The life-history ecology of *Platycephalus bassensis* and *Nemadactylus macropterus*

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Statements

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Abstract

The ecology of all life-history stages of two species of demersal fish, sand flathead (*Platycephalus bassensis*) and jackass morwong (*Nemadactylus macropterus*) found in coastal and continental shelf waters of southern and eastern Tasmania was investigated to determine the spatial and temporal patterns of spawning distribution and larval transport, recruitment, abundance and distribution, and size and age composition. The seasonal and interannual variations of the hydrography of shelf waters are described and the influence of such variability on the life-history stages assessed.

Spawning in *P. bassensis* occurred for an extended period of up to six months between October and March in estuaries, coastal embayments and shelf waters of southern and eastern Tasmania. The distribution of spawning fish, larvae and patterns of hydrography indicate that spawning on the shelf is primarily inshore. Larval development of *P. bassensis* is described. Larvae are concentrated in mid-water which retain larvae inshore as cross-shelf subsurface currents are predominantly onshore.

Spawning in *N. macropterus* occurred between early January and late April in mid- and outer-shelf waters. Ichthyoplankton data indicate *N. macropterus* larvae are concentrated in surface waters, with few larvae caught during subsurface sampling of shelf waters over three years, despite large interannual differences in the extent of vertical mixing and stratification. The surface distribution of larvae appears to be a strategy to maximise offshore transport as movement of surface waters of the shelf are generally offshore. However, large interannual variations in the influence of subtropical and subantarctic waters on the shelf are described and the influence of such variations on larval transport assessed.

Significant seasonal and spatial variations in abundance of mature *P. bassensis* were evident, the variations attributed primarily to the seasonal movement of fish between shelf and nearshore waters. Overlying the seasonal trends in abundance were interannual variations that were at least an order of magnitude in difference. Mature *P. bassensis* were generally more abundant on the inner-shelf, with little evidence of size-structuring with increasing depth. Settlement occurred over an extended period in summer with juveniles showing a strong preference for unvegetated habitats in

nearshore waters, compared to beds of the seagrass, *Heterozostera tasmanica*. However, mature *P. bassensis* in nearshore waters showed no preference between vegetated and unvegetated habitats. There is evidence of a seasonal movement of these nearshore fish out onto the shelf close to the size at maturity.

In contrast, *N. macropterus* on the shelf showed size-structuring between depths and regions, with juveniles dominating the inner-shelf in both regions surveyed, while the mid- and outer-shelf of the east coast was dominated by mature fish. Settlement from the pelagic post-larval phase occurred in spring and early summer at between 7 to 9 cm and 9 to 12 months old. Storm Bay appears to be principally a nursery area for the species with migration from the region occurring upon maturity. In addition, the size-structuring by depth was one of the main factors attributed to the significant variations in abundance across the shelf. Significant seasonal variations in abundance were also apparent, which is attributed to the seasonal movement of fish from south-eastern Tasmanian shelf waters.

The age, growth and spatial and interannual trends in age composition of *P. bassensis* and *N. macropterus* were examined using transverse sections of sagittal otoliths. The first annual increment was defined in both species by examination of the progression of otolith radius and length of the 0+ cohort. Sex specific growth curves are presented for both species. Maximum ages of *P. bassensis* was 17 years for males and 13 for females, while *N. macropterus* reached 41 years for males and 30 for females. The age composition of both species was dominated by 4 to 7 years olds with considerable recruitment variability evident with a strong year-class in 1986 for *P. bassensis* and in 1988 for *N. macropterus*. The relationship between the life-history strategies of *P. bassensis* and *N. macropterus* and recruitment variability is discussed.

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Chapter 1 Introduction

1.1 General

Understanding the relative contribution of each life-history stage of marine fish in regulating year-class abundance is a major goal of fisheries ecologists. Interannual variations in the reproductive success of a species can lead to considerable variability in recruitment. Such variability was identified early in this century by Hjort (1914), who hypothesised that variations in the survival of the larval stage due to starvation and transport were the main determinants of year-class strength. Determining the relative importance of such physical and biological processes in survival of the planktonic phase and ultimate recruitment has been the focus of considerable research (Cushing 1975, Lasker 1981, Sinclair et al. 1985). It is clear, however, that the link between larval survival and recruitment remains uncertain, with suggestions that all pre-recruit stages contribute to interannual variations in year-class strength (Sissenwine 1984, Peterman et al. 1988, Bradford 1992). In addition, the influence of such factors as the distribution of spawning, larval transport and habitat selection at settlement on recruitment will depend greatly on the system and scale studies, and are likely to be species specific. While the role of post-settlement losses in influencing recruitment is not well understood, factors such as food limitation, shelter and predation (Shulman and Ogden 1987, Jones 1991) and physical disturbance (Stephens et al. 1994, Jenkins et al. 1997a) appear to be significant. In this study, recruitment refers to the abundance of juveniles measured at some arbitrary time after settlement, and as such, represents the combined influence of all the above factors.

1.1.1 Spawning and larval distribution

The influence of advection and retention of pelagic larval stages in the recruitment process has been widely recognised (eg. Parrish et al. 1981, Bakun and Parrish 1982, Norcross and Shaw 1984, Sinclair 1988). Most demersal and sedentary marine species that have pelagic larvae must either remain in suitable settlement areas or be transported to these areas to complete their pelagic stage. Variations in the supply of larvae to an appropriate habitat have been shown to influence variability in recruitment of invertebrates (Gaines et al. 1985, Roughgarden et al. 1988), and fishes associated with coral reefs (Milicich et al. 1992, Doherty and Fowler 1994, Milicich

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and Doherty 1994, Sponaugle and Cowen 1996), temperate reefs (Cowen 1985) and temperate soft-sediment habitats (Bell *et al.* 1988, Jenkins and Black 1994, Jenkins *et al.* 1997a).

For fish species whose larvae are distributed inshore and whose nursery areas are also inshore, particularly those whose nursery areas are spatially separated from spawning areas, variable offshore transport of pelagic eggs and larvae can play a major role in determining recruitment success (Bailey 1981). Such variable transport has often been related to the loss of larvae through offshore Ekman transport (Bailey 1981) and mesoscale hydrographic events such as eddies and offshore jets (Mooers and Robinson 1984, Flierl and Wroblewski 1985). In south-eastern Australia, variations in westerly winds and hydrography strongly influences the temporal pattern of recruitment of *Sillaginodes punctata* into Port Phillip Bay, Victoria from waters offshore (Jenkins *et al.* 1997a). Parrish *et al.* (1981) suggested that in order to minimise offshore losses, species in upwelling regions have adapted to spawn at a time of minimum upwelling and offshore Ekman transport. Some pelagic fish species in regions of high oceanographic variability respond to fluctuating conditions by varying the both the location and timing of spawning to make best use of seasonal patterns of ocean stability and favourable transport (Parrish *et al.* 1983, Shelton and Hutchings 1989). This is particularly evident in areas influenced by El Niño/Southern Oscillation (ENSO) events which are known to influence the timing and area of spawning of pelagic populations (MacCall 1979, Le Clus 1990, Hammann 1991).

The hypothesis that spawning in upwelling regions takes place when offshore transport is at a minimum is only partially supported, as some species of rockfish, *Sebastes* spp. spawn at a time of maximum offshore transport (Moser and Boehlert 1991). However, while their larvae are an important component of the offshore ichthyoplankton assemblage (Richardson *et al.* 1980, Kendall and Clark 1982), it is unclear whether this is an important source of mortality in many *Sebastes* species (Moser and Boehlert 1991). A similar offshore distribution occurs in bluefish (*Pomatomus saltatrix*) larvae in the South Atlantic Bight, which appears to be an adaptive response to transport larvae close to nursery areas (Hare and Cowen 1996).

The influence of hydrology on the distributional patterns of larvae will be strongly influenced by their vertical distribution as the direction of current flow often varies with depth. By regulating their vertical distribution, crustacean larvae have been shown to influence the patterns of dispersal (Phillips 1981, Shanks 1986). Abundances of larval fish, however, are generally highest in the upper mixed layer and thermocline, with the depth distribution often related to the depth of the thermocline (Ahlstrom 1959, Moser and Boehlert 1991). Vertical stratification of fish larvae can also be independent of the thermal stratification, suggesting that larval behaviour can play a major influence determining the vertical distribution (Lenarz et al. 1991, Gray 1996). Lenarz et al. (1991) suggested that small *Sebastes* larvae respond to increased surface advection offshore in winter by remaining deep in the water column. In contrast, the offshore transport of larvae appears to be maximised in fish species that have larvae associated with surface waters (Richardson and Pearcy 1977, Shenker 1988).

