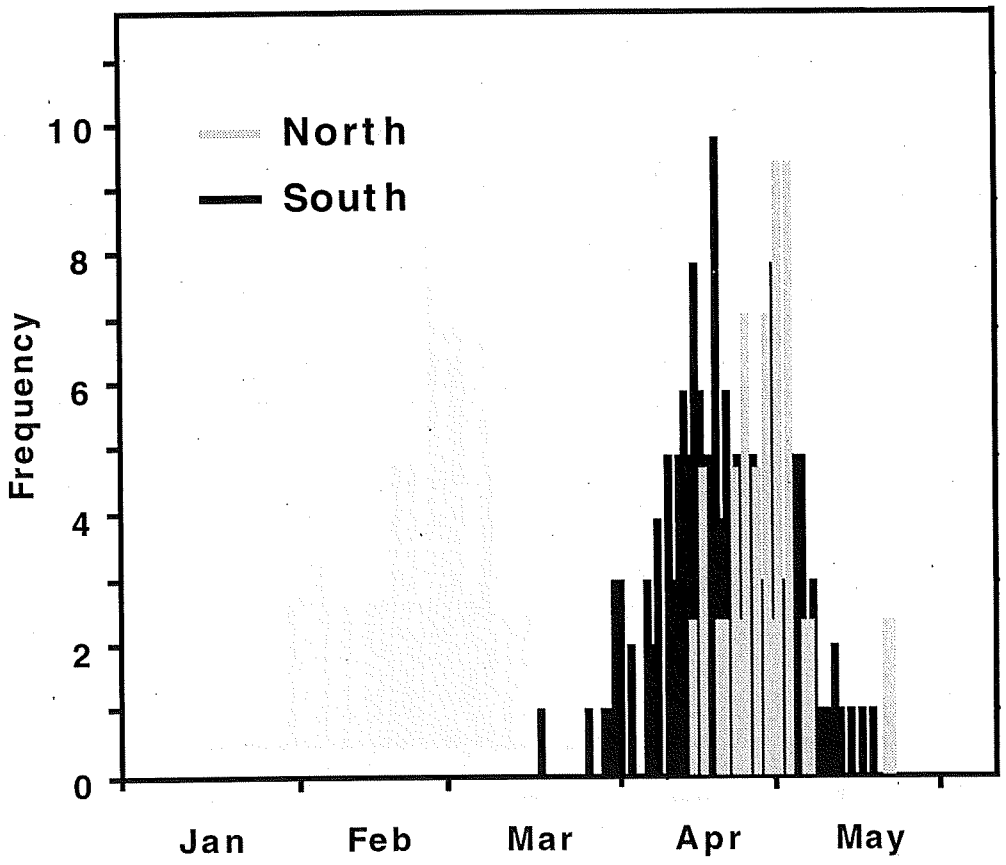


Figure 6. Back calculated spawning dates for jackass morwong larvae in 1993. North = larvae collected north of STC within EAC. South = larvae collected south of STC within SAW.

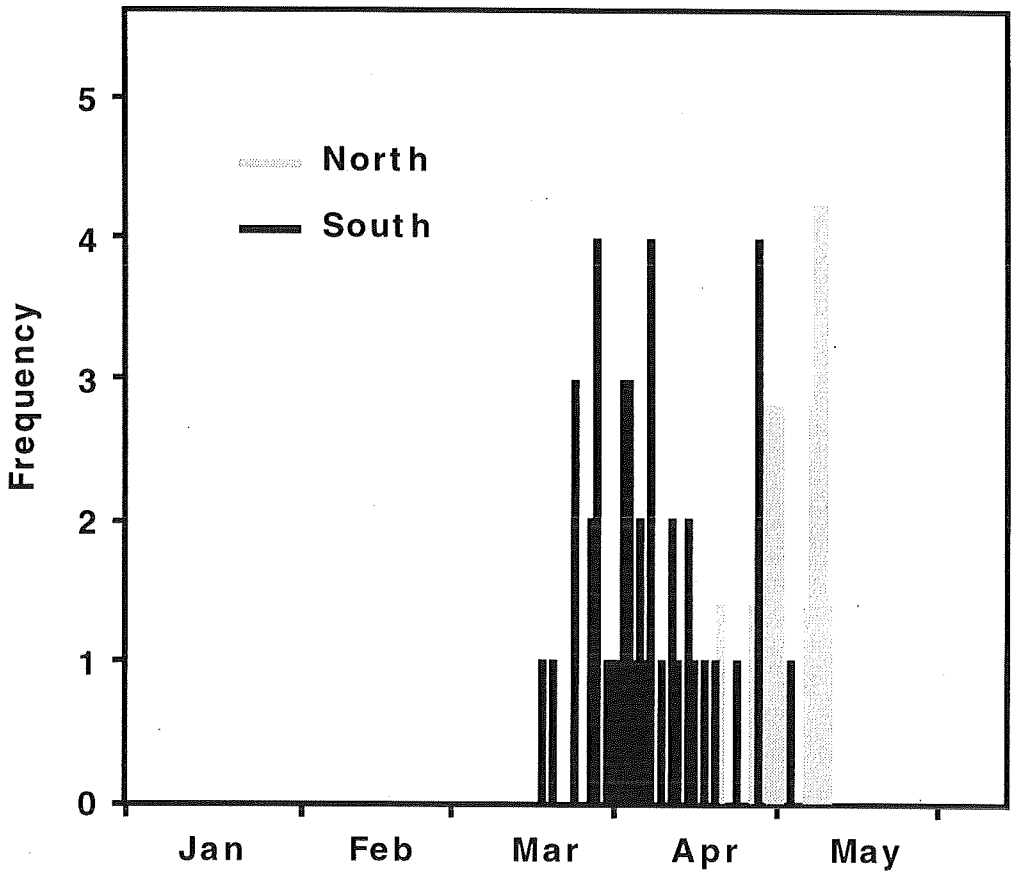


Figure 7. Back calculated spawning dates for jackass morwong larvae in 1994. North = larvae collected north of STC within EAC. South = larvae collected south of STC within SAW.

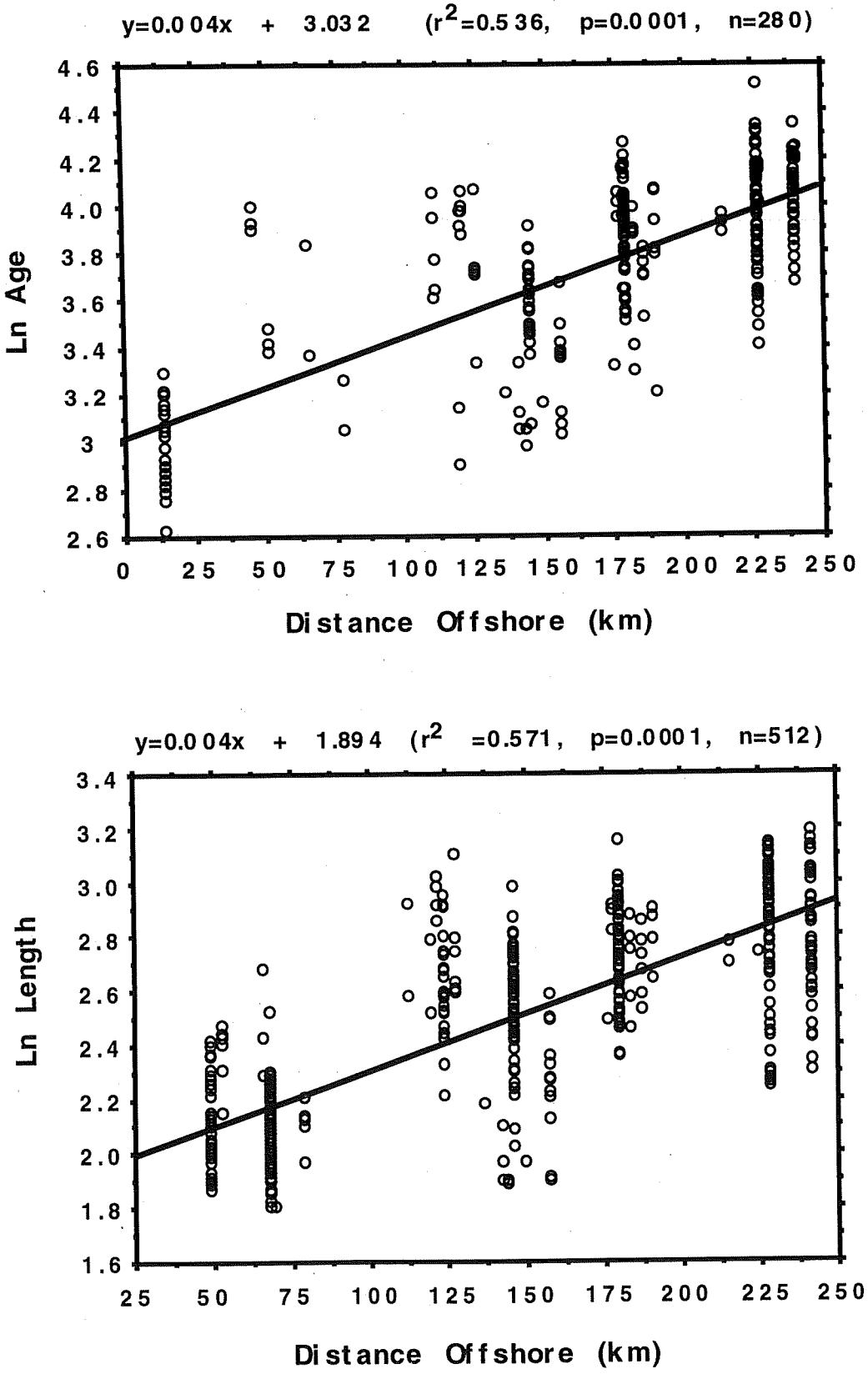


Figure 8. Relationship between age of jackass morwong larvae and distance offshore; length of jackass morwong larvae and distance offshore.

south of the front were recorded on 24 d over a 46 d period from 16 March to 1 May. North of the front, spawning dates were recorded on 11 d over a 20 d period from 18 April to 8 May.

(d) Larval advection (age vs distance offshore).

There was a significant increase in increment age and size of larvae with distance offshore (Figure 8: age r^2=0.536, p=0.0001, n=280; size r^2=0.571, p=0.0001, n=512) The strength of these correlations are surprising given the unlikelihood that offshore advection trajectories are linear. The largest/oldest specimens were collected at the limit of offshore sampling (250 km) suggesting that the distribution of jackass morwong larvae extended beyond the sampling region.

The slope of the regression provided an estimated offshore advection rate of 3.6 km per day. Considerable variability was observed with individual advection rates ranging between 2.5–7.6 km/day. These rates were consistent with the rates of offshore advection of satellite tracked surface drifters (Cresswell *et al.* 1994).

4.1.6 DISCUSSION AND CONCLUSIONS

Previous data on cheilodactylids, although sparse, suggest that an extended, neustonic, offshore larval phase is widespread within the group (Nielson, 1963; Barnard, 1927; Vooren, 1972, 1975; Tong and Saito, 1977; Bruce, 1989). These early life history characteristics, combined with presettlement stages attaining a large size (40–90 mm), and hence presumably enhanced swimming and net avoidance capabilities, have no doubt contributed to the lack of cheilodactylid material from conventional ichthyoplankton sampling in shelf and slope waters. Whilst such offshore early life history strategies have been reported for several tropical taxa (Sale, 1970; Leis, 1986, 1989, 1991), there are relatively few temperate examples. Of these, most have been associated with particular oceanographic features (e.g. separation of the Gulf Stream from the coast (Hare and Cowan, 1993) or regarded as transport events leading to the loss or expatriation of larvae (Nelson *et al.* 1977).

The consistent pattern of offshore larval distribution for jackass morwong off south east Australia and the significant relationship between both age and length with distance from shore suggests that this is a regular strategy and does not represent an anomalous transport of early life history stages. The close correspondence between the rate of offshore movement of satellite tracked surface drifters and rate of larval advection suggests that larval dispersal is linked to surface circulation patterns.

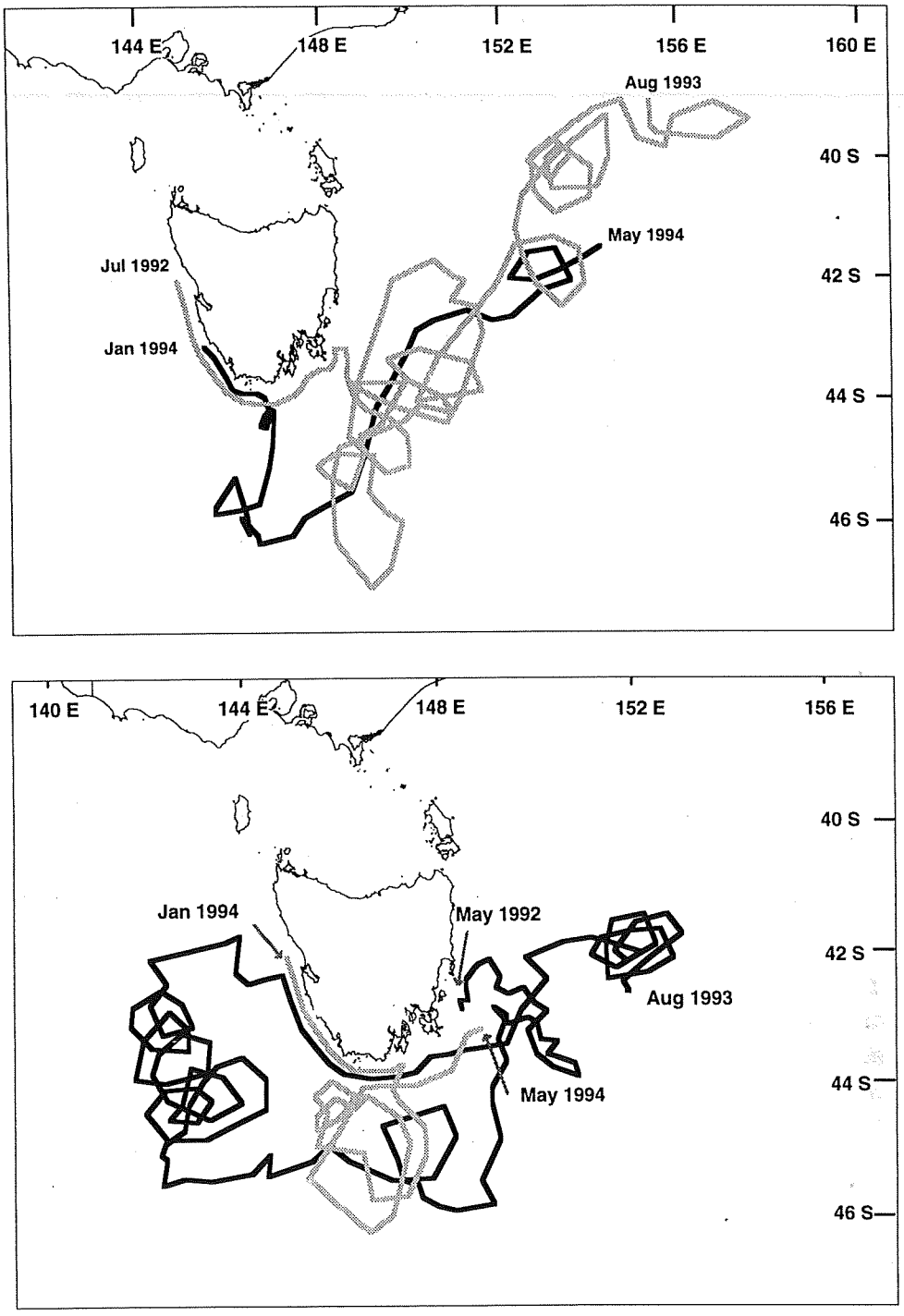


Figure 9. Trajectories of 4 satellite tracked surface drifters in the south western Tasman Sea (after Cresswell *et al.* 1994).