Distinct larvae fish assemblages, often taxa specific, are associated with subsurface and surface waters (Kingsford 1988, Sabates 1990, Leis 1991, Gray 1996). These assemblages become less distinct in pelagic juveniles due to ontogenetic changes in vertical distribution, often resulting in increased abundance in surface waters (Moser and Boehlert 1991, Larson et al. 1994). While such ontogenetic changes may result in higher rates of anomalous transport, this may be minimised by the increased swimming capabilities of the pelagic juveniles (Stobutzki and Bellwood 1994). Horizontal swimming has also been implicated in the onshore movement of pelagic juveniles from offshore waters (Larson et al. 1994, Hare and Cowen 1996), although the onshore transport of pelagic larvae and juveniles still appears to be associated with hydrological features, such as internal waves (Shanks 1983, Kingsford and Choat 1986), warm core ring streamers (Hare and Cowen 1996) and Ekman transport (Norcross and Shaw 1984, Shenker et al. 1993, Milicich 1994). As the duration of the pelagic larval and juvenile phase and size at settlement varies markedly between species, the significance of behavioural mechanisms in influencing patterns of recruitment are likely to be species specific.

1.1.2 Juvenile distribution

Transport of pelagic pre-settlement stages of demersal fish to suitable juvenile habitats is critical for successful recruitment, with the importance of nearshore

habitats as nursery areas well established. Coastal areas identified as important nursery areas include estuaries (Day *et al.* 1981, Beckley 1983, Lenanton and Potter 1987, Bell and Pollard 1989, Potter *et al.* 1990), nearshore reefs (Jones 1984, Cowen 1985, Lincoln Smith *et al.* 1991, Levin 1993), sheltered nearshore waters (Hyndes *et al.* 1996) and surf zones (Robertson and Lenanton 1984, Clark *et al.* 1994, Harris and Cyrus 1996). Within soft-sediment habitats, seagrass beds are widely recognised as an important nursery area for many species of commercial and recreational importance by providing protection and increased food resources compared to bare substrates (see Bell and Pollard 1989). Shallow unvegetated habitats are, however, becoming increasing recognised as an important habitat for juvenile fishes (Ferrell and Bell 1991, Ruiz *et al.* 1993, Ayvazian and Hyndes 1995, Edgar and Shaw 1995a, Hyndes *et al.* 1996, Jenkins *et al.* 1997b), particularly for species that are protected by either camouflage or schooling behaviour. Despite levels of food production being higher in seagrass beds (Edgar 1990, Edgar *et al.* 1994), enhanced food production in shallow unvegetated habitats can occur due to the presence of detached macrophytes (Robertson and Lenanton 1984, May and Jenkins 1992) and regular phytoplankton blooms (McLachlan *et al.* 1981).

Despite the extensive distribution of these nearshore habitats throughout Tasmania, the dependence of life-history stages of fish on these habitat have been documented for few species. This is particularly significant given the decline in the extent of seagrass beds (Rees 1993) and the continued degradation of unvegetated habitats throughout estuarine and coastal waters around Tasmania resulting from increased nutrients and turbidity, algal and dinoflagellate blooms, accumulation of wood pulp effluent and introduction of exotic species. These impacts highlight the need for assessing the dependence on these habitats for life-history stages of fish in these waters.

While there has been an emphasis on coastal waters as nursery areas for demersal fishes, the inner regions of the continental shelf have also been identified as an important nursery area for commercially important demersal species (Vooren 1975, Love *et al.* 1991, Francis 1995, Hyndes *et al.* 1996, Jordan 1997). Surveys of the continental shelf of southern and eastern Tasmania found that most economically important demersal species on the shelf utilised inner-shelf waters (~10-50 m) as a nursery area (Jordan 1997). A distinct trend of increasing size with depth was also

evident for several species, indicating a size- or age-specific migration from nursery areas to deeper adult grounds. Such spatial separation of size-classes has been suggested to reduce the potential for intraspecific competition (Hyndes *et al.* 1996).

1.1.3 Adult distribution

While continental shelf waters of southern Australia support diverse and abundant populations of commercially important demersal fish (see Tilzey *et al.* 1994), there is little published information detailing the spatial and temporal variations in abundance and distribution. Wankowski and Moulton (1986) reported distinct seasonal and depth variations in the abundance of individual demersal species on the shelf of eastern Bass Strait, and attributed such variations to seasonal movement between depths and changes in vulnerability, possibly due to spawning activity. Spatial variations in the abundance of several demersal species also occurs on the New South Wales shelf, and were related to differences in nearshore and offshore demersal assemblages (Gray and Otway 1994), and size compositions (Graham *et al.* 1996). Temporal differences for many species were attributed to the seasonal movement of fish along the shelf (Graham *et al.* 1996). One of the main factors attributed to the spatial variations in abundance of several demersal species on the shelf of eastern Tasmania was size structuring by depth, with juveniles inshore and adult fish in deeper water (Jordan 1997). The presence of spatial and temporal variability has important implications for the interpretation of such data from the commercial fishery, as variations in size compositions and catch rates from the fishery may reflect shifts in effort across these scales rather than changes in the size composition or stock abundance.

While seasonal and spatial variations have been investigated for a number of demersal species in southern Australia (Wankowski and Moulton 1986, Gray and Otway 1994), few studies have examined interannual variations in abundance and distribution. The oceanography and productivity of eastern and southern Tasmanian shelf waters shows considerable interannual variability due to the changing influence of warm, nutrient-poor East Australian Current (EAC) water and cool, nutrient-rich water of subantarctic origin (Harris *et al.* 1987). The relative importance of the two water masses from year to year is determined by a combination of zonal westerly wind strength and large-scale oceanographic circulation associated with El Niño/Southern Oscillation (ENSO) events (Harris *et al.* 1987). Such variations in

oceanography have profound effects on the physical and biological structure of southern and eastern Tasmanian shelf waters. During years of increased EAC influence, the shelf is strongly stratified and there is little recycling or influx of nutrients (Harris *et al.* 1991). In addition, the dominant large zooplankter, krill (*Nyctiphanes australis*), disappear from the shelf, which in turn leads to a disappearance of pelagic fish, principally jack mackerel (*Trachurus declivis*) (Young *et al.* 1993). Interannual variations in oceanography also influences micronekton production, with an increase in gelatinous zooplankton biomass in windy years (Young *et al.* 1996).

The effect of variations in oceanography on patterns of egg and larval distribution, timing of spawning, larval growth, and adult distribution has also been well documented for several pelagic fish species in Tasmania (Thresher *et al.* 1988, Gunn *et al.* 1989, Young *et al.* 1993, Jordan 1994a, Jordan *et al.* 1995). However, the influence of such variability on the spatial and temporal patterns of abundance, spawning distribution and larval transport of demersal fish species in these waters has been poorly examined. Studies on the relationship between oceanography and demersal productivity, and its association with pelagic production have also been lacking, and hence, there is little understanding of the processes influencing temporal and spatial patterns of demersal species.

In addition, despite the significance of shelf associated demersal species to commercial and recreational landings in Tasmania, little information has been available to researchers or managers on the life-history ecology and population parameters of key demersal species. Basic information such as size at sexual maturity, spawning distribution, recruitment processes and age and growth is lacking for most demersal species. Such information is necessary to understand the dynamics of populations and define many life-history parameters that are an essential part of developing age-based stock assessments. It is also an important part of establishing the age composition of a population in order to assess the extent of year-class variability. While such assessment is principally based on fishery dependant data, an important part of the process is the collection of fishery independent data, including independent estimates of stock abundance and size/age structure.

Given the paucity of information on demersal species in Tasmania, the aim of this thesis is to examine and compare the ecology of all life-history stages of two species of demersal fish commonly found in coastal and continental shelf waters of southern and eastern Tasmania, sand flathead (*Platycephalus bassensis*) and jackass morwong (*Nemadactylus macropterus*). Firstly, I examine the relative influence of the spatial and temporal distribution of spawning and regional hydrography in determining larval distribution and influencing patterns of recruitment throughout southern and eastern Tasmania. The seasonal, interannual and spatial patterns in abundance and size composition of juvenile and adult *P. bassensis* and *N. macropterus* are then examined in both inshore and continental shelf waters in order to assess the influence of variations in oceanography and size specific migrations in determining the patterns of distribution and abundance. Finally, I determine the age and growth of both species in order to examine spatial trends in age composition, assess the extent of recruitment variability and examine the aspects of the life-history that may explain such variations in recruitment.

Thus, the specific objectives of this study were to:

(1) describe the reproductive biology, spawning and larval distribution and larval development of *P. bassensis* and *N. macropterus*, and assess the influence of seasonal and interannual variations in the hydrography of eastern Tasmania shelf waters on patterns of larval distribution;

(2) assess the spatial and temporal patterns of juvenile distribution in continental shelf and inshore seagrass and unvegetated habitats in order to examine recruitment processes and evaluate the importance of these areas as nursery grounds for *P. bassensis* and *N. macropterus*;

(3) examine temporal and spatial variations in the abundance and size composition of adult *P. bassensis* and *N. macropterus* on the continental shelf and inshore waters of southern and eastern Tasmania; and

(4) determine the age and growth of *P. bassensis* and *N. macropterus*, and examine the interannual and spatial trends in age composition.

1.2 Study species

The Family Platycephalidae (flatheads) contains around 60 species (Nelson 1994), found primarily in coastal and estuarine waters of the Indo-Pacific region. Several species are found in coral reef and continental shelf areas. There are around 41 species in 12 genera recorded from Australian waters, 17 of which are endemic (Knapp 1984, Paxton and Hanley 1989, Keenan 1991). In temperate Australian waters the family is represented by 5 genera and 13 species (Gomon *et al* 1994).

Platycephalus bassensis is found from the central coast of New South Wales to eastern South Australia, but is most common in southern New South Wales, Victoria and Tasmania (Gomon *et al.* 1994). The species occurs on sandy and muddy substrates down to 100 m, but are most common in shallow coastal waters less than 65 m. Commercial fishing for *P. bassensis* occurs in eastern Bass Strait, several Victorian bays and inlets, and around Tasmania. Catch records from these areas since the early 1960's show a reasonably stable level of landings averaging about 400 tonnes year^{-1} (Kailola *et al.* 1993). Recent annual commercial landings from Victoria are around 30 tonnes (Neira *et al.* 1997), with a significant landings also being taken by recreational fishers (Hall and MacDonald 1986).

The commercial catch of *P. bassensis* in Tasmanian waters is unknown, as both *P. bassensis* and *Neoplatycephalus richardsoni* are pooled on commercial catch records. Up until the late 1980's the total flathead catch ranged between 20 and 50 tonnes, however since 1990 landings have been relatively stable at around 120 tonnes (Jordan 1994b). In Tasmania, *P. bassensis* are caught mainly by otter trawling and Danish seining in open coastal waters, while small landings are made by gill nets in more sheltered waters. The commercial fishing of flathead in Tasmanian state waters occurs relatively evenly throughout the east and south-east coasts with highest catches in late spring to autumn. In addition, *P. bassensis* are the most important recreational species in the state, with targeting by anglers mainly during summer.

The Family Cheilodactylidae (morwongs) are represented in south-eastern Australian waters by six species found throughout a range of habitats including rocky reefs, seagrass beds and across the continental shelf. The major commercial species in this family is jackass morwong *(Nemadactylus macropterus)*, which is distributed

throughout southern Australia from about Sydney (New South Wales) to Perth (Western Australia), including Tasmania (Gomon *et al.* 1994). It is also found in New Zealand waters.

Commercial fishing for *N. macropterus* in south-east Australian waters has occurred since the mid 1940's. Catches rose quickly to 1700 tonnes and then stabilised at around 1000 tonnes year^{-1} until landings increased to 1300 tonnes in the early 1970's (Smith 1994). Landings peaked at 2300 tonnes in 1980-81 due to strong recruitment and increased effort (Smith 1989). Despite lower catches in recent years, they continue to be an important commercial species in the South East Fishery (SEF), with 896 tonnes landed in 1996 (Tilzey 1998). The bulk of the landings are taken off southern New South Wales, eastern Bass Strait and eastern Tasmania by both Danish seiners and otter trawlers (Smith 1994).

In Tasmanian inshore waters, *N. macropterus* are caught mainly by otter trawl, although up to 10% are caught by gillnets (Jordan 1994c). Landings in this fishery were small during the early 1980's, increased to around 145 tonnes in 1992 before falling to approximately 25 tonnes in 1995/96 (Jordan 1994c, Lyle 1998). The main fishing grounds for the inshore fishery are in eastern and south-eastern Tasmania where approximately 95% of the catch is taken (Lyle 1994). Monthly landings from the Tasmanian inshore fisheries show highest catches are made during spring and early summer (Jordan 1994c). While the recreational catch of *N. macropterus* in Tasmania is unknown, it is assumed to be significant with fish caught on line and in recreational gillnets.

Chapter 2 Study areas and general methods

2.1 Shelf region

2.1.1 Survey areas

Storm Bay and the east coast in the area of Maria Island were chosen as suitable continental shelf survey areas as they represented known areas of commercial trawl activity. From 1989 to 1992 approximately 75% of state inshore trawl catches came from these two areas (Lyle 1994), representing landings from the east coast and Storm Bay of around 260, 190, 255 and 315 tonnes year^{-1}. The principal demersal species caught are jackass morwong (*Nemadactylus macropterus*), tiger flathead (*Neoplatycephalus richardsoni*), sand flathead (*Platycephalus bassensis*) and eastern school whiting (*Sillago flindersi*). In addition, significant pelagic fisheries exist in the area with landings of up to 40,000 tonnes recorded for jack mackerel (*Trachurus declivis*) (Williams and Pullen 1993), and 400 tonnes for southern bluefin tuna (*Thunnus maccoyii*) (Caton *et al.* 1995).

Storm Bay is a large (>500 km^2 in area) marine embayment situated between the Tasman Peninsula and eastern shore of Bruny Island and is exposed to the prevailing westerly winds and swell (Fig. 2.1). Bottom type varies considerably from reef to sand and muddy sand. The east coast of Tasmania in the vicinity of Maria Island is a wide area of continental shelf that consists mainly of muddy sand, although soft mud dominates the outer shelf in the north (Fig. 2.1).
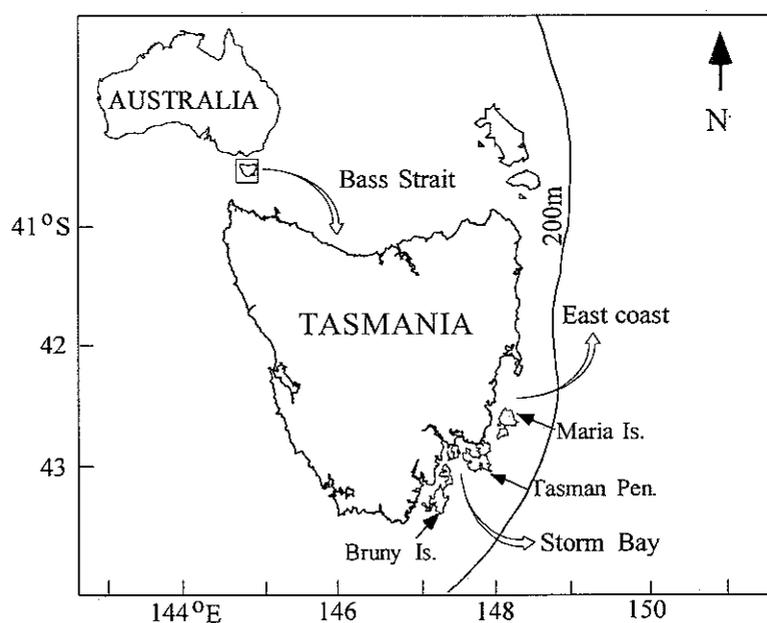
Fig. 2.1 Position of continental shelf survey areas in the eastern and southern Tasmania.

The oceanography of these waters is determined by a combination of the large scale oceanographic circulation and local westerly wind stress. The region is dominated by the warm, stratified, nutrient-poor East Australian Current (EAC) water, and cool, well-mixed, nutrient-rich water of subantarctic origin (Harris *et al.* 1987). The EAC water (characterised by the 17° C isotherm) appears as eddies or filaments during summer and autumn meeting the subantarctic water off the east coast of Tasmania in the vicinity of Maria Island (Fig. 2.2A), to create a broad frontal zone known as the subtropical convergence (STC) (Harris *et al.* 1987).