Spawning in jackass morwong occurs over a protracted period from February to June (Lyle and Ford, 1993; Kailola *et al.* 1993). Back calculated spawning dates, from larvae captured during 1993 and 1994, consistently indicated spawning between mid March and May. This narrower range in spawning may be due to a combination of the timing and spatial extent of sampling. Given the tight correlation between larval age and distance offshore, larvae were moving through the sampling area at an average rate of 3.6 km per day. If this advection pattern through the area of sampling is a consistent feature of the region (as suggested by satellite drifters) then sampling at a different time of the year and/or outside of the survey region should provide larvae with back calculated spawning dates further covering the range of the reported spawning period. This is supported by the capture of larvae on an earlier, separate cruise in March 1994. These specimens were 6.7–9.6 mm in length, 19–28 increments, with back calculated spawning dates between 10–24 February.

Australian nursery areas for jackass morwong have been recorded in bays and estuaries of southern Tasmania and in Bass Strait waters (Tilzey *et al.* 1990). Settlement in southern Tasmanian waters occurs between September and December at a size of 70–90 mm (D. Mills, A. Jordan DPIF Fisheries Tasmania pers comm) thus supporting Vooren's (1972) conclusion of a minimum 8 - 10 month pelagic phase for the species. Settlement stage morwong (referred to as paperfish) are presumably required to return to these nursery areas to complete development.

Surface circulation patterns may not only provide an offshore transport mechanism but may also facilitate the retention of early life history stages within the Tasmanian region. The trajectories of satellite-tracked surface drifters show a complex pattern of movement (Cresswell *et al.* 1994). The predominant trend is for drifters to, eventually, move eastwards into the South Tasman Sea towards New Zealand. However, two major patterns were observed. First, some drifters headed quickly offshore from eastern Tasmania but then spent a considerable period (up to 8 months) in a complex circulation pattern between 148°E and 155°E (Figure 9*a*). Second, some drifters headed offshore south or south east of Tasmania and either remained in that vicinity or tracked west for up to 12 months before being entrained in an eastward flowing coastal current following the Tasmanian continental shelf (Figure 9*b*). The periods over which these drifters were within offshore Tasmanian waters are roughly consistent with the pelagic duration of jackass morwong and thus offer a possible mechanism for retention of larvae within the region. The actual process whereby paperfish move back inshore is unknown. However, given their size and presumed swimming capabilities, active orientation and movement may play a role. Given an average swimming speed of 2 body lengths per second (Blaxter 1986), an 80 mm paperfish would require approximately 18 days to return from 250 km offshore. Directed swimming towards coral reefs by settlement stage larvae has been described by Leis *et al.* (in press) and Stobutzki (1995). These observations

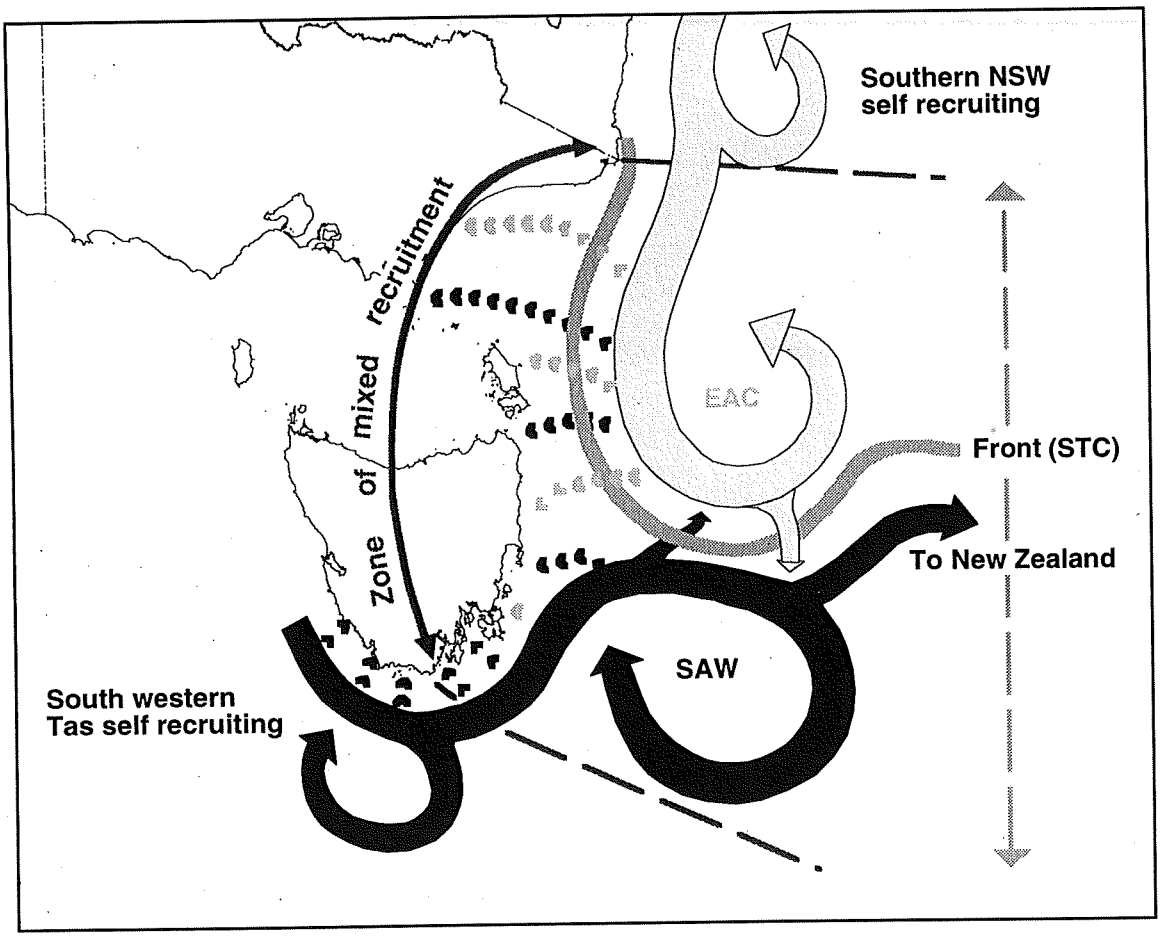


Figure 10. Summary of larval advection processes for jackass morwong larvae in the south western Tasman Sea.

have, however, generally been made within a few kilometres from reefs. At this range, acoustic or chemical cues may assist larvae orienting towards the reef (Leis *et al.* in press). It is unclear what cues a paperfish tens to hundreds of kilometres from the coast may use to locate inshore nursery areas.

Implications for stock structure

Available data provide a conflicting view of the structure and number of jackass morwong stocks in southern Australia. Results from genetic studies suggest that there is a single stock in Australian waters that is distinct from a New Zealand (west coast South Island) population (Elliott & Ward, 1994; Richardson, 1982). Otolith microchemistry analyses provide a more complex picture. Thresher *et al.* (1994) suggested that there are possibly four stocks within southern Australia, two of which occur in south eastern Australia. These latter two comprised a south western Tasmanian stock and a NSW/Vic stock. Some degree of mixing between stocks was evident between the south east Tasmanian coast and Bass Strait. Furthermore, their otolith analyses could not separate individuals caught off southern Tasmania and from those caught off New Zealand (west coast South Island). The extended offshore pelagic phase of jackass morwong offers ample opportunity for widespread dispersal (and presumably mixing between populations of at least some larvae) thus it is not surprising that genetic analyses suggest little sub-structuring across southern Australia. Otolith microchemistry techniques are less sensitive to mixing rates and hence are able to provide a finer level of stock resolution (Thresher *et al.* 1994).

The maintenance of separate stocks of jackass morwong in southern Australia requires that offspring recruit back to their source stock and that mixing between stocks is restricted. Given the protracted larval stage of jackass morwong and the strong correlation between surface water movement and larval advection, we hypothesised that surface circulation may provide the underlying mechanism determining recruitment patterns.

The surface waters of the south western Tasman Sea are dominated by two water masses, the EAC and SAW (Harris *et al.* 1987). The location of these water masses varies seasonally and between years. The EAC reaches its maximum southerly extension (just south of SE Cape, see Figure 1) between February and April. The EAC then retreats progressively northwards and, by August, is between eastern Bass Strait and Gabo Island. The retreating EAC is subsequently replaced by SAW off eastern Tasmania (Figure 10). Offshore waters of south west Tasmania continuously remain under the influence of SAW and similarly offshore waters north of Gabo Is remain under the influence of the EAC. Jackass morwong larvae were present in both EAC and SAW water. Larvae collected in the EAC had consistently wider increments than SAW larvae over their entire life history. This suggests larvae were in separate water masses

for their entire early life history. Back calculated spawning dates were also consistently later in larvae from EAC water thus further supporting a distinction between the two groups.

EAC water travels predominantly southwards in a series of complex eddies and loop currents (Cresswell and Legeckis, 1986). Thus jackass morwong larvae originating from NSW and Victoria would be expected, once offshore, to be advected southwards. Given this, it is reasonable to expect that the southerly extent of advection of larvae originating from NSW/Vic would be eastern Tasmania. Similarly, jackass morwong larvae spawned in Tasmanian waters, might be advected as far north as eastern Bass Strait. The seasonal cycling of the water masses, combined with some mixing along the frontal zone, provides a possible mechanism to explain the mixed recruitment signal detected from otolith microchemistry between SE Tasmania and eastern Victoria (Figure 10). Regions outside this mixed recruitment area, specifically south-western Tasmania and NSW, would be less likely to receive larvae from either further north or south respectively. In addition, paths of satellite-tracked surface drifters (Cresswell *et al.* 1994) suggest that circulation cells exist that are conducive to retention of larvae off south western Tasmania and NSW and thus self recruitment is likely to both these regions.

The trans-Tasman movement of satellite tracked drifters south of the frontal zone suggests a physical transport link between southern Tasmania and New Zealand's South Island. A link between southern Tasmanian and NZ populations of jackass morwong was also suggested by otolith microchemistry data, although it was not resolved whether this was due to mixing of larvae or the similarity of environmental signals between the two regions (Thresher *et al.* 1994). The time frame for drifter movement between southern Tasmania and New Zealand (approximately 15–24 months, Cresswell *et al.* 1994) exceeds the estimated larval duration of jackass morwong. However, given that drifters are drogued at 15 m and larvae are at the surface, it is possible that larvae are subjected to much higher transport rates. In addition the maximum possible larval duration of jackass morwong is yet to be established and may well facilitate the cross-Tasman dispersal of some individuals.

In summary, the distribution and dispersal of jackass morwong larvae in SE Australian waters is linked to mesoscale oceanographic circulation patterns within the region (Figure 10). Patterns of surface circulation as well as the seasonal variability in the movement of major water masses off the SE Australian coast suggest that jackass morwong stocks in south western Tasmania as well as southern NSW are self-recruiting, and that a region of mixed recruitment of northern and southern stocks should exist covering eastern Tasmania and eastern Victoria. These circulation patterns thus provide mechanisms that may account for the multiple stock scenario suggested by otolith microchemistry analyses (FIRTA Report 1991/32). Furthermore, the degree of population mixing suggested by these patterns, particularly off eastern Tasmania, undoubtedly

accounts for the lack of distinct genetic differences throughout the SE Australian region. Whether stocks remain sufficiently distinct to be managed separately remains unresolved. However, the correspondence between recruitment patterns predicted from larval advection and those from otolith microchemistry suggest that the latter technique may be useful in quantifying the extent of mixing between stocks in SE Australia.

4.2 BLUE GRENADIER

4.2.1 INTRODUCTION

The blue grenadier, *Macruronus novaezelandiae* supports major trawl fisheries in both Australia and New Zealand. In Australian waters, blue grenadier are considered to be represented by a single stock (Kailola *et al.* 1993). This conclusion is based on there being a single major spawning ground for the species off western Tasmania (Gunn *et al.* 1989) to which adults from across southern Australia are believed to migrate, advection patterns of larvae from west coast spawning grounds to east coasts nursery areas (Thresher *at al.* 1989; Lyne and Thresher, 1995) and a general pattern of genetic homogeneity (Milton and Shacklee, 1987). However, some data regarding stock structure of blue grenadier in southern Australia are more ambiguous. Milton and Shacklee (1987) also noted that although there was no overall pattern to suggest geographically distinct populations, a high degree of microspatial heterogeneity existed. They suggest that this may be due to the existence of two or more stocks of blue grenadier overlapping in time and space. A preliminary examination of long-lived endo parasites by Lester (reported in Milton and Shacklee, 1987) also did not support extensive movement of blue grenadier between east and west coasts of Tasmania. More detailed analyses have not been presented and it is difficult at this stage to further interpret these data.

Although only a single spawning ground has been located in southern Australia, multiple spawning areas are consistent with the species' biology in New Zealand where significant concentrations of spawning blue grenadier have recently been located in Cook Strait and on the east coast, away from the major spawning ground on the west coast of the South Island (Murdoch and Chapman, 1989; Livingston, 1990). Their discovery has had major implications for industry and has lead to the establishment of separate management zones between east and west coasts (Livingston, 1990; Annala, 1995). A second spawning ground for blue grenadier in Australian waters was suggested by Thresher *et al.* (1988) based on their collection of small numbers of larvae from north-east Tasmania. Subsequent intensive sampling, however, failed to locate any further concentrations of blue grenadier larvae either in that area or outside of Tasmanian waters, leading to the conclusion that if spawning did occur off north-east Tasmania, it was both minor and intermittent (Gunn *et al.* 1989).

There are also persistent (but unconfirmed) reports of ripe blue grenadier in areas other than west coast waters and juveniles (<20 cm) are commonly reported from south east mainland Australia (J. Garvey pers. comm.). These data suggest that spawning may also occur in other areas of southern Australia.