Recent studies, however, have included subantarctic water into a broader STC, the boundary of which may be as far south as 47° S (Clementson *et al.* 1998). Despite the changing definitions of particular water masses, it is clear that a major oceanographic boundary exists on the east coast of Tasmania between waters of subtropical and subantarctic origin. As the STC is usually located offshore, the shelf generally consists of a combination of water of subantarctic origin mixed with west coast water and river runoff creating a flow of cold, nutrient rich water onto the shelf (Cresswell *et al.* 1994). This water has a large influence on Storm Bay and the east coast, particularly during winter and spring (Fig. 2.2B) (Harris *et al.* 1987, Clementson *et al.* 1989). However, the relative influence of these water masses on the shelf of southern and eastern Tasmania shows considerable interannual variability and has been coupled with interannual variations in westerly wind stress and large scale oceanographic circulation often associated with El Niño/Southern Oscillation (ENSO) events (Harris *et al.* 1987).

2.1.2 Sampling gear and regime

2.1.2.1 Trawl surveys

Demersal trawl surveys of the shelf were conducted from the FRV *Challenger*, a stern trawler with the following specifications: length 21.3 m; beam 5.85 m; gross tonnage 87 tonnes; horsepower 500. Trawling was conducted with a demersal trawl with the following specifications; headline length 26 m, sweeps 38 m, bridles 25 m, wing mesh 120 mm, top and bottom panel mesh 100 mm, codend mesh 80 mm and a 20 mm codend liner. The ground rope consisted of rubber bobbins and a steel danleno at each wingtip and was approximately 0.2 m off the bottom.
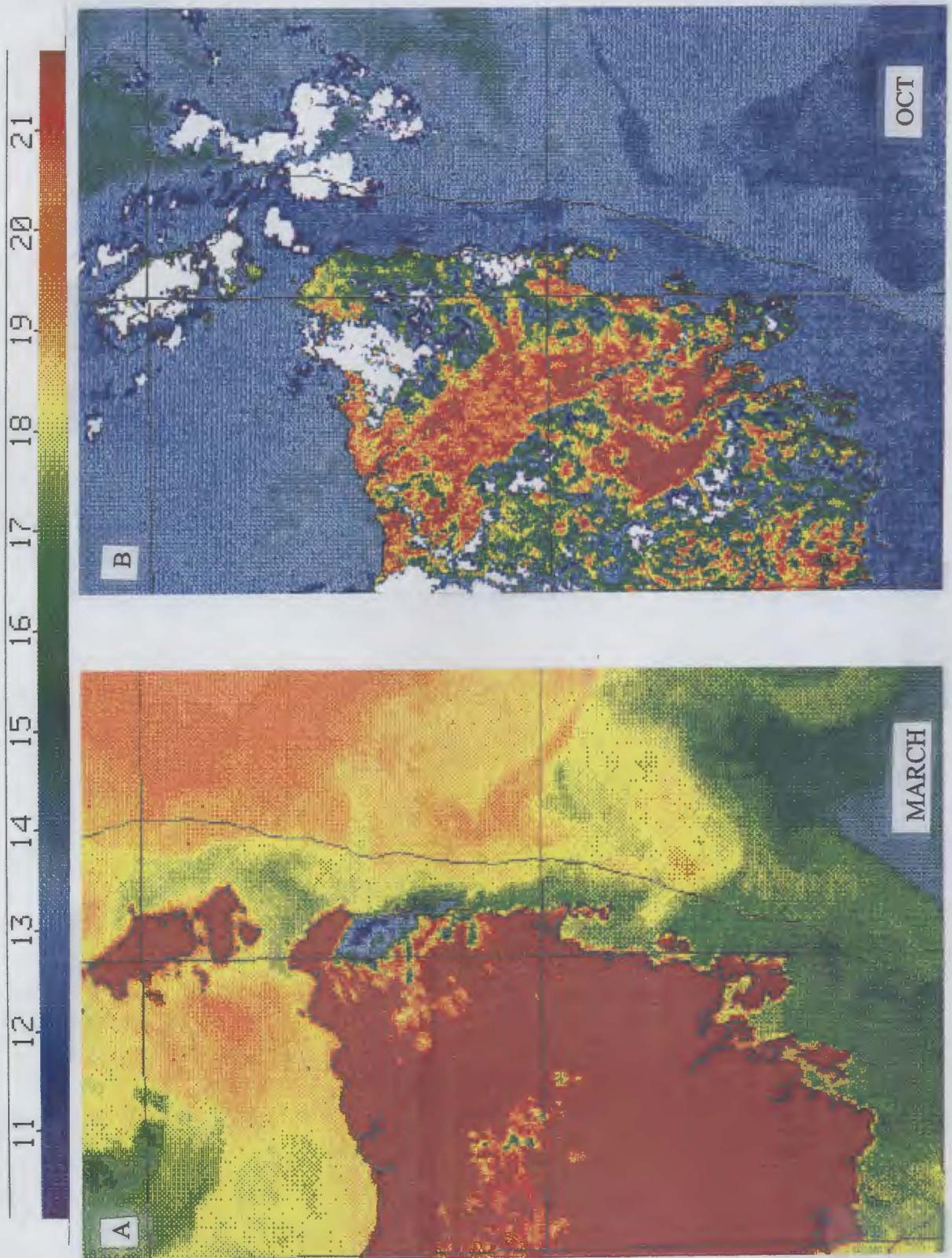
Fig. 2.2 Satellite image of sea-surface temperature of eastern Tasmania taken on (A) 26 March 1990 and (B) 20 October 1989. Land red; cloud white. The shelfbreak is represented by the dark line along the 200 m contour.

Platycephalus bassensis and *Nemadactylus macropterus* were sampled by demersal trawl during surveys of the shelf conducted in depths of 10 to 200 m on the east coast of Tasmania between the southern end of Marion Bay and Schouten Is., and in depths of 10 to 100 m in Storm Bay (Fig. 2.3). Depth strata in the survey area were defined from published bathymetric charts.
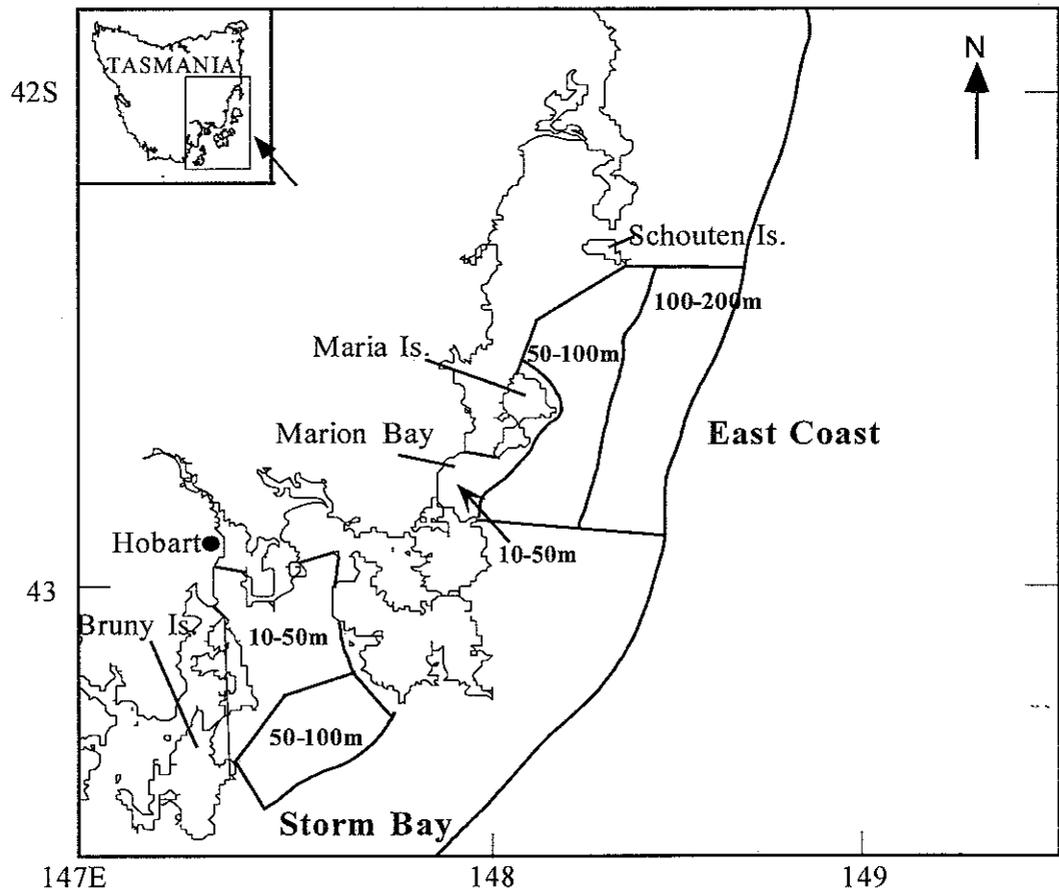
Fig. 2.3 Position of depth strata for shelf surveys on the east coast and Storm Bay, Tasmania.

The survey was based on a depth stratified random trawl survey design to determine relative abundance and distribution. Such surveys have been widely used in the assessment of abundance and distribution of fish stocks (Grosslein 1969, Francis 1984, Livingston and Schofield 1995). The survey area was stratified into three depth strata; inner-shelf (10-50 m), mid-shelf (50-100 m) and outer-shelf (100-200 m) on the east coast, and the inner-shelf (10-50 m) and mid-shelf (50-100 m) in Storm Bay (Fig. 2.3). As variance normally increases with population density the precision of biomass estimates increases when more stations are allocated to high density strata (Francis 1981, 1984). However, as this survey was designed to collect

data on several species, and as no prior knowledge of fish densities was available, depth strata were allocated stations proportional to the area of the stratum. Stratum areas were calculated by scanning the bathymetric charts into a graphics package, digitising the area within the depth contours and calibrating this against a known area. Details of stratum areas, number of stations and station density are presented in Table 2.1.

Table 2.1 Details of stratum areas, number of stations and station density ($N.km^{-2}$) for east coast (EC) and Storm Bay (SB) survey areas in each season.

YEAR	SEASON	REGION	STRATUM	AREA (km²)	NO. STATIONS TRAWLED	STATION DENSITY
1993	SUMMER	EC	10-50	112	3	1/37
			50-100	565	16	1/94
			100-200	416	4	1/104
		SB	10-50	377	7	1/54
			50-100	383	10	1/38
1993	AUTUMN	EC	10-50	112	2	1/56
			50-100	565	11	1/52
			100-200	416	8	1/52
		SB	10-50	377	10	1/38
			50-100	383	8	1/48
1993	WINTER	EC	10-50	112	2	1/56
			50-100	565	11	1/52
			100-200	416	6	1/69
		SB	10-50	377	9	1/42
			50-100	383	9	1/43
1993	SPRING	EC	10-50	112	1	1/112
			50-100	565	8	1/71
			100-200	416	7	1/59
		SB	10-50	377	10	1/38
			50-100	383	10	1/38
1994	SUMMER	EC	10-50	112	1	1/112
			50-100	565	9	1/63
			100-200	416	7	1/59
		SB	10-50	377	10	1/38
			50-100	383	8	1/48
1994	AUTUMN	EC	10-50	112	1	1/112
			50-100	565	6	1/94
			100-200	416	5	1/83
		SB	10-50	377	8	1/47
			50-100	383	8	1/48
1994	WINTER	EC	10-50	112	2	1/56
			50-100	565	9	1/43
			100-200	416	5	1/83
		SB	10-50	377	8	1/47
			50-100	383	8	1/48
1995	SUMMER	EC	10-50	112	2	1/56
			50-100	565	9	1/63
			100-200	416	8	1/52
		SB	10-50	377	8	1/47
			50-100	383	8	1/48

The surveys consisted of demersal tows at a maximum of 20 random stations in Storm Bay and 23 on the east coast with stations a minimum of 2 Nm apart (Table 2.1). The number of stations was based on a sampling intensity of around one station per 50km². Trawlable areas were restricted in Storm Bay due to hard bottom running in a narrow band through the entire bay in a south-west direction towards the southern tip of Bruny Island. Trawling was also excluded from two areas on the east coast north of Maria Island - the outer-shelf stratum due to soft mud and the inner-shelf stratum due to marine farming activities. Some problems were also encountered in the inner-shelf stratum on the east coast due to high densities of red drift weed clogging the demersal trawl. When allocated stations were untrawlable an additional random station was added in that depth stratum.

At each station the net was towed for 30 minutes (bottom time) at 3.0 knots. When a constant warp length to bottom depth ratio is used both wingspread and/or doorspread have been found to be greater with increasing depth (Hurst and Bagley 1992, Graham and Liggins 1995). Hence, the ratio of warp length to bottom depth was increased from 3:1 in depths >150 m to around 8:1 in depths <40 m. The aim of varying the ratio was to gain the desired wingspread of 50% of headline length. Tows less than 15 minutes were excluded from abundance and size composition estimates. Stations were abandoned if, after the trawl path was surveyed, the bottom proved unsuitable for trawling. Tows were conducted between sunrise and sunset. At each shelf station, catch rates of *P. bassensis* and *N. macropterus* were calculated as the number of fish per tow.

2.1.2.2 Plankton surveys

The distribution of platycephalid and cheliodactylid larvae on the shelf of eastern Tasmania was determined from plankton samples collected at fixed stations on five transects from Bicheno in the north (T1) to Marion Bay in the south (T5) (Fig. 2.4). Larvae were sorted from samples taken on two surveys in January 1989 and two in January 1990. Transects consisted of three stations designated as inner-shelf (at a bottom depth of 30-50 m), mid-shelf (depth 70-100 m), and shelf break (0.5 n mile inshore of the shelf break at an average depth of 150 m).

Ichthyoplankton were collected with a 45 cm diameter bongo net with mesh 500 μm. Each station consisted of an oblique tow to a maximum depth of 100 m (bottom

depth permitting) at a tow speed of ~3 knots. At each station the net was sent to the required depth quickly, held there for 1-2 minutes and then retrieved on an oblique path. Filtered volume was estimated using calibrated flowmeters. Sampling was restricted to daylight hours (~0600 to 2000 hrs). Sea-surface temperature (SST) and thermal stratification of the shelf of eastern Tasmania was assessed from cruises conducted fortnightly in January 1989, 1990 and 1991, and monthly from February to April in the same years. Temperature ($\pm0.1°$ C) and depth (±0.1 m) were recorded with a temperature/depth probe which was attached to the net during each tow. Surface temperatures were recorded from an on-board temperature recorder ($\pm0.1°$ C). Samples from one side of the bongo were preserved in 95% ethanol, and the other side in buffered 10% seawater formalin. The vertical distribution of larvae was assessed during January 1989 on the mid-shelf station on Transect 5, where a series of six oblique tows was made in order of progressively shallower depths between 78 m and the surface. The net was towed at the desired depth for 10-15 min, with the descent and ascent of the net done as quickly as possible to minimise contamination.
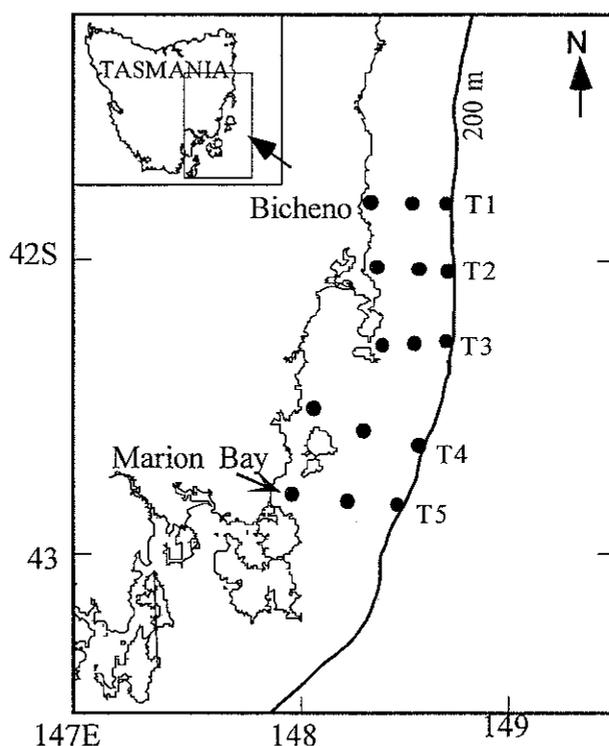
Fig. 2.4 Position of ichthyoplankton sampling stations on five transects (T1-T5) along the east coast of Tasmania. Shelfbreak is represented by the 200 m contour.