We report herein, the first discovery of blue grenadier larvae from southern New South Wales and north-east Victoria. Our data further supports the location of a second spawning area for blue grenadier in eastern Bass Strait/north eastern Tasmanian waters.

4.2.2 LARVAL IDENTIFICATION

Larvae were identified using the criteria of Bruce (1988, in press).

4.2.2 METHODS

(a) Samples examined

Larvae were sorted from ichthyoplankton samples collected on 5 transects spaced roughly equidistantly between Bermagui (NSW) and Pt Hicks (Vic) and a series of stations along the west and south coasts of Tasmania (SS05/93 - Figure 1). Each transect consisted of 4 stations (nearshore 40–50 m bottom depth), midshelf (100–120 m), shelf edge (180–200 m) and offshore (10 nm seaward of the shelf edge). Sampling in Tasmanian waters targeted midshelf locations where previous sampling had recorded large numbers of both blue grenadier larvae and those of other commercial species (Thresher *et al.* 1989, FIRTA Report 1984/63). Samples were collected from *Southern Surveyor* between 16–25 August 1993. Stations were occupied on arrival, regardless of the time of day. At each station, temperature and salinity profiles were recorded using a Neil Brown CTD. Satellite images of sea surface temperature were obtained for the region during the period of sampling to determine the location of major oceanographic features.

Surface and double oblique tows were taken at each station using bongo nets (70 cm dia., 500 µm mesh). Double oblique tows were taken to a maximum depth of 200 m or to within 10 m of the bottom. Depth and tow profiles were monitored in real time using either a submersible data logger attached to the frame of the bongo net (see Davis *et al.* 1990 for details) or a SCANMAR depth sensing unit. Surface nets were towed for 15 minutes beside the vessel. Volume filtered was calculated for each net using calibrated General Oceanics flowmeters. Numbers of larvae are standardised to 1000 m^3 volume filtered. For each tow, a sample from one side of the bongo was fixed in 10% formalin (for identification) and the other in 95% ethanol (for ageing).

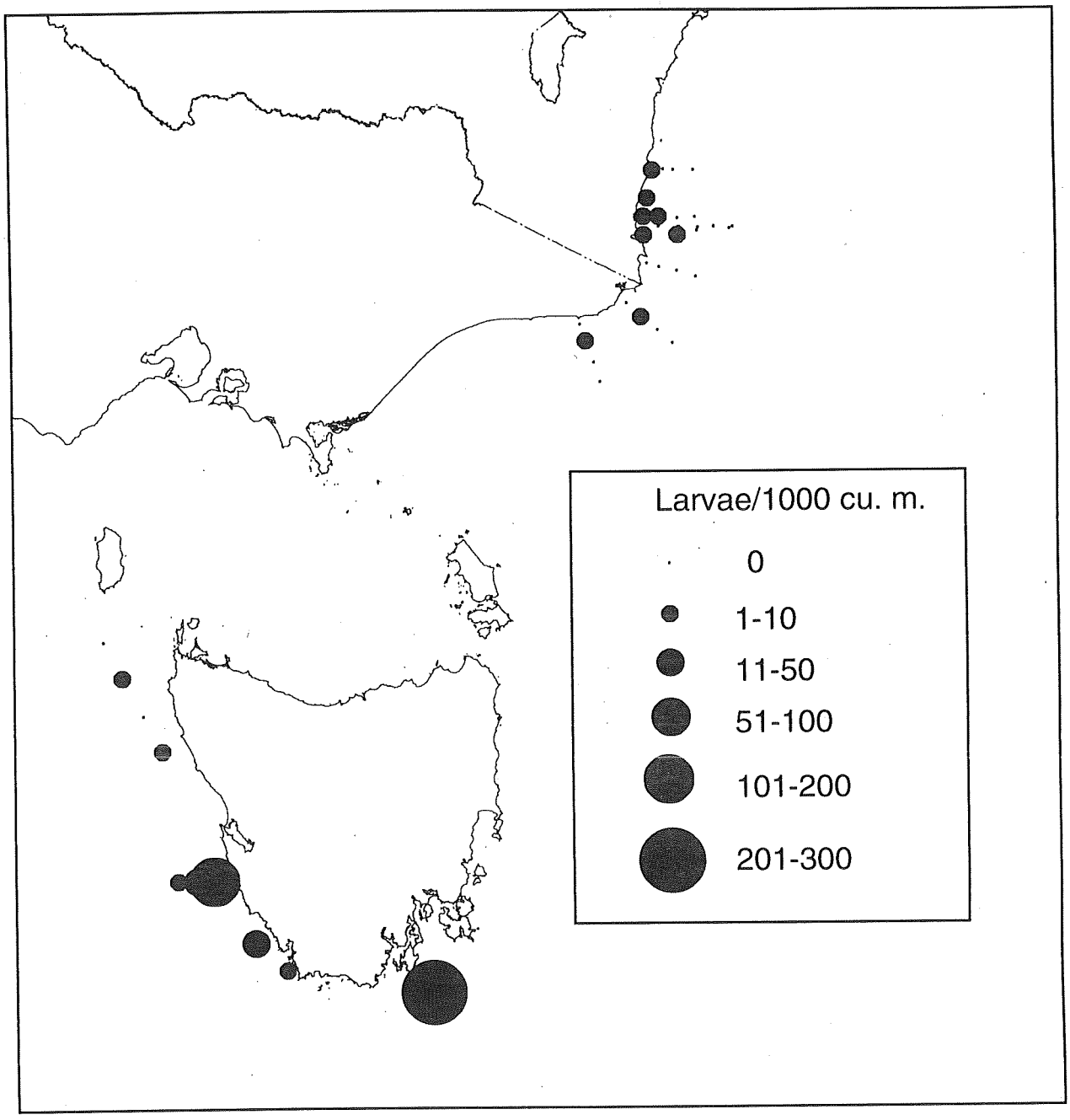


Figure 11. Distribution of blue grenadier larvae off south eastern Australia, August 1993.

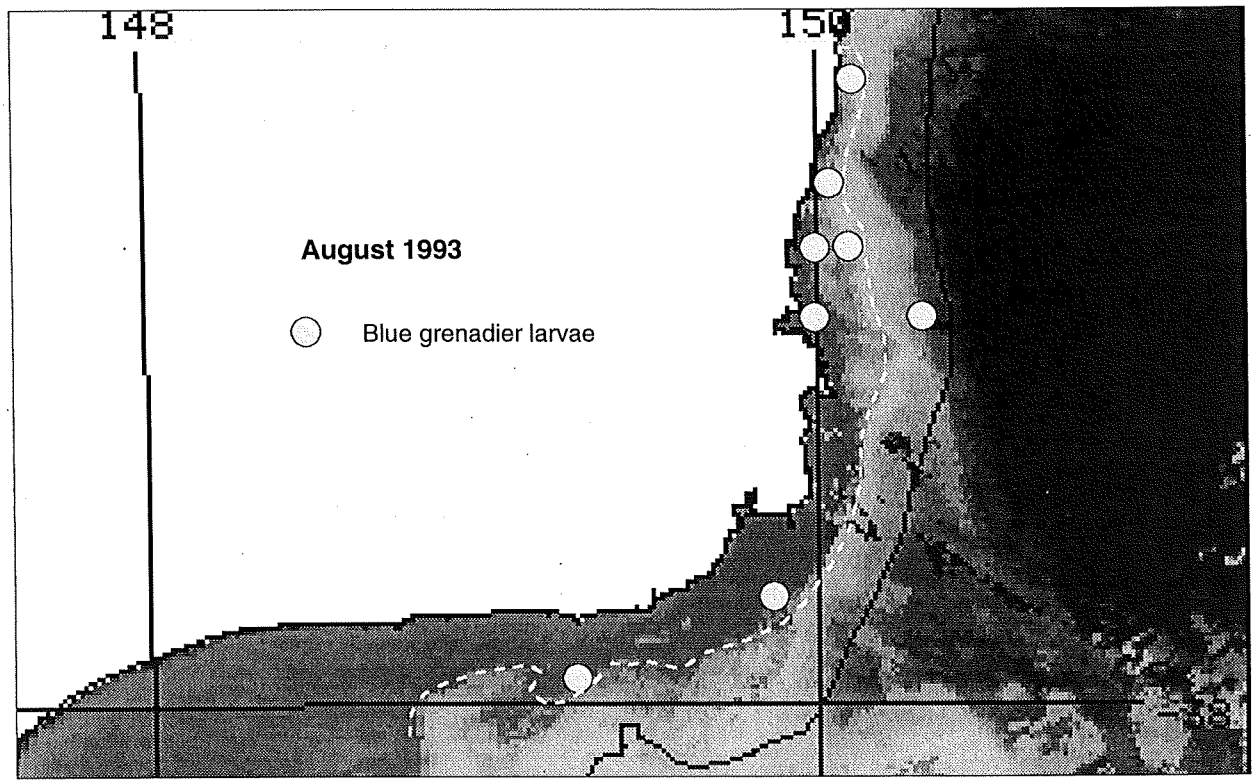


Figure 12. Satellite image of sea surface temperature, August 1993. White dotted line denotes approximate position of frontal boundary between cool inshore northward flowing water mass and warm EAC derived water.

(b) Otolith analyses

The total age (i.e. increment age + 6) of all blue grenadier larvae fixed in ethanol were determined from otolith microstructure following the procedures of Thresher *et al.* (1989). Growth rates were calculated using body length (Leis and Trnski, 1989) and are uncorrected for shrinkage. Statistical analyses were done using Statview FPU 4.02.

Increment widths were measured on lapilli of 20 specimens via an Apple MacIntosh computer linked to the ITC video system and using the program Bony Parts (Brittnacher and Botsford, 1994). Measurement protocols followed those of Thresher *et al.* (1989). Increment widths were compared between larvae collected from different areas (NSW/Vic and Tasmania). Ten larvae of approximately the same age were selected from each area for analysis. Ages of larvae analysed ranged from 23–31 d (17–25 increments). Otoliths were read and processed "blind" without knowlege of the location of capture. Width comparisons were made between the same increment number rather than increments formed on the same day (i.e. the width of the first increment was compared across all specimens irrespective of total age, then the second and so on). This was necessary to avoid confounding effects of ontogenetic differences in increment widths (Bruce *et al.* submitted).

4.2.3 RESULTS

(a) Larval distribution

Blue grenadier larvae were most commonly collected off the west and south coast of Tasmania between Pt Hibbs and Cape Bruny (Figure 11) in regions where sampling at similar times of the year had previously recorded large numbers (Gunn *et al.* 1989).

Small numbers of larvae were also recorded off southern NSW and eastern Victoria. Larvae recorded within this area were located at either inshore or midshelf stations, the single exception being a larva collected at the shelf edge off Eden. Larvae were largely confined to a cool water region bounded by a marked frontal feature located on the shelf (Figure 12). The structure of plumes associated with this frontal feature (identified from AVHRR sea surface temperature images) suggested that this cooler water was part of an inshore northerly flow extending from eastern Bass Strait to just north of the Bermagui transect (P. Craig CSIRO Division of Oceanography, Hobart pers. comm.). Seaward of the frontal zone was a southerly flowing warm water mass of EAC origin extending as far southwards as central Tasmania.

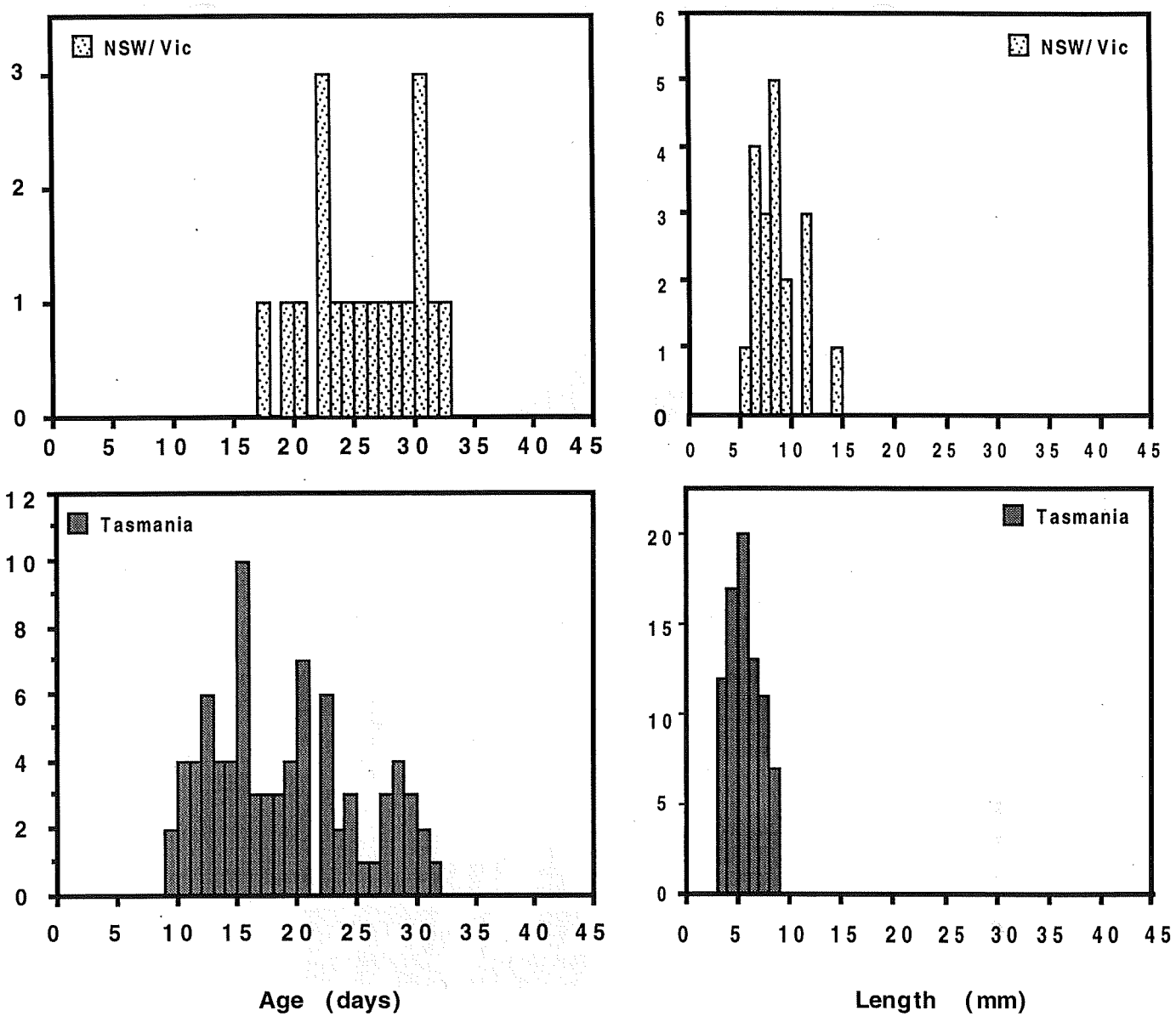


Figure 13. Age and size distribution of blue grenadier larvae by area.