2.2 Inshore region

2.2.1 Survey areas

The demersal and larger mobile fish fauna were routinely sampled from soft-sediment habitats in the inshore region in three areas around the coast of Tasmania - Norfolk Bay, Prosser Bay and Georges Bay (Fig. 2.5). Norfolk Bay is a large marine dominated bay situated on the south-east coast of Tasmania linked by a wide entrance (~3.7 km) to Storm Bay via Frederick Henry Bay. It has a small tidal range (~1.3 m) with little estuarine influence. The bay is characterised by a rocky shore composed of sandstone or dolerite and shallow sand embayments, most containing discrete beds of the seagrass *Heterozostera tasmanica* (hereafter referred to as *Heterozostera*) in the 2 to 7 m depth range. However, a more extensive bed of *Heterozostera* exists in a broader area of shallow ground (~5 m deep) on the eastern side of the bay. Small amounts of the seagrass, *Halophila australis* are also present in some embayments, while small, sparse beds of *Zostera muelleri* exist in the intertidal zone in several sand embayments. The center of the bay is characterised by soft-mud sediments and is mainly between 10 and 15 m deep.

Georges Bay is a large coastal lagoon situated on the north-east coast of Tasmania linked by a narrow entrance and extensive barway to the Tasman Sea (Fig. 2.5). It has a small tidal range (~1.3 m) and experiences strong tidal flows in the entrance channel. The bay is characterised by wide sandy embayments separated by rocky headlands composed of sandstone or granite and intertidal mudflats on the northern shore. Seagrass in the bay is predominantly *Heterozostera* occurring in a wide bed along the southern shore, in narrow patchy bed on the north-western shore, and on intertidal sand banks adjacent to the entrance channel. The centre of the bay is dominated by soft mud sediments and is predominantly between 10 and 20 m deep.

Prosser Bay is a semi-exposed marine embayment situated on the central east coast of Tasmania linked to the Tasman Sea via Mercury Passage (Fig. 2.5). The bay has a small tidal range (~1.3m), experiences little estuarine influence and is characterised by moderately exposed sandy beaches separated by rocky headlands composed of sandstone or dolerite. Seagrass is predominantly *Heterozostera* occurring in patchy beds in depths of 1 to 5 m. The mouth of Prosser Bay is sand at around 12 m deep.
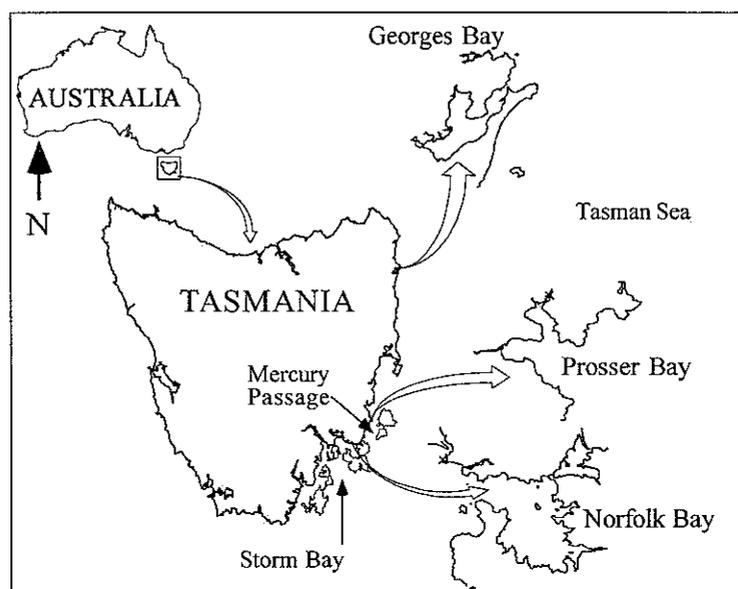
Fig. 2.5 Position of inshore survey areas on the eastern and southern coast of Tasmania.

2.2.2 Sampling gear and regime

2.2.2.1 Beam trawl and gill-net surveys

Several types of sampling gears have traditionally been used in surveys of shallow inshore demersal fish communities, primarily beam trawls (eg. Young 1981, Bell *et al.* 1992, Warburton and Blaber 1992, Ferrell *et al.* 1993) and seine nets (eg. Ferrell and Bell 1991, Connolly 1994, Edgar and Shaw 1995a, Clarke 1997). The choice of inshore sampling gear for this study was dictated by the depth distribution of soft-sediment habitats around Tasmania, particularly deep (8-12 m) unvegetated areas and seagrass beds. Intertidal seagrass beds are extremely limited in distribution, with the exception of a few sparse, seasonally transient *Zostera muelleri* beds in very sheltered estuaries and embayments. The inner margins of *Heterozostera* beds mostly occur greater than 1 to 2 m below the low water mark, and often start outside a wide inner margin (~100 m) of sand with a deep outer margin normally in depths of around 8 m.

The use of beach hauled seine nets for research purposes is considered to be practical in depths of up to 2 m (Gray and Bell 1986), while boat hauled seine systems have been used successfully in depths of up to 5 m (Edgar and Shaw 1995a). As a requirement for the present study was to take comparable samples across all depths at which *Heterozostera* occurs in eastern Tasmania, the use of a beam trawl was considered the best option. Therefore, the demersal fish fauna was sampled at each site with a beam trawl with an opening of 2.0 x 0.9 m. The trawl consisted of a 2.0 m beam (with skids and ground chain) with a 5 m long net with the following specifications: headline length 2.6 m, panel mesh 13 mm, codend liner mesh 7 mm.

Larger and more mobile fishes were sampled with 30 m long multi-panel gillnets comprising three randomly placed 10 m panels of increasing gillmesh size (64, 89 and 108 mm). Two multi-panel gillnets were set overnight at each gillnet site on each sampling occasion being set as close to dusk and retrieved as close to dawn as practical. Details of net specifications are given in Table 2.2. The gillnets were buoyed at both ends and anchored at one end with a 1.5 kilogram lead weight.

Table 2.2 Gill-net specifications for three mesh sizes used in the study

Stretched mesh size (mm)	64	89	108
Mesh drop (no.)	50	40	33
Hanging ratio (%)	50	50	50
Hung length (m)	10	10	10
Hung depth (m)	1.6	1.8	1.8
Monofilament gauge (mm)	0.38	0.45	0.52

2.2.2.2 Specific sampling sites

In each inshore area, sites in the 1 to 12 m depth range were chosen to be representative of unvegetated (mud and sand) and seagrass habitats. Seagrass sites consisted almost exclusively of *Heterozostera tasmanica*. Site characteristics and sampling gear used for all sites in all inshore regions are presented in Table 2.3. Three seagrass and three unvegetated sites were sampled in Norfolk Bay every 2 months from February 1995 to December 1996 (Fig. 2.6). Two seagrass and two unvegetated sites were sampled in Georges Bay (Fig. 2.7), and a single seagrass and unvegetated site in Prosser Bay (Fig. 2.8) seasonally from February to October 1995. At each site beam trawl site three non-overlapping 3 min trawls were conducted at a tow speed of 2 knots. In addition, bottom temperature and salinity were taken on each sampling occasion. All trawl sampling was conducted within 2 hours of high tide. Beam trawl catch rates were calculated as the number of fish per tow. Gillnet catch rates were calculated as the number of fish per hour.

In addition, to assess the temporal patterns of recruitment of juvenile *P. bassensis* and *N. macropterus*, beam trawl sampling was conducted during both day and night at a single site in both North West Bay (NW Bay) and Nutgrove Beach (NB), located in south-east Tasmania (Fig. 2.9, Table 2.4). North West Bay was sampled every two months from March to July 1996 and then monthly until May 1997, while Nutgrove Beach was sampled monthly between October and December 1995. The sampling site in both areas was unvegetated soft-mud between 3 and 10 m deep.
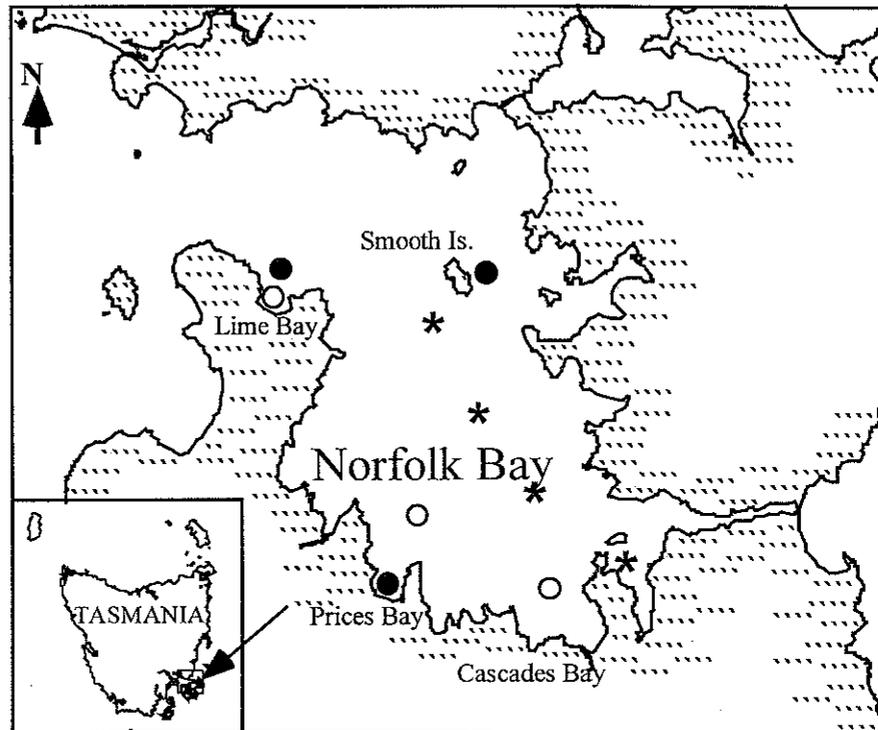
Fig. 2.6 Position of beam trawl and gill-net sampling sites in Norfolk Bay, south-east Tasmania. Dark circles represent *Heterozostera tasmanica* and open circles unvegetated sites. Stars represent ichthyoplankton sampling sites.
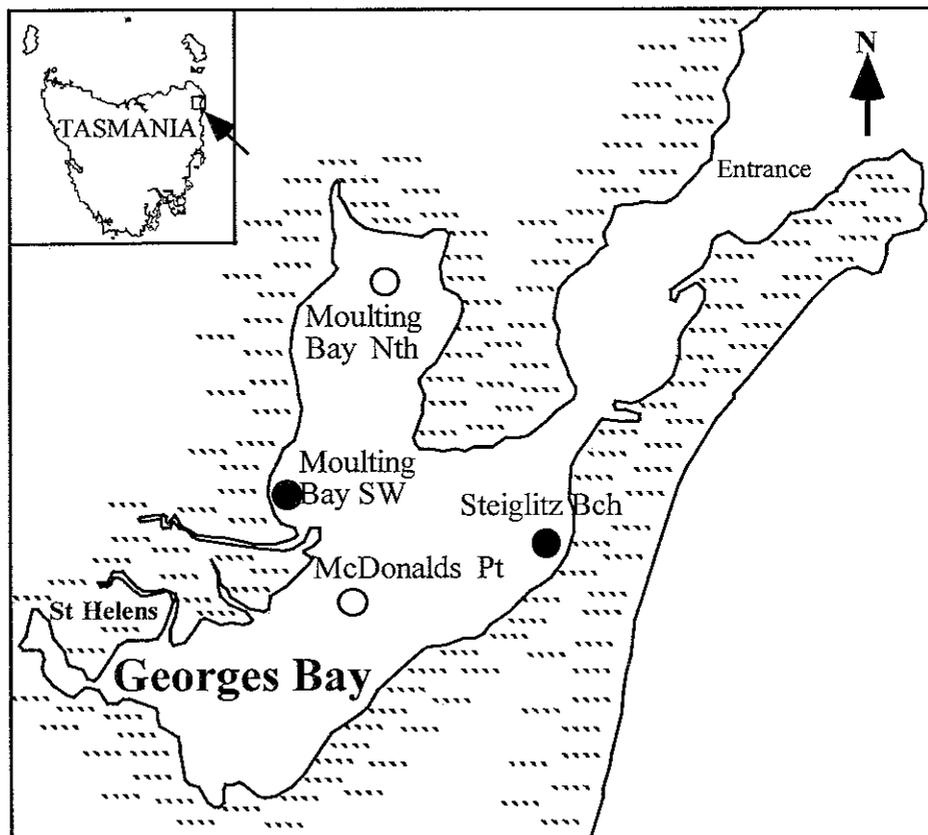
Fig. 2.7 Position of beam trawl and gill-net sampling sites in Georges Bay, north-east Tasmania. Dark circles are *Heterozostera tasmanica* and open circles unvegetated sites.
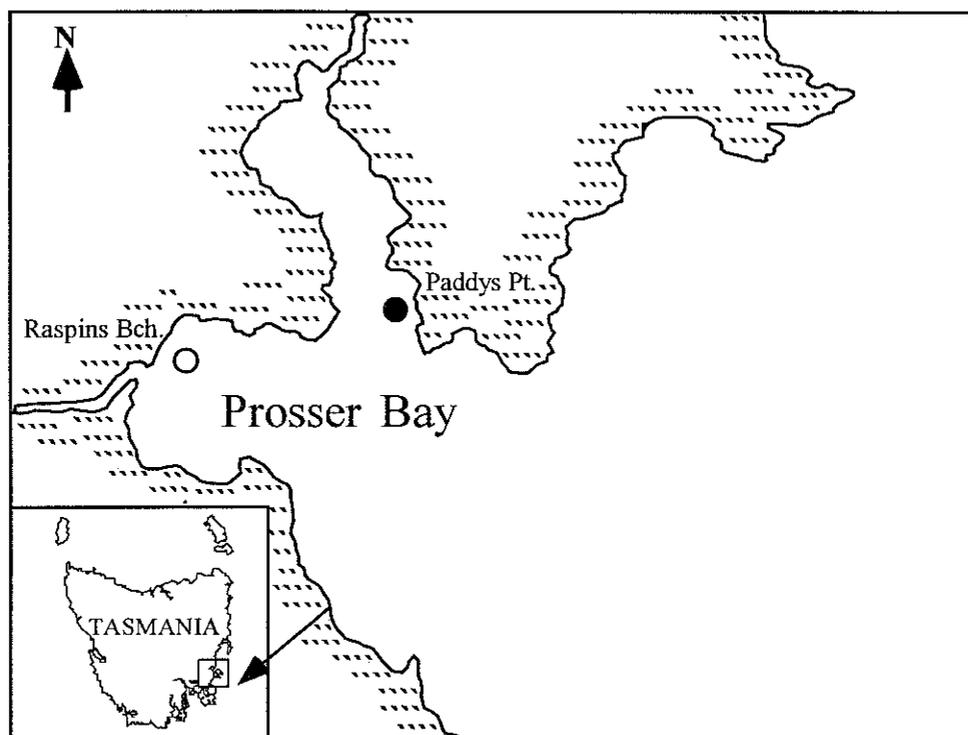
Fig. 2.8 Position of beam trawl and gill-net sampling sites in Prosser Bay, eastern Tasmania. Dark circles represent *Heterozostera tasmanica* and open circles unvegetated sites.

Table 2.3 Habitat characteristics of sites sampled in Norfolk Bay, Georges Bay and Prosser Bay.

Area/Site	Habitat	Seagrass Density	Depth (m)	Gear deployed
Norfolk Bay				
Cascade Bay	Mud		8 - 12	BT, GN
Prices Bay	*Heterozostera*	Medium	3 - 6	BT
Prices Bay	Mud		8 - 12	BT
Lime Bay	*Heterozostera*	Medium	3 - 6	BT, GN
Lime Bay	Sand		1 - 3	BT
Smooth Island	*Heterozostera*	Low	4 - 6	BT
Georges Bay				
Steiglitz Beach	*Heterozostera*	High	2 - 5	BT, GN
McDonalds Pt.	Mud		8 - 12	BT
Moulting Bay Nth	Mud		3 - 5	BT, GN
Moulting Bay SW.	*Heterozostera*	Low	2 - 4	BT
Prosser Bay				
Paddys Point	*Heterozostera*	Low	3 - 5	BT, GN
Raspins Beach	Sand		2 - 4	BT, GN

2.2.2.3 Plankton surveys

The inshore distribution of platycephalid larvae was assessed during ichthyoplankton sampling conducted in October, November and December 1996 at four stations in Norfolk Bay (Fig. 2.6). Samples were collected with a 100 cm diameter ring net with 500 μm mesh. Each station consisted of a single surface and oblique tow to a maximum depth of 15 m (bottom depth permitting), at a tow speed of ~3 knots. During inshore surveys, surface and bottom temperatures were recorded with a temperature/depth probe ($\pm$0.1° C). All other sampling protocols were the same as those previously detailed for plankton sampling conducted on the shelf.