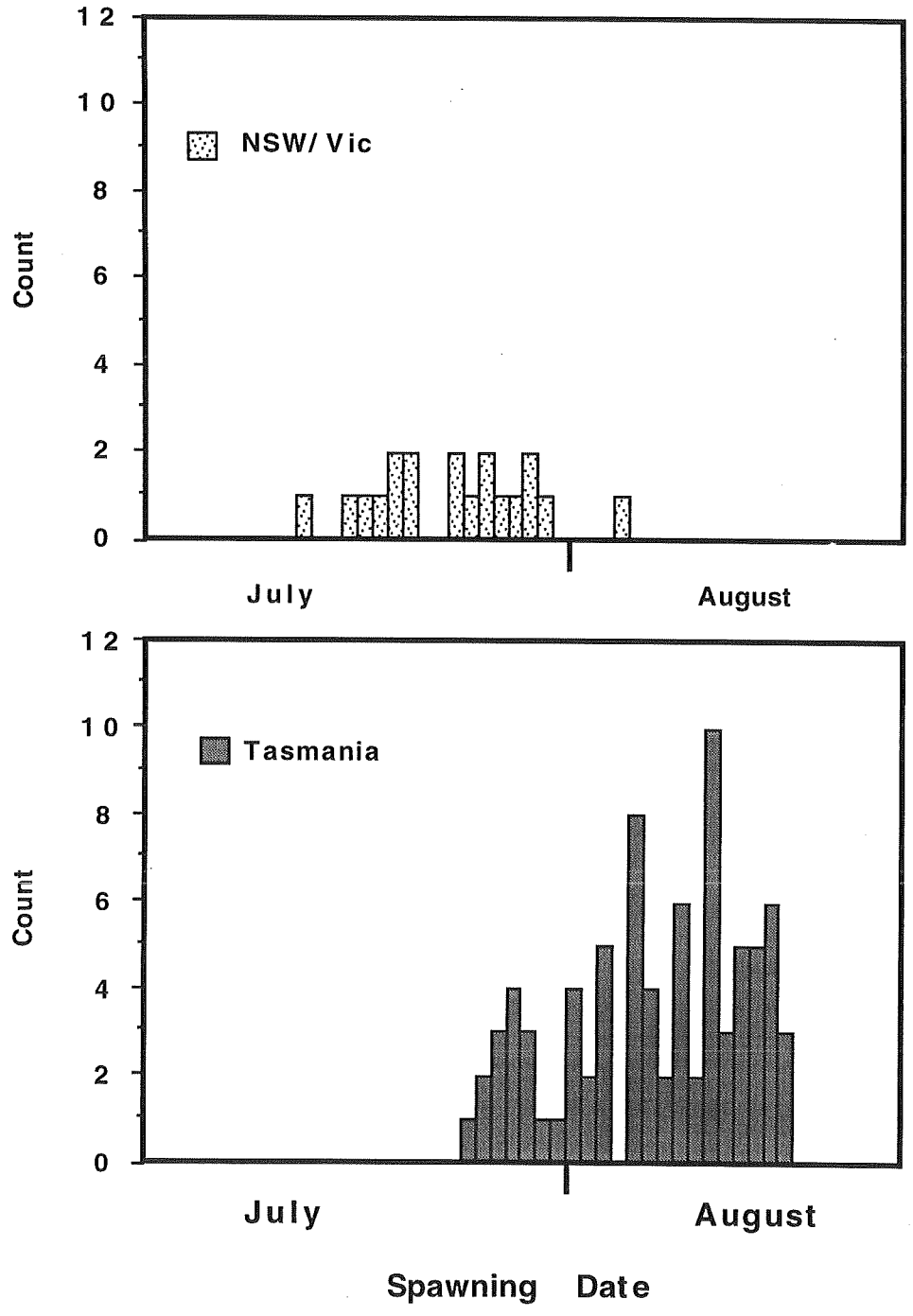


Figure 14. Back calculated spawning dates for blue grenadier larvae in 1993.

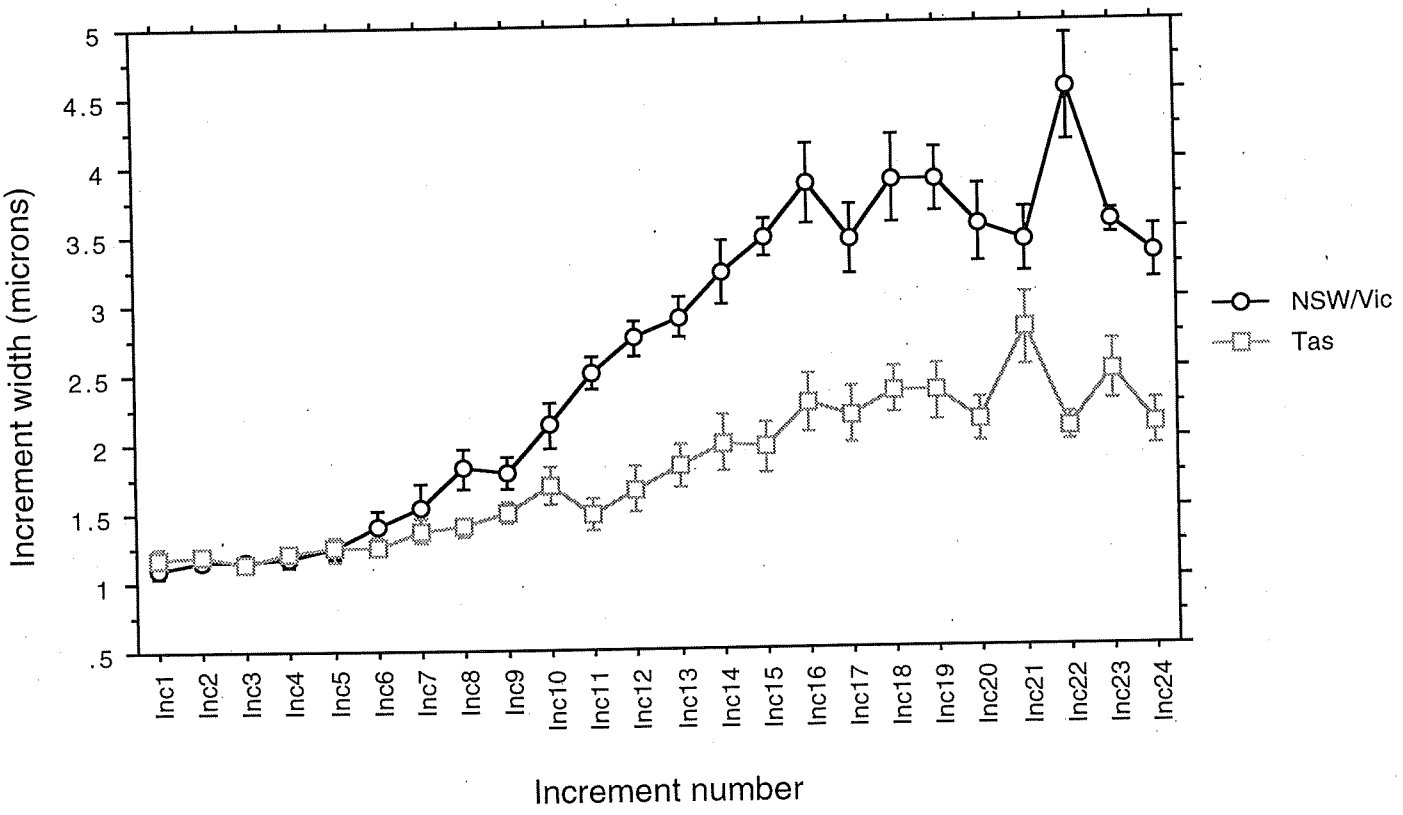


Figure 15. Otolith increment widths of blue grenadier larvae by area. Bars = 1 standard deviation.

(b) Otolith analyses

Otolith microstructure was similar to that described for blue grenadier larvae by Thresher *et al.* (1989). Blue grenadier larvae collected from western and southern Tasmanian coast ranged from 3.1–8.6 mm and 9–31 days (total age). Larvae from NSW/Vic were, on average, both larger and older than those from Tasmanian waters (5.3–14.5 mm and 17–36 days respectively – Figure 13). Age and size structure of larvae on the west and south coast of Tasmania were consistent with advection of larvae southwards around Tasmania as described by Thresher *et al.* (1989) and Lyne and Thresher (1995). A pattern of age distribution in larvae from NSW/Vic was less clear, although there was a tendency for larvae to increase in age northwards along the coast.

Back calculated spawning dates varied between regions with a tendency for NSW/Vic larvae to have been spawned earlier than those from Tasmania. For Tasmanian larvae, calculated spawning dates occurred essentially continuously (21 d over a 22 d period) from 24 June to 15 July with no defined peak in spawning activity. Back calculated spawning dates from NSW/Vic larvae were recorded on 14 d over a 22 d period between 13 June and 4 July (Figure 14).

Widths of the first 7–9 increment were similar in larvae from both areas, but rapidly diverged thereafter. Subsequent increment widths were significantly larger in larvae from NSW/Vic (t=8.749, $p<0.0001$) (Figure 15). Larvae from both areas had the same pattern of increasing increment widths up until approximately increment 16, with widths then oscillated around means of approximately 3.6 μm (NSW/Vic) and 2.8 (Tas) μm respectively.

4.2.4 DISCUSSION AND CONCLUSIONS

Our discovery of blue grenadier larvae in NSW/NE Vic waters again suggests the species may have more than one spawning ground in southern Australia. Interestingly, a previous survey of the same NSW/NE Vic area failed to locate any blue grenadier larvae (Thresher *et al.* 1988). However, that survey restricted its sampling to the shelf edge which, based on our observations, would fail to sample the cooler inshore water where we found larvae. Examination of satellite records (1988–1994) indicate that this cooler inshore water mass is a consistent feature of the inner shelf region during the June–August period.

Comparison of back calculated spawning dates for larvae from both Tasmania and NSW/Vic indicate a trend towards earlier spawning for larvae from the latter. However, both spawning date ranges fall well within the spawning period previously documented for western Tasmanian grounds (Gunn *et al.* 1989). Thus, if NSW/Vic larvae originated from a second spawning ground it is likely that spawning is roughly simultaneous with western Tasmania.

Simultaneous spawning between different spawning grounds is also a feature of New Zealand blue grenadier populations (Livingston, 1990).

In contrast to New Zealand where the blue grenadier fishery primarily operates on spawning aggregations, the southern Australian fishery comprises both a winter spawning aggregation fishery off western Tasmania and a non-winter market fishery in eastern regions. Although catch rates are highest in the former, the market fishery takes a greater proportion of the total catch (Kailola *et al.* 1993). The location of spawning aggregations outside the western Tasmania region may have two important consequences for the fishery. First, fishers may benefit (through higher catch rates) by targeting additional, and currently unfished, spawning aggregations. Second, simultaneous but geographically separate spawning grounds may indicate a more complex stock structure than previously interpreted (cf Gulland, 1983) and thus may impact regional management, as is currently the case in New Zealand where the east coast is fishery is managed separately to that of the west coast (Annala, 1995).

There are three likely scenarios regarding the source of the NSW/Vic blue grenadier larvae. First, larvae may have originated from the area where they were caught. Second, larvae may have originated from western Tasmanian spawning grounds and advected from there to the sampling area. Third, larvae may have originated from a second, as yet unidentified, spawning area separate to either of the above.

The lack of either eggs or newly hatched specimens, the location of larvae within an inshore, northward flowing water mass and the pattern of roughly increasing age with distance north along the coast suggest that the NSW/Vic blue grenadier larvae were not from a local spawning but from a more southerly source. Only a single larva was captured outside the cool inshore water. This specimen, captured near the shelf break off Eden, was the largest and oldest (14.5 mm, 36 d) collected and most likely had become entrained in southward flowing EAC water after originally being part of the northward flow.

The similarity of increment widths between larvae from Tasmania and NSW/NE Vic for the first 6–10 days post first feeding suggests that (a) they originated from the same locality and subsequently moved into separate water masses; (b) larvae were spawned in different areas but experienced similar initial growth conditions or (c) increment widths are initially ontogenetically determined and poorly reflect growth characteristics for the first 6–10 days post-first feeding. Our data cannot distinguish between these possibilities.

The normal advection pathway for blue grenadier larvae from western Tas spawning grounds is southwards around Tasmania to east coast nursery areas (Thresher *et al.* 1989). The rate of advection (11–21 cm/sec) is consistent with both empirical and modelled longshore currents (Lyne and Thresher, 1995) and implies a largely passive transport mechanism. Indeed our observations, based

on ages of larvae collected during sampling of the west and south coasts of Tasmania, support such southerly transport. The advection rate required for larvae to follow a southerly route around Tasmania and then north to the NSW/Vic area (a distance of 1050–1250 km) is 48–71 cm/sec, clearly well in excess of that previously recorded.

The shortest passage from western Tas to SE Aust is via Bass Strait. Given the age of blue grenadier larvae collected and the distance from west coast spawning grounds (650–850 km), a mean advection rate of 33–37 cm/sec would be required to transport larvae to SE Australia. Thresher *et al.* (1989) did note that a small number of drift cards released over west coast spawning grounds tracked north and were returned from King Island, western Victoria and Western Port Bay. One card was also returned from SE mainland Australia although this was after several months and it was unclear whether it had followed a path around southern Tas or through Bass Strait. Circulation within Bass Strait is strongly influenced by local wind forcing and is coupled to that of the continental shelves on both western and eastern sides (Middleton and Black, 1994). Modelled circulation patterns (Middleton and Black, 1994) predict a narrow northward flowing current along the continental shelf from eastern Bass Strait through our sampling area that is consistent with both satellite images and CTD data. Wind speed and direction for 30 d prior to our sampling period consistently ranged between 10–20 Kt from west-north-west. Given these parameters, predicted current speeds through Bass Strait and adjacent shelf waters would be in the order of 10–25 cm/sec depending on depth (Middleton and Black, 1994; P. Craig CSIRO Division of Oceanography pers. comm.). This speed is well below that needed to advect blue grenadier larvae from western Tasmania to NSW/NE Vic in the time required.

Unconfirmed observations by commercial fishers of ripe blue grenadier off both Portland and eastern Bass Strait provide other possible sources for east coast larvae. Using similar calculations, advection rates of 36–43 cm/sec would be required to transport larvae from Portland to our sampling area, again well exceeding the rate predicted from wind data.

Advection rates required to transport larvae from NE Tasmania (19–20 cm/sec) are, however, on par with that from the wind data. Given this match and the continuity of water mass properties between our sampling area and NE Tasmania, we suspect that our NSW/NE Vic larvae originate from either spawning in this vicinity or eastern Bass Strait. Our data thus further supports previous conclusions by Gunn *et al.* (1989) regarding spawning in the area. Neither the annual regularity nor the exact location of this spawning event can yet be determined. Juvenile blue grenadier (<30 cm) have been recorded, in some years, from outer shelf and slope waters of southern NSW and eastern Victoria (J. Garvey per. comm.) suggesting either irregular spawning or irregular recruitment to the area.

In summary, our data on the distribution of blue grenadier larvae further supports the presence of a second spawning area for the species in south eastern Australia. Based on the age of larvae as well as both empirical and modelled circulation patterns, this spawning area is most likely located off north east Tasmania or eastern Bass Strait as originally hypothesised by Thresher *et al.* (1988). Neither the exact location, annual regularity nor the magnitude of this spawning event can yet be determined and these questions provide potential areas for future research.

4.3 SPOTTED AND BLUE WAREHOU

4.3.1 INTRODUCTION

Spotted and blue warehous (*Seriolella punctata* and *S. brama*) are commercially important trawl fish found throughout NSW, Victoria, Tasmania and South Australia. Significant catches of blue warehou are also taken by gill net fishers in the southern shark fishery (Smith, 1994). Both species are commercially fished throughout New Zealand waters (Ayling and Cox, 1982). There have been no studies on stock structure for either species in southern Australia and both are assumed to be represented by single stocks for management purposes (Kailola *et al.* 1993). Smith (1989) reported that spawning by both blue and spotted warehous occurred in western Bass Strait in winter and winter/spring respectively and that both species probably spawned throughout their range in southern Australia. Regular reports by commercial fishers of "running ripe" warehou in various localities in southern Australia support this conclusion. Very little published information exists regarding the early life history of either species. Robertson (1975) provided a brief description of blue warehou eggs and Grimes and Robertson (1981) described eggs and yolk sac larvae of spotted warehou. Several authors have reported the close association between small juvenile warehous and jellyfish (e.g. Last *et al.* 1983). However, an inability to identify and distinguish between larvae of these two warehou species has largely precluded further analyses. We provide herein descriptions of both spotted and blue warehou larvae and report patterns of distribution of both species in south eastern Australia. Our data supports multiple spawning areas for both species and variations in spawning times between different areas.

4.3.2 LARVAL IDENTIFICATION

Centrolophid larvae are moderate to elongate, have large eyes, weak preopercular spines (except *Ichichthys lockingtoni*) and develop a rounded snout characteristic of the suborder Stromateoidei. Preflexion larvae have characteristic series of pigment spots on dorsal and ventral midlines. Pigment

blotches or bands are common on the trunk and tail in post flexion larvae. Postflexion larvae and juveniles are commonly associated with jellyfish or floating objects (Last *et al.* 1983; Ahlstrom *et al.* 1976). Larvae were identified to species based on myomere counts, fin meristics and unique pigment features (see Bruce *et al.* in press for details).

Identification of spotted warehou larvae was confirmed by rearing eggs from known adults collected on *Southern Surveyor* cruise SS05/93 and comparing to wild caught larvae. Running ripe adults were collected via a demersal trawl in 250 m of water approx 40 km south of Pt Hicks. Eggs were stripped from two females and placed in a small amount of unfiltered seawater in a 500 ml polycarbonate jar for a period of 2 mins. Milt from several ripe males was then added to the jar and allowed to stand for 5 mins. Eggs were subsequently washed in unfiltered seawater and incubated in 500 ml glass jars. Incubation temperature varied between 16.0°C and 19.0°C. Development was monitored every hour for the first 12 h and every 6 h thereafter. Seawater was changed in the jars every day. Wild caught zooplankton was added to jars after larvae had developed pigmented eyes and a functional mouth. Zooplankton was collected from the surface beside the vessel using a 100 µm mesh net. Zooplankton was sieved through 500 micron mesh, prior to being added to rearing jars, to remove large zooplankters.

Spotted warehou eggs hatched after 53 h at a size of 2.8–3.1 mm. This period is much shorter than that reported by Grimes and Robertson (1981) for spotted (= silver) warehou in New Zealand (146 h at 10–13°C). The accelerated development times in our rearing probably reflects our higher incubation temperatures. In our rearing, yolk absorption was complete and larvae had developed pigmented eyes and a functional mouth by 69–89 h post hatch (i.e. approximately 5–6 d post fertilisation).

4.3.3 BRIEF DESCRIPTION OF SPOTTED WAREHOU LARVAE

Figure 16.

(see Bruce et al in press, for further details)

Morphology

Body elongate to moderate (BD 11.1%–34.2%), depth increasing during development. Head small to moderate in preflexion larvae (HL 14.1%–25.4%); large in postflexion (HL 33.2%–35.1%). Gut long (PAL 50.4%–65.3%), initially straight, becomes coiled but not compact by 5.9 mm and broadly triangular in postflexion larvae. Small villiform teeth form on the premaxilla and dentary during flexion. Gas bladder over anterior portion of gut. No gap between anus and anal fin. Three to four small preopercular and 1–2 anterior preopercular spines form during flexion. These increase to 7–8 and 4–6 respectively in

postflexion larvae. A single lower opercular spine forms by 10.4 mm. Pectoral and pelvic fins become large and fan-like in larvae >11.0 mm.

Size at	
Hatching	2.3–2.7 mm
Notochord flexion	6.5–8.8 mm
Formation of fins:	
Caudal	6.3–8.8 mm
Anal	6.5–9.6 mm
Dorsal	6.5–11.3 mm
Pelvic	7.9–9.5 mm
Pectoral	8.4–11.3 mm

Pigmentation

Larvae are moderately pigmented. External melanophores: Scattered melanophores over tips of both jaws, dentary, between eyes and over brain. 1–2 small melanophores at angle of lower jaw. Series of 5 large, stellate melanophores between nape and caudal peduncle; 2 posterior-most becoming elongate in flexion larvae. Additional melanophores develop along dorsal midline in postflexion larvae, resulting in coalescing of this dorsal series. Pigment extends into finfold above and below caudal peduncle during flexion and onto bases of dorsal rays in post flexion larvae. Scattered stellate melanophores develop over the gut by 7.0 mm. Scattered melanophores along ventral midline of head and trunk from just anterior to cleithral symphysis to anus. 2–5 melanophores ventrally on tail. These coalesce to form an evenly pigmented band from the anus to the caudal peduncle by 5.9 mm. Lateral midline series of elongate melanophores on tail extending anteriorly to trunk in postflexion larvae. Secondary lateral series of melanophores develop above anal fin ray bases in flexion larvae and below dorsal fin ray bases in postflexion larvae. Melanophores (approximately 1 per base) develop over dorsal and anal fin ray bases by 11.4 mm. Internal melanophores: Pigment extends from below otic capsule, along entire length of gut to above anus. Pigment cap over gas bladder. Melanophores on snout below nasal pit, over hindbrain and below nape. Melanophores develop over vertebrae (approximately 1 per vertebra) extending posteriorly from above gas bladder to caudal peduncle in flexion larvae.

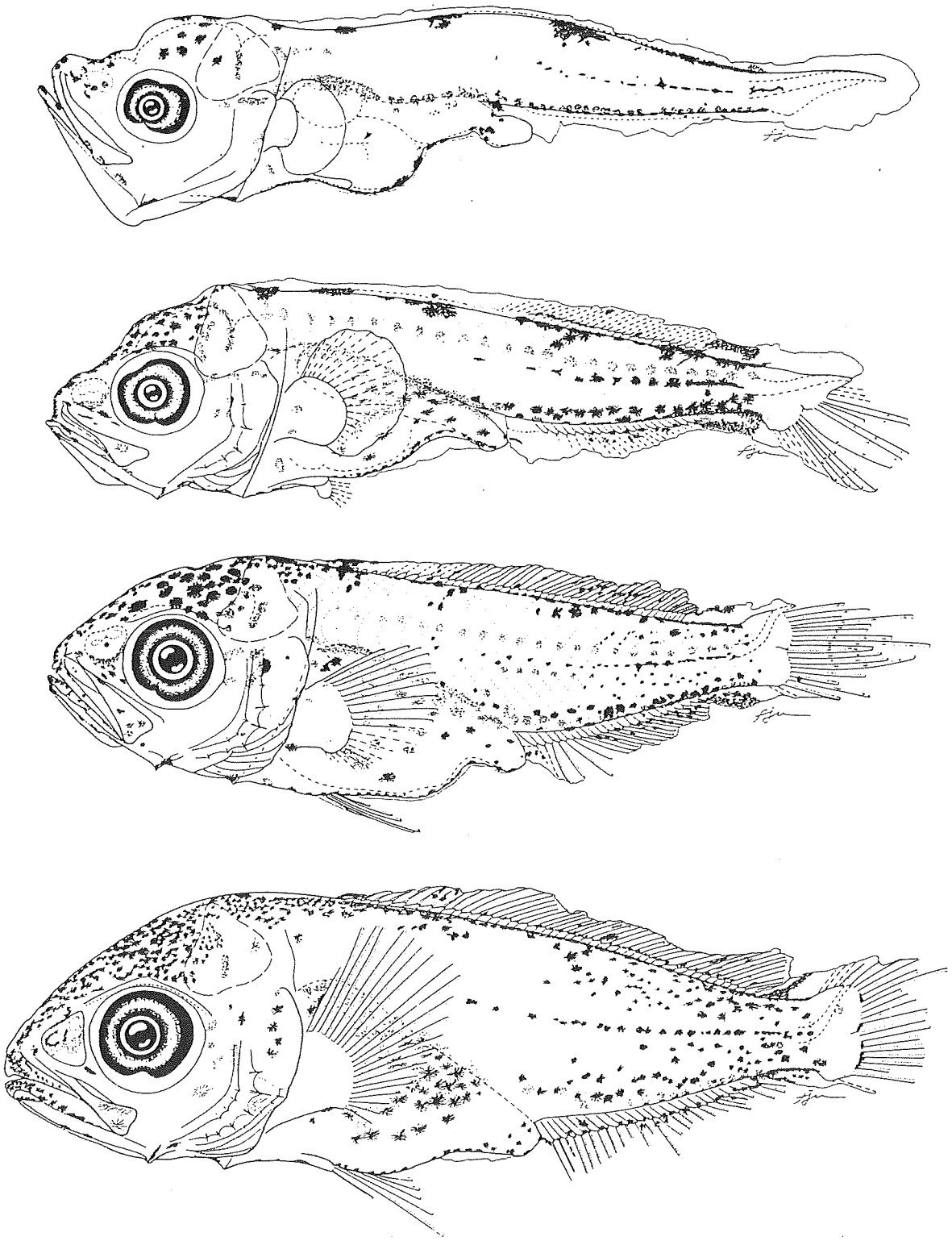


Figure 16. Larval development of spotted warehou (*S. punctata*). (A) 6.4 mm; (B) 8.3 mm; (C) 9.0 mm; (D) 10.6 mm. Drawn by F. J. Neira.

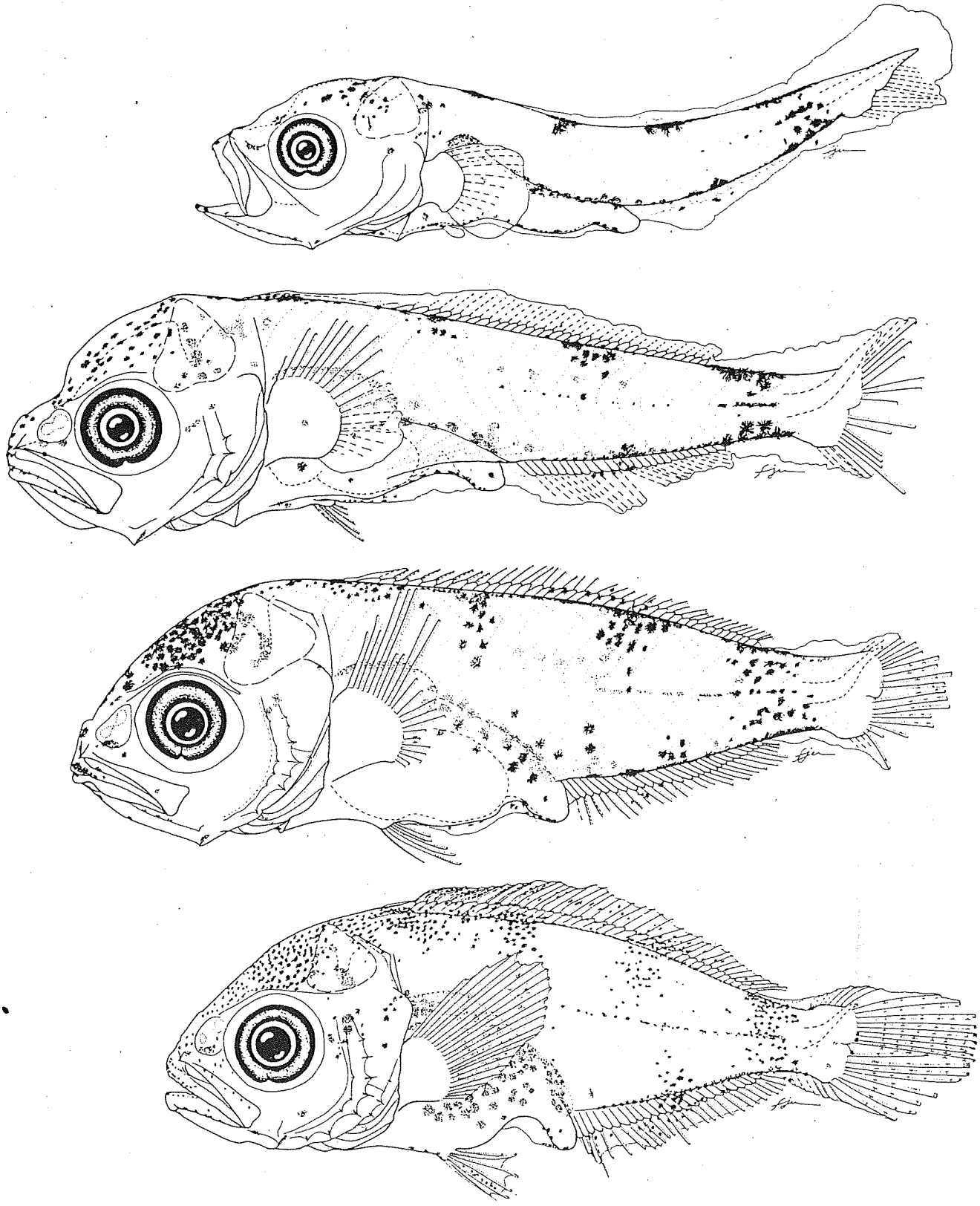


Figure 17. Larval development of blue warehou (*S. brama*). (A) 7.6 mm; (B) 8.3 mm; (C) 9.6 mm; (D) 11.7 mm. Drawn by F. J. Neira.

4.3.4 BRIEF DESCRIPTION OF BLUE WAREHOU LARVAE

Figure 17.

(see Bruce *et al.* in press for further details)

Morphology

Body moderate (BD 16.9%–36.5%), depth increasing during development. Head moderate in preflexion and flexion larvae (HL 23.7%–32.4%); moderate to large in postflexion (HL 33.0%–36.5%). Gut long (PAL 54.9%–66.2%), initially straight, becomes coiled but not compact by 6.1 mm and broadly triangular in postflexion larvae. Small villiform teeth form on the premaxilla and dentary during flexion. Gas bladder over anterior portion of gut. No gap between anus and anal fin. Three to four small preopercular spines and up to 5 anterior preopercular spines form during flexion. Anterior preopercular spines become less obvious in postflexion larvae, reducing in number to 2–4; 7–9 preopercular spines are present. A single lower opercular spine forms by 9.2 mm; 2–3 are present in post flexion larvae. Pectoral and pelvic fins become large and fan-like in larvae >14.0 mm.

Size at	
Hatching	4.2 mm
Notochord flexion	6.9–9.4 mm
Settlement	–
Formation of scales	–
Formation of fins:	
Pelvic	7.4–10.0 mm
Pectoral	7.4–10.0 mm
Caudal	7.9–9.4 mm
Dorsal	7.9–10.1 mm
Anal	7.9–10.1 mm

Pigmentation

Larvae are moderately pigmented. External: Scattered melanophores over tips of both jaws, dentary, between eyes and over brain. Single small melanophore at angle of lower jaw. Series of 4 large stellate melanophores between nape and caudal peduncle; posterior-most becoming elongate in flexion larvae. Scattered

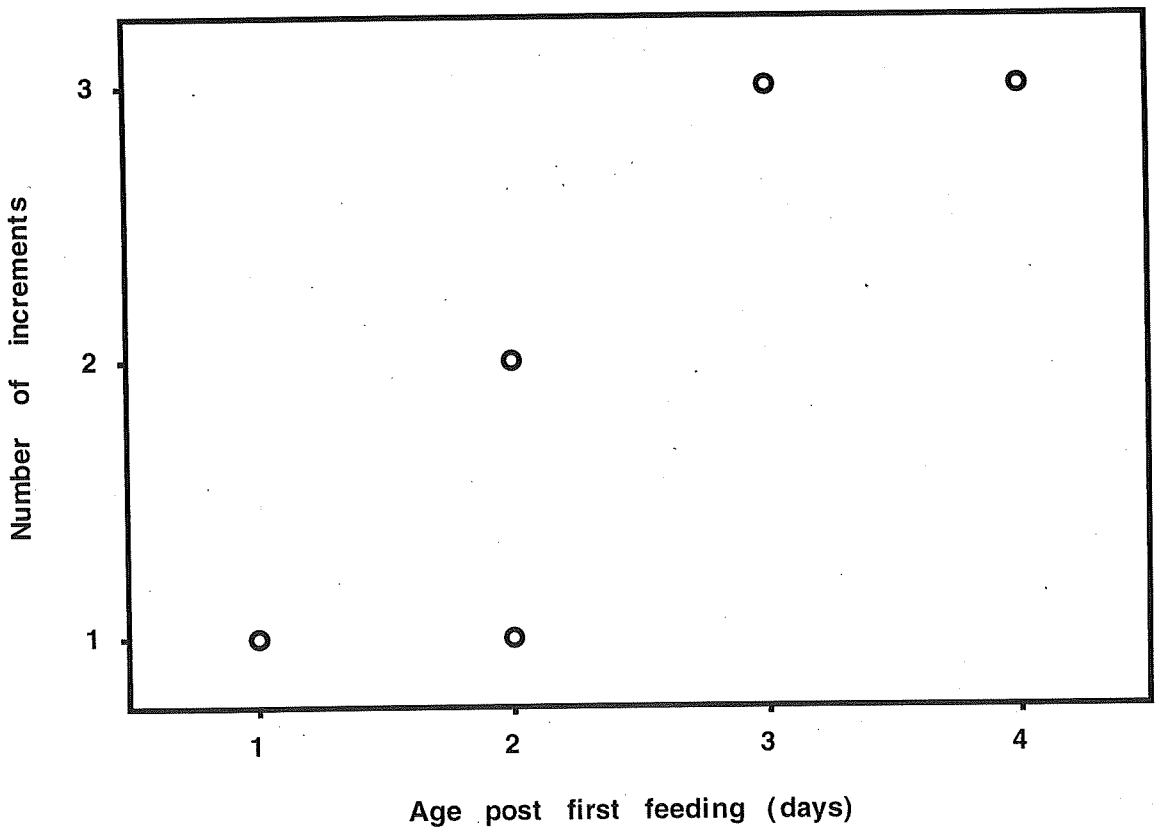


Figure 18. Number of increments verses total age (in days) for reared spotted warehou larvae.

melanophores develop over gut by 8.2 mm. Scattered melanophores over ventral midline of head and trunk from just anterior of cleithral symphysis to anus. Scattered melanophores on ventral midline of tail forming 2 distinct areas of pigment which become obvious and separate by 7.9 mm. Lateral midline series of elongate melanophores on tail, extending anteriorly to trunk in postflexion larvae. Additional melanophores develop and extend laterally from the dorsal series and ventral pigment regions of tail by 8.8 mm, forming two bands of melanophores in post flexion larvae. Melanophores form over the pelvic fin and extend into dorsal and anal fin rays by 9.2 mm and form along the leading edges of dorsal fin spines by 12.5 mm. Internal: Pigment below otic capsule, above gas bladder and over gut between gas bladder and anus. Melanophores on snout below nasal pit, over hind brain and below nape. Melanophores develop over vertebrae (approximately 1 per vertebra) extending posteriorly from above gas bladder to caudal peduncle by 9.2 mm. Some melanophores of lateral midline series become overlain by musculature by 12.5 mm.

4.3.5 METHODS

(a) Samples examined.

Larvae were sorted from ichthyoplankton samples collected on 5 transects spaced roughly equidistantly between Bermagui (NSW) and Pt Hicks (Vic) and a series of stations along the west and south coasts of Tasmania (SS05/93 - Figure 1). Sampling details are provided in section 4.2.3 (*a*).

(b) Otolith analyses

Larvae of both spotted and blue warehou were aged by examining otolith microstructure following the procedures of Brothers *et al.* (1976). Increment formation was assumed to be daily in both species based on the similarity of increment structure to that in species for which age validation has been previously documented (e.g. blue grenadier — Thresher *et al.* 1989, green back and long nosed flounder — Jenkins, 1987). Indirect evidence of daily increment formation was gained from the coincidence of back calculated spawning dates with documented spawning periods (Smith, 1989; Kailola *et al.* 1993) and, for spotted warehou, via examination of otoliths from reared material.

Otoliths (sagittae) were extracted from 20 reared spotted warehou larvae ranging from 1 h–139 h (5.7 d) post fertilisation. Increments were only visible in reared spotted warehou larvae with pigmented eyes and functional mouths (n=7). The radius to the first increment varied between specimens but did not differ significantly between reared larvae (mean 12.2, range 10.1–13.0, n =7) and

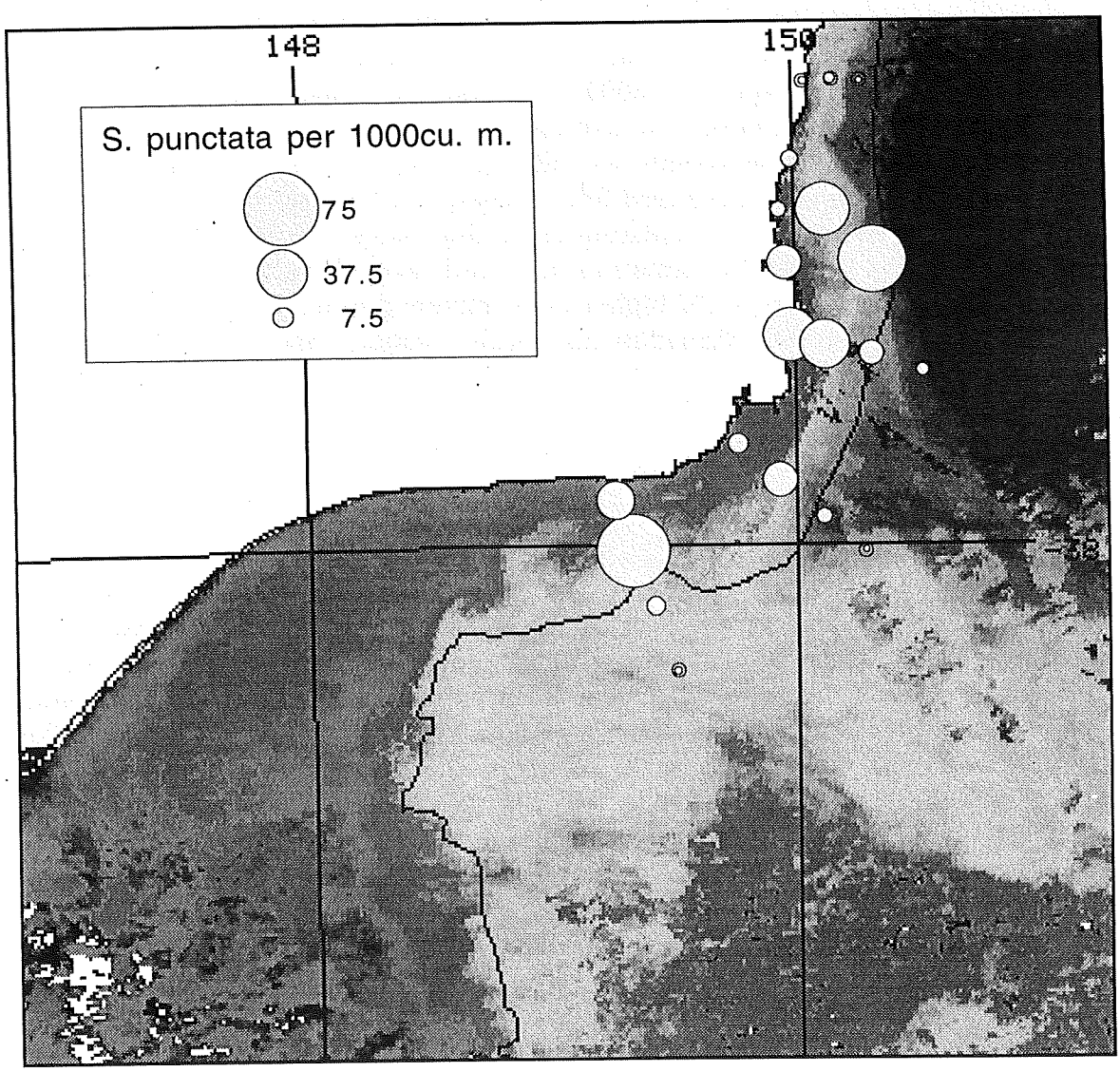


Figure 19. Distribution of spotted warehou larvae off south eastern Australia in August 1993.

wild caught larvae (mean 12.9, range 9.9–14.1, n=10) (P>0.1, two tailed t-test). This suggests that first increment formation commences at first feeding. The number of increments increased with age after first feeding. The increase was indicative of one increment per day, however, too few larvae survived to enable a statistical analysis (Figure 18)

Increment counts were taken from whole unprocessed sagittae mounted in a drop of lens immersion oil. Sagittae were examined under transmitted light at 1200-2500x using a Leitz orthoplan microscope fitted with a high resolution television camera (Ikegami CTC–6000) and linked to a high resolution monitor. Increment age was estimated by averaging counts from both sagitta (where counts from a respective otolith set did not differ by 5%). Otolith pairs not satisfying this criteria were rejected from subsequent analyses (2.1%). Increment age +6 was used in back calculating spawning dates, based on time to first feeding and first increment formation in reared spotted warehou (see above). Rearing temperature was 2–4°C higher than ambient temperature, thus our value of 6 d to first increment formation may underestimate that for field collected larvae.

4.3.6 RESULTS

(a) Larval distribution of spotted warehou

Spotted warehou larvae were present throughout the NSW/Vic sampling area (Figure 19). Larvae ranged from 3.3–12.0 mm and 8–49 d. Larvae were recorded either side of a frontal zone separating cool northerly flowing inshore water and warm southward flowing water of EAC origin. The only stations where spotted warehou larvae were not recorded were the outer-most stations of the Bermagui and Eden transects. These latter stations were located within an eddy of the EAC and contained a markedly different larval fish fauna to other stations (CSIRO unpublished data). Spotted warehou larvae were most common at inshore and midshelf stations within a cool northerly flowing water mass extending from eastern Bass Strait to just north of Bermagui.

To examine for evidence of northward or southward advection, larvae were pooled by water mass (i.e. those within the cool inshore water forming one group and those in offshore, warmer water in another). Neither size nor age of larvae were correlated with either distance northwards along the coast (for larvae within the cool inshore zone) or southwards along the coast (for larvae in offshore waters). Similarly, there was no correlation between larval age or size and distance offshore.

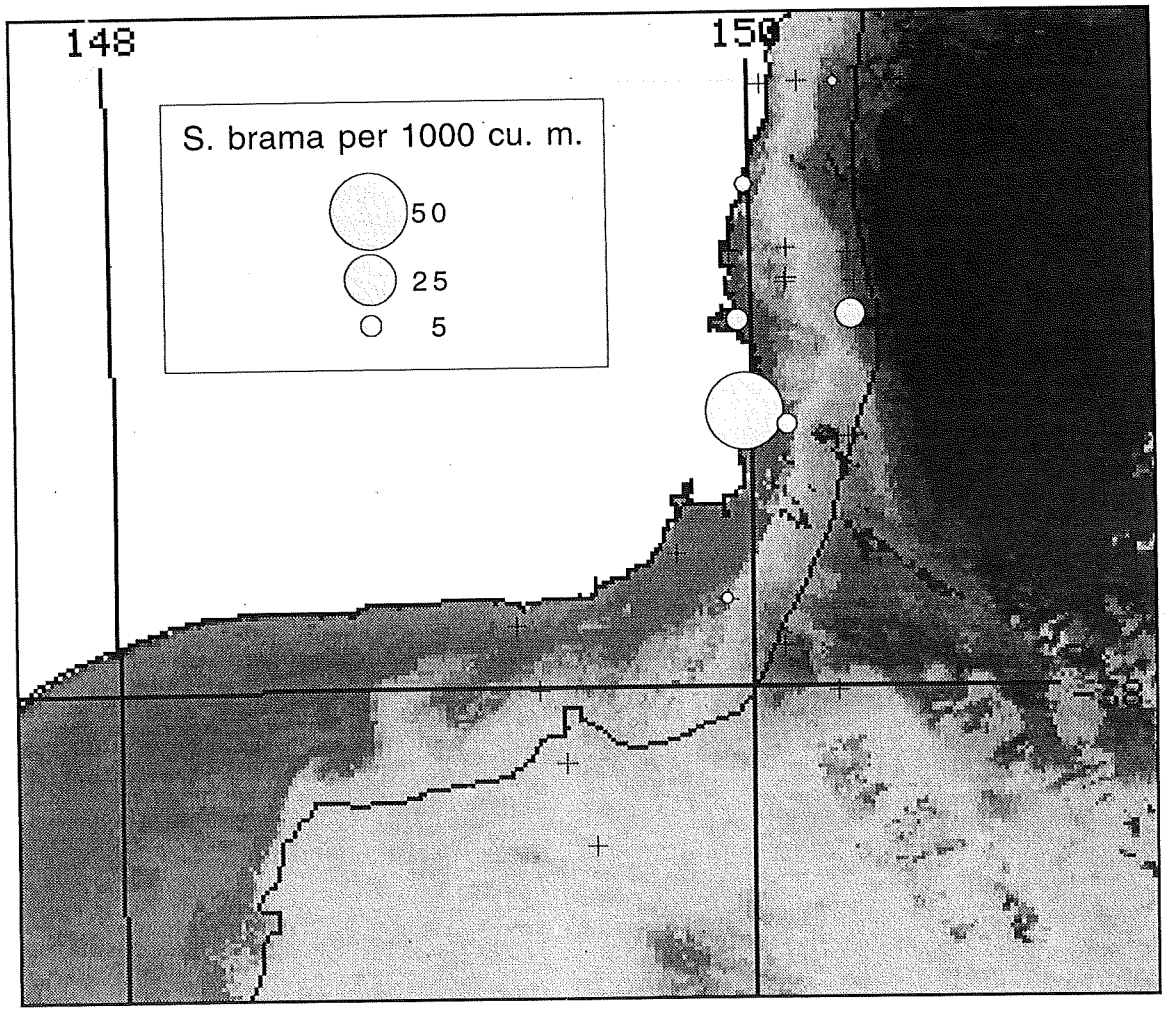


Figure 20. Distribution of blue warehou larvae off south eastern Australia in August 1993.

Spotted warehou larvae were also caught in small numbers on the west and south coast of Tasmania. Larvae in these areas were small, ranging in size from 3.0–4.5 mm and 8–16 d.

(b) Larval distribution of blue warehou

Blue warehou larvae were collected in small numbers off both NSW/Vic and southern Tasmania (Figure 20). Larvae ranged from 2.9–18.6 mm and 10–60 d. Larvae were primarily concentrated within the cool northward flowing inshore water mass although small numbers were also present at the shelf edge stations off both Eden and Bermagui. The smallest larvae were collected at the latter station. Insufficient numbers of larvae were collected throughout the area to determine advection pathways.

Blue warehou larvae collected from southern Tasmanian waters were small (3.1–4.2 mm, 7–14 d).

(c) Otolith analysis - spotted warehou

Back calculated spawning dates varied between regions with spawning occurring earlier in NSW/Vic. Spawning was recorded on 27 d over a 41 d period from 28 June to 8 August for spotted warehou larvae collected off NSW/Vic. A distinct peak in back calculated spawning dates was recorded around 24 July. Back calculated spawning dates from Tasmanian larvae were recorded on 5 d over a 9 day period from 7 to 15 August (Figure 21).

(d) Otolith analysis - blue warehou

Similarly to spotted warehou, calculated spawning dates for blue warehou varied between regions with spawning occurring earlier in NSW/Vic. Spawning was recorded on 22 d over a 36 d period from 28 June to 3 August for blue warehou larvae collected off NSW/Vic. Insufficient larvae were available to detect any distinct peak in spawning. Back calculated spawning dates from Tasmanian larvae were recorded on 5 d over an 8 day period from 6 to 18 August (Figure 22).

4.3.7 DISCUSSION AND CONCLUSIONS

The distribution of young spotted warehou larvae throughout both NSW/Vic as well as western and southern Tasmania waters, suggests spawning is widespread throughout the SEF zone. This is further supported by the capture of running ripe adults off Eden (during this study), eastern Tasmania (during a

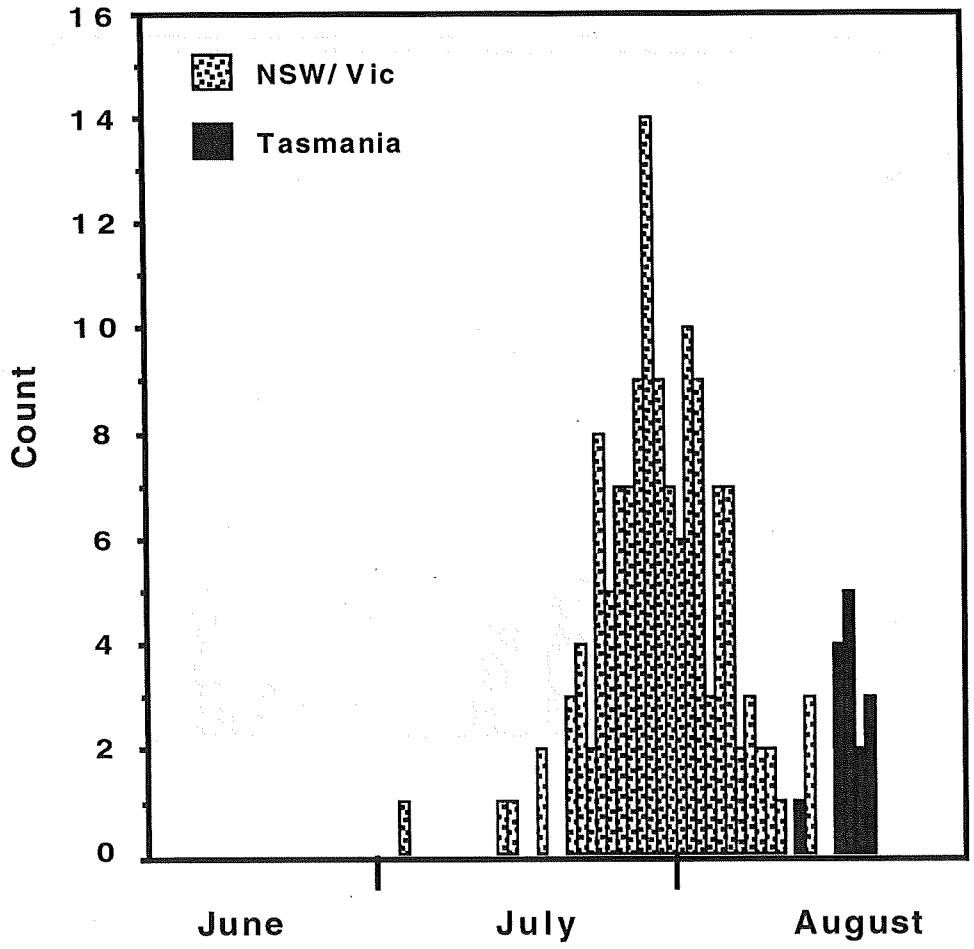


Figure 21. Back calculated spawning dates for spotted warehou larvae in 1993.

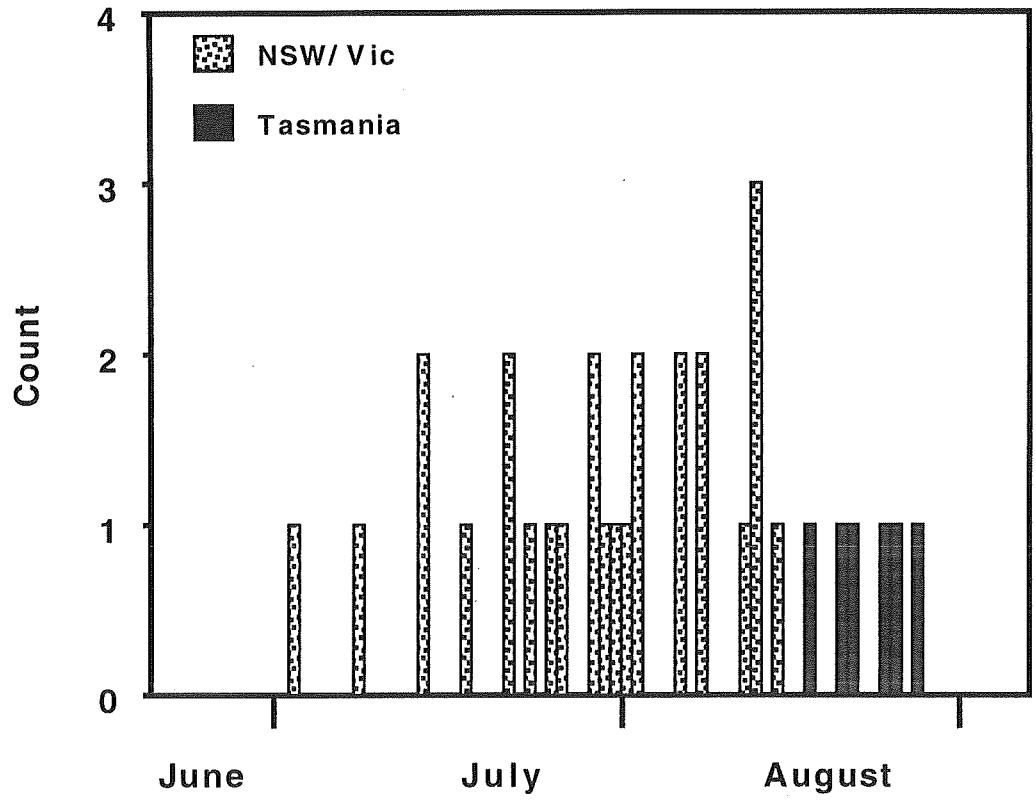


Figure 22. Back calculated spawning dates for blue warehou larvae in 1993.

CSIRO study of blue grenadier in 1985, CSIRO unpublished data) and western Bass Strait (Smith, 1989). Similarly, although less conclusive due to the smaller number of specimens, the distribution of young blue warehou larvae also suggests widespread spawning activity.

Back calculated spawning dates suggest that both species are winter/spring spawners, but that blue warehou commence spawning earlier than spotted warehou off NSW/Vic. This timing is consistent with peaks in GSI values reported by Smith (1989) for both species off western Bass Strait. Spawning dates for warehou larvae of both species collected in Tasmanian waters suggest that spawning in this area probably commences later than areas further north. Infact spawning appears only to have just commenced in this area at the time of sampling. A later spawning in Tasmanian waters is further supported by back calculated spawning dates from 8 blue warehou larvae dipnetted in Storm Bay in October/November 1993. Larvae were 9–17 mm, 36–51 d with spawning dates ranging from 9–17 September.

Large numbers of postflexion larvae and juveniles of both warehou species were observed under the jellyfish *Cyanea capillata* in Storm Bay and the lower Derwent River between October and December in 1993 and 1994. Similar observations were reported by Last *et al.* (1983) and led Lyle and Ford (1994) to conclude that inshore bays of southern Tasmania were important nursery areas for both species. Associations with jellyfish appear to be widespread within the group and have been reported for larvae and juveniles of several other centrolophid species (Mansuetti, 1963; Kingsford, 1993). The nature of such associations is unclear, nor whether they represent a facultative or obligate relationship. However, it is interesting to note that both jellyfish and warehou larvae/juveniles were absent from the lower Derwent and Storm Bay in 1995 and that very few juveniles were present in inshore bays in early 1996 (D. Mills/A. Jordan Tas Dept Sea Fisheries pers. comm.). This suggests that either the distribution or survival of early life history stages may be related to the presence of jellyfish within the area.

The presence of multiple spawning areas and the distribution of larvae in various water masses suggests a complex pattern of larval advection within the SEF. Larvae in southern NSW, for example, were present in both the inshore northward flowing water mass as well as the offshore southward EAC flow. Thus larvae within the area may represent the product of spawning activity north, south and within the area of sampling. Such distributions may result in mixing of larvae from different source areas.

The implications for stock structure of multiple spawning areas and observed patterns of larval advection within the SEF are unclear and require material from areas across the range of both species in southern Australia for a more complete analysis. However, the complex pattern of mixing of larvae between regions

suggests that the current strategy of managing both species as single respective stocks is appropriate.

5. BENEFITS

The lack of detailed stock structure information for the majority of SEF quota species represents a significant problem for efficient management and sustainable utilisation of the fisheries' resources. Given that the fishery is managed by output controls (total allowable catch — TAC), it is important that stocks are defined and that where multiple stocks exist, they are managed separately. Failure to do so could result in stocks being fished to the point of collapse if the bulk of the TAC is taken from a stock (Tilzey, 1994).

Not all techniques used to establish stock structure are applicable for every species and providing an unambiguous analysis is a difficult task. However, by combining techniques, where appropriate, a more plausible explanation of observed patterns can be achieved.

This study has established the utility of ichthyoplankton data for interpreting stock structure where other techniques have provided ambiguous results. The major benefits of this research are thus an enhanced ability to interpret stock structure and thereby facilitating the sustainable exploitation of fisheries resources.

6. INTELLECTUAL PROPERTY

No commercial intellectual property arose from this work.

7. FURTHER DEVELOPMENT

Further development is recommended in two areas.

ANALYSIS OF ARCHIVED SAMPLES

Ichthyoplankton samples can provide valuable sources of information regarding:

- the location of spawning grounds,
- reproductive biology (e.g. timing and periodicity of spawning),
- factors influencing larval dispersal and supply to nursery areas (hence recruitment and ecosystem dynamics),

- fisheries independent estimators of biomass (eg egg surveys), and
- interpretation of stock structure.

Over the last 10 years a considerable number of plankton and fine mesh midwater trawl samples have been collected in southern Australian waters. Samples provide a broad scale coverage of coastal and offshore areas of southern Australia within which are nested more detailed data sets that would allow interannual comparisons and vertical distribution to be established for key areas (eg NSW coastal waters, Tasmanian coastal and offshore waters). Samples have been collected by CSIRO, state government institutions and university researchers. Considerable expense and effort has been expended on obtaining these existing samples. FRDC funds have initiated some these collections. In most cases, larval fish have been extracted, but only specific species have been identified, leaving a large number of larvae of commercial species (including the majority of SEF quota species) undocumented. These samples represent a powerful data set and we recommend that they be analysed. This both extends the value and represents a cost effective use of previously collected material.

Documenting and reanalysing existing data sets were part of the original proposal for this study. However, locating many of the samples and analysing their contents were beyond the scope of the modified objectives. Two factors now make these analyses possible:

Identification of larvae: - Identification of larvae has previously been a major problem in southern Australia. With the impending publication of an atlas of southern Australian fish larvae (Neira *et al.*, in press) covering 125 species from 57 families (including nearly all SEF quota species), this has largely been rectified.

Regional archive of larval fish material: A recently funded FRDC project will result in the archiving of available larval fish material in Australian waters. This initiative will guarantee the safe storage and accessibility of existing material. The project will not, however, document the content of currently unidentified material.

TESTING THE STOCK STRUCTURE HYPOTHESIS FOR JACKASS MORWONG

The correspondence between recruitment patterns suggested by both larval advection and otolith microchemistry suggests that the latter technique may be of use in determining mixing rates between stocks in southern Australia for at least jackass morwong. Analysing microchemical signals from larvae north and south of the STC frontal zone in the SW Tasman Sea (hypothesised to be of separate origin) would test this hypothesis. This work is planned for mid 1996.

8. STAFF AND ACKNOWLEDGEMENTS

8.1 STAFF

Ronald Thresher	Principle Investigator
Barry Bruce	Project supervisor
Caroline Sutton	Ichthyoplankton biologist

8.2 ACKNOWLEGEMENTS

Several people assisted with this work. We wish to thank K. Evans, D. Mills, Dr F.J. Neira, Dr A. G. Miskiewicz, D. Furlani, K. Haskard, T. Cracknell, C. Proctor, C. Bulman, J. Young, A. Jordan, Dr A. Koslow, Dr N. Elliott and the Master and crew of the *Southern Surveyor*.

9. REFERENCES

Annala, J. H. (1995). Report from the Fishery Assessment Plenary, May 1995: stock assessments and yield estimates. 277 p. MAF Fisheries Greta Point Wellington NZ.

Ahlstrom, E. H., Butler, J. L. and Sumida, B. Y. (1976). Pelagic stromateoid fishes (Pisces: Perciformes) of the eastern Pacific: kinds, distribution and early life histories and observations on five of these from the northwest Atlantic. *Bull. Mar. Sci.* 26: 285-402.

Ayling, T. and Cox, G. J. (1982). Collins Guide to the Sea Fishes of New Zealand. Collins, Auckland NZ.

Barnard, K. H. (1927). A monograph of the marine fishes of South Africa. Part II. *Ann. S. African Mus.* 21: 456–8.

Blaxter, J. H. S. (1986). Development of sense organs and behaviour of teleost larvae with special reference to feeding and predator avoidance. *Trans. Am. Fish. soc.* 115: 98–114.

Brittnacher, J. and Botsford, L. (1994). Bony parts: an image analysis program. University of California, Davis California.

Brothers, E. B., Mathews, C. P. and Lasker, R. (1976). Daily growth increments in otoliths from larval and adult fishes. *Fish. Bull.* (US) 74: 1–8.

Brownell, C. L. (1979). Stages in the early development of 40 marine fish species with pelagic eggs from the Cape of Good Hope. *Rhodes Univ. J. L. B. Smith Inst. Icthyol. Bull.* 40.

Bruce, B. D. (1988). Larval development of blue grenadier, *Macruronus novaezelandiae* (Hector), from Australian waters. *Fish. Bull.* (U.S.) 86: 119–128.

Bruce, B. D. (1989). Cheilodactylidae — morwongs. *In* J. M. Leis and T. Trnski (eds). The larvae of Indo-Pacific shorefishes. *University of New South Wales Press*, Sydney, pp 150–153.

Bruce, B. D. (in press). Cheilodactylidae — morwongs. *In* F. J. Neira, A. G. Miskiewicz, T. Trnski (eds). The larvae of temperate Australian Fishes. *University of Western Australia Press*, Nedlands WA.

Bruce, B. D. (in press). Macruronidae — grenadier. *In* Neira F. J., Miskiewicz A. G. and Trnski, T. (eds). The larvae of temperate Australian Fishes. *University of Western Australia Press*, Nedlands WA.

Bruce, B. D., Sutton, C. A. and Neira, F. J. (in press). Centrolophidae — warehous. *In* Neira F. J., Miskiewicz, A. G. and Trnski, T. (eds). The larvae of temperate Australian Fishes. *University of Western Australia Press*, Nedlands WA.

Bruce, B. D., Young, J. W., Evans, K., Sutton, C. A. and Furlani, D. M. (submitted). The influence of mesoscale oceanographic processes on larval distribution and stock structure in a temperate ground fish. *Mar. Biol.*

Cresswell, G., Wells, G. and Petersen, J. (1994). Australian satellite tracked Drifters 1991–1994. Report to Fisheries Research and Development Corporation. CSIRO Hobart.

Cresswell, G. R. and Legeckis, R. (1986). Eddies off southeastern Australia. *Deep-Sea Res.* 33: 1527–1562.

Davis, T. L. O., Jenkins, G. P. and Young, J. W. (1990). Patterns of horizontal distribution of the larvae of southern bluefin (*Thunnus maccoyii*) and other tuna in the Indian Ocean. *J. of Plankton Res.* 12: 1295–1314.

Elliott, N. G. and Ward, R. D. (1994). Enzyme variation in jackass morwong, *Nemadactylus macropterus* (Schneider 1801) (Teleostei: Cheilodactylidae) from Australian and New Zealand waters. *Aust. J. Mar. Freshwater Res.* 45: 51–67.

Gauldie, R. W. and Nathan, A. (1977). Iron content of the otoliths of Tarakihi (Teleostei: Cheilodactylidae). *N.Z. J. Mar. Freshwater Res.* 11: 179–191.

Grewe, P. M., Smolenski, A. J. and Ward, R. D. (1994). Mitochondrial DNA variation in jackass morwong, *Nemadactylus macropterus* (Teleostei: Cheilodactylidae) from Australian and New Zealand waters. *Can. J. Fish. Aquat. sci.* 51: 1101–1109.

Grimes, P. J. and Robertson, D. A. (1981). Egg and larval development of the silver warehou, *Seriolella punctata* (Pisces: Centrolophidae). *N.Z. J. Mar. Freshwater Res.* 15: 261-266.

Gulland, J. A. (1983). Fish stock assessment, a manual of basic methods. FAO-Wiley Series on Food and Agriculture Vol. 1. 223 p.

Gunn, J. S., Bruce, B. D., Furlani, D. M., Thresher, R. E. and Blaber, S. J. M. (1989). Timing and location os spawning of blue grenadier, *Macruronus novaezelandiae* (Teleostei: Merlucciidae) in Australian coastal waters. *Australian Journal of Marine and Freshwater Research* 40: 97–112.

Hare, J. A. and Cowan, R. K. (1993). Ecological and evolutionary implications of the larval transport and reproductive strtegy of bluefish, *Pomatomus saltatrix. Mar. Ecol. Prog. Ser.* 98: 1–16.

Harris, G., Nilsson, C., Clementson .L. and Thomas, D. (1987). The water masses of the east coast of Tasmania: Seasonal and interannual variability and the influence on phytoplankton biomass and productivity. *Aust. J. Mar. Freshwater Res.* 38: 569–590.

Jenkins, G. P. (1987). Age and growth of co-occurring larvae of two flounder species, *Rhombosolea tapirina* and *Ammotretis rostratus*. *Mar. Biol.* 95: 157–166.

Kingsford, M. J. (1990). Linear oceanographic features: a focus for research on recruitment processes. *Aust. J. Ecol.* 15: 27–37.

Kingsford, M. J. (1993). Biotic and abiotic structure in the pelagic environment: importance to small fishes. *Bull. Mar. Sci.* 53: 393-415.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A. and Grieve, C. (1993). Australian fisheries resources. Bureau of Rural Resources and Fisheries Research and Development Corporation, Canberra, ACT.

Last, P. R., Scott, E. O. G. and Talbot, F. H. (1983). Fishes of Tasmania. Tasmanian Fisheries Development Authority, Hobart. 563 pp.

Leis, J. M. (1986). Vertical and horizontal distribution of fish larvae near coral reefs at Lizard Island, Great Barrier Reef. *Mar. Biol.* 90: 505–516.

Leis, J. M. (1989). Larval biology of butterflyfishes (Pisces, Chaetodontidae): what do we really know? *Environm. Biol. Fishes* 25: 87–100.

Leis, J. M. (1991). The pelagic stage of reef fishes: the larval biology of coral reef fishes. *In:* PF Sale, The ecology of fishes on coral reefs. Academic Press, San Diego.

Leis, J. M. and Trnski, T. (1989). The larvae of Indo-Pacific shorefishes. University of New South Wales Press, Sydney.

Leis, J. M., Sweatman, H. and Reader, S. (in press). Field studies of behaviour in coral reef fish larvae. *Mar. Freshwater Res.*

Livingston, M. E. (1990). Spawning hoki (*Macruronus novaezelandiae* Hector) concentrations in Cook Strait and off the South Island, New Zealand, August-September 1987. *N. Z. J. Mar. Freshwater Res.* 24: 503–517.

Lyle, J. M. and Ford, W. B. (1994). Review of trawl research 1979-1987, with summaries of biological information for the major species. Dept Sea Fisheries, Tasmania Technical Rept. 46: 169 pp.

Lyne, V. D. and Thresher, R. E. (1995). Dispersal and advection of *Macruronus novaezelandiae* larvae off Tasmania: simulation of the effects of physical forcing on larval distribution. *In* Sammarco, P. (ed) Multidisciplinary studies of recruitment of Australian Marine populations. Springer Verlag.

Mansuetti, R. J. (1963). Symbiotic behaviour between small fishes and jellyfishes with new data on the stromateoid, *Peprilus alepidotus*, and the scyphomedusa, *Chrysaora quinquecirrha*. *Copeia* 1963: 40-80.

Middleton, J. F. and Black, K. P. (1994). The low frequency circulation in and around Bass Strait: a numerical study. *Cont. Shelf Res.* 14: 1495–1521.

Milton, D. A. and Shacklee, J. B. (1987). Biochemical genetics and population structure of blue grenadier, *Macruronus novaezelandiae* (Hector) (Pisces: Merlucciidae), from Australian waters. *Aust. J. Mar. Freshwater Res.* 38: 727–742.

Murdoch, R. C. and Chapman, B. E. (1989). Occurrence of hoki (*Macruronus novaezelandiae*) eggs and larvae in eastern Cook Strait. *N.Z. J. Mar. Freshwater Res.* 23: 61–67.

Nelson, W. R., Ingham, M. C. and Schaaf, W. E. (1977). Larval transport and year class strength of Atlantic menhaden, Brevoortia tryannus. *Fish. Bull.* 75: 23–41.

Neira, F. J., Miskiewicz, A. G. and Trnski, T. (in press). The larvae of temperate Australian fishes: a laboratory guide for larval fish identification. *Uni. Western Aust. Press*. Nedlands WA.

Nielson, J. D. and Green, G. H. (1985). Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile chinook salmon *Onchorhynchus tshawytscha*. *Fish. Bull.* US. 83: 91–101.

Nielson, J. G. (1963). On the development of *Cheilodactylus variegatus* Valenciennes 1833 (Cheilodactylidae). *Copeia* 1963 (3): 528–533.

Radtke, R. L. and Dean, J .M. (1982). Increment formation in the otoliths of embryos, larvae and juveniles of the mummichog, *Fundulus heteroclitus*. *Fish. Bull.* US. 80: 201–215.

Richardson, B. J. (1982). Geographical distribution of electrophoretically detected protein variation in Australian commercial fishes. II: Jackass morwong, *Cheilodactylus macropterus* (Bloch and Schneider). *Aust. J. Mar. Freshwater Res.* 33: 927–931.

Robertson, D. A. (1978). Spawning of tarakihi (Pisces: Cheilodactylidae) in New Zealand waters. *N.Z. J. Mar. Freshwater Res.* 12: 277–286.

Robertson, D. A. (1975). A key to the planktonic eggs of some New Zealand marine teleosts. *N.Z. Fish. Res. Div. Occas. Publ.* No. 9.

Sale, P. F. (1970). Distribution of acanthurid larvae off Hawaii. *Copeia* 1970: 765–766.

Smith, D. C. (1994). Blue warehou (*Seriollela brama*). *in* Tilzy (ed) The south east fishery: a scientific review with particular reference to quota management. *Bureau of Resource Sciences. AGPS Canberra*. pp 179-188.

Smith, D. C. (1989). Summary of available data on warehous *Seriolella brama* and *S. punctata*. Prepared for DPFRG 28, Hobart.7-10 November 1989. *Marine Science Laboratories Internal Report* No. 183.

Stobutzki, I. C. (1995). Sustained and directional swimming of presettlement juvenile coral reef fishes and the implications for reef fish ecology. (Abstract only). International Larval Fish Conference, Sydney Australia.

Tilzey, R. D. J. (1994). The south east fishery: a scientific review with particular reference to quota management. *Bureau of Resource Sciences. AGPS Canberra*. 360 p.

Tilzey, R. D. J., Zann-Schuster, M., Klaer, N. L. and Williams, M. J. (1990). The south east fishery: biological synopsis and catch distributions for seven major commercial fish species. *Bureau Rural Resources Bulletin* 6: 80 pp.

Tong, L. J. and Saito, R. (1977). Further postlarvae of tarakihi in New Zealand waters. *N.Z. J. Mar. Freshwater Res.* 11: 159–162.

Thresher, R. E., Proctor, C. H. Gunn, J. S. and Harrowfield, I. R. (1994). An evaluation of electron-probe microanalysis of otoliths for stock identification of nursery areas in a southern temperate groundfish, *Nemadactylus macropterus* (Cheilodactylidae). *Fish. Bull.* (US) 92: 817–840

Thresher, R. E., Bruce, B. D., Furlani, D. M., and Gunn, J. S. (1989). Distribution, advection and growth of larvae of the southern temperate gadoid, *Macruronus novaezelandiae* (Teleostei: Merluccidae) in Australian coastal waters. *Fish. Bull.* (US) 87: 29–48.

Thresher, R. E., Gunn, J. S., Bruce, B. D. and Furlani, D. M. (1988). Spawning by blue grenadier in Australian coastal waters. *Australian Fisheries* 47: 47–51.

Vooren, C. M. (1975). Nursery grounds of tarakihi (Teleostei: Cheilodactylidae) around New Zealand. *N.Z. J. Mar. Freshwater Res.* 9: 121–158.

Vooren, C. M. (1972). Post-larvae and juveniles of tarakihi (Teleostei: Cheilodactylidae) in New Zealand. *N.Z. J. Mar. Freshwater Res.* 6: 601–618.

Young, J. W., Bradford, R. W., Lamb, T. D. and Lyne, V. D. (in press). Biomass of zooplankton and micronekton in the southern bluefin tuna fishing grounds off eastern Tasmania, Australia. *Mar. Ecol. Prog. Ser.*