2.2.2.4 Beach seine survey

The demersal fish fauna of nearshore beach habitats were sampled monthly from December 1996 to February 1997 at 27 sites throughout south-eastern Tasmania. The distribution of sampling sites is presented in Fig. 2.9, and site characteristics detailed in Table 2.4. Sites were chosen to be representative of the nearshore zone with varying levels of exposure. The fish fauna was sampled with a 25 m beach seine with a 3 m drop and mesh size of 20 mm. At each site three seine net hauls were conducted parallel to shore sampling an area of 40 m^2. Sampling was conducted within one hour of the high tide.
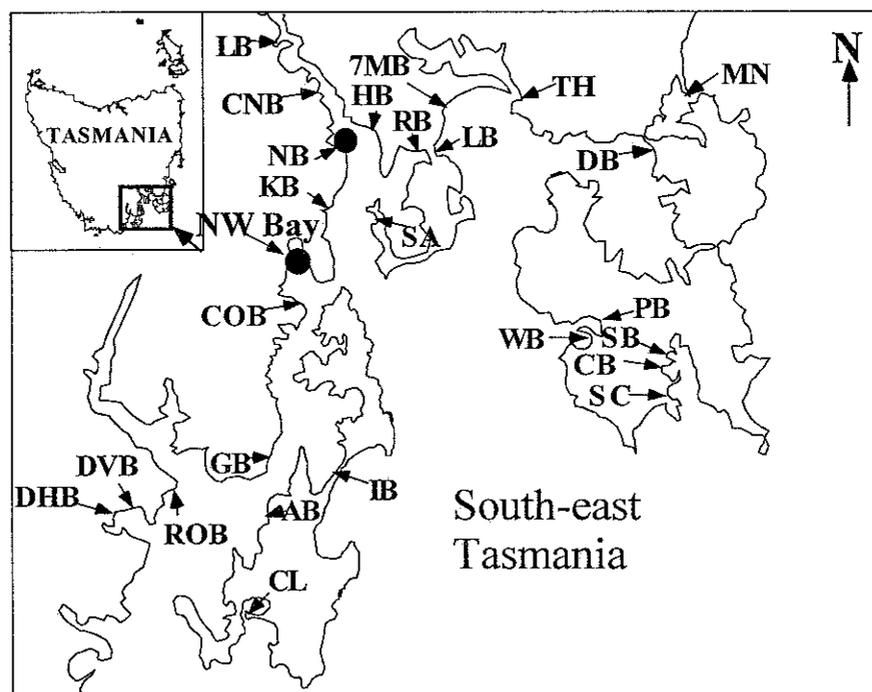
Fig. 2.9 Position of beach seine sampling sites in south-east Tasmania. Details of site codes are presented in Table 2.3. Dark circles represent sites where additional beam trawl sampling was conducted in North West Bay (NW Bay) and Nutgrove Beach (NB).

Table 2.4 Site and habitat characteristics of beach seine sampling sites around south-eastern Tasmania. Site codes are in parentheses.

Site	Substrate	Exposure	Max depth (m)
Coningham Beach (COB)	Sand	Moderate	1.5
Gordon Beach (GB)	Sand/ *Heterozostera*	Moderate	1.0
Roaring Beach (ROB)	Sand	V. high	1.5
Dover Beach (DVB)	Sand/ *Heterozostera*	Moderate	1.5
Dover Hotel Beach (DHB)	Silt / Sand	Low	0.5
Alonnah (AB)	Sand	High	1.0
Cloudy Lagoon (CL)	Sand/ *Heterozostera*	Moderate	1.0
Cloudy Lagoon (CL)	Sand	Low	1.5
Isthmus Bay (IB)	Sand	High	0.5
Lowecroft Bay (LB)	Silt / *Heterozostera*	Low	0.5
Cornelian Bay (CNB)	Silt / Sand	Low	0.5
Nutgrove Beach (NB)	Sand	Moderate	1.5
Kingston Beach (KB)	Sand	High	1.5
North West Bay (NW Bay)	Mud	Low	1.5
Howrah Beach (HB)	Sand	High	1.5
Rokeby Beach (RB)	Silt / Sand	Moderate	1.0
South Arm Beach (SA)	Sand	High	1.5
Lauderdale Beach (LB)	Sand	Moderate	1.5
Seven Mile Beach (7MB)	Sand	High	1.5
Tiger Head Ramp (TH)	*Heterozostera*	Low	1.0
Dunalley Beach (DB)	Sand	High	0.5
Marion Bay Narrows (MN)	Sand/ *Heterozostera*	Moderate	0.5
Parsons Bay (PB)	Silt / Sand	Low	0.5
White Beach (WB)	Sand	High	1.5
Stewarts Bay (SB)	Sand	Low	1.5
Carnarvon Bay (CB)	Sand/ *Heterozostera*	Low	1.0
Safety Cove (SC)	Sand	Moderate	1.5

2.3 Biological data

During shelf trawl surveys, *P. bassensis* and *N. macropterus* were sorted at each station and total catch weight estimated with either a 15 kg or 40 kg clock face scale to the nearest 0.1 kg. In each season, a maximum of 50 fish were retained in each stratum and processed for biologicals back at the laboratory. The remaining fish were sampled for fork length (length of the shortest caudal ray), a minimum of 100 of these by sex, with on-board measurements rounded down to the nearest half centimetre. During inshore beam trawl and gill-net surveys all fish were retained for biologicals. Biological processing for all fish included fork length (FL) (to the nearest millimetre), total weight (to the nearest gram) and sex, gonad stage, and gonad weight (to the nearest gram). Gonads were staged macroscopically according

to the criteria modified from Blackburn and Gartner (1954) (Table 2.5). For
P. bassensis and *N. macropterus* sampled during shelf surveys, sagittal otoliths were
removed from a random sample of 20 fish in each depth stratum each season, while
otoliths were removed from all fish from inshore surveys.

Table 2.5 Macroscopic gonad staging criteria used for *Platycephalus bassensis* and *Nemadactylus macropterus*.

Stage. Category	Macroscopic criteria
FEMALES	
1. Virgin	Small strap, less than 3/4 of body cavity. Firm texture.
2. Maturing Virgin	Virgin - Small strap with rounded edge at least 3/4 of body length, pink and transparent.
	Recovering - as long as body cavity, bloodshot and flabby at posterior.
3. Developing	Almost length of body cavity, opaque and becoming yellow. Ova not discernible.
4. Late Developing	Full length of body cavity, opaque and yellowish pink. Ova discrete.
5. Ripe	Full length of body cavity and swollen occupying all available space. Ovary and ova become translucent.
6. Running ripe	Eggs expressed with slight pressure. Ovary pinkish, clear and granular.
7. Spent	Slack and bloodshot. Few residual oocytes present.
MALES	
1. Virgin	Small strap, less than 3/4 of body cavity. Firm texture.
2. Maturing Virgin	Virgin - Small strap with sharp edge at least 3/4 of body length, pink and opaque.
	Recovering - as long as body cavity, bloodshot and flaccid at posterior.
3. Developing	Almost length of body cavity, opaque and becoming larger.
4. Late Developing	Full length of body cavity and larger.
5. Ripe	Full length of body cavity and swollen occupying all available space. No milt expressed with slight pressure.
6. Running ripe	Milt expressed with slight pressure. Testes granular.
7. Spent	Flaccid and bloodshot.

Chapter 3 Reproductive biology, early life-history and recruitment of sand flathead (*Platycephalus bassensis*)

3.1 Introduction

While there are 60 species of platycephalids distributed primarily in estuarine and coastal waters of the Indo-Pacific, the early life history stages have been poorly described. Larval descriptions have been given for *Platycephalus indicus* and *Onigocia spinosa* from Japan (Fujita and Ueno 1956, Chang *et al.* 1980, Kojima 1988) and *Kumococcius detrusus* from China (Zhang *et al.* 1985). Around 41 species are known to occur in Australia, of which 13 species are found in temperate waters (Paxton and Hanley 1989, Keenan 1991, Gomon *et al.* 1994). Despite their commercial and recreational importance in these waters (Kailola *et al.* 1993), descriptions are given for only two species, *P. speculator* (Hyndes *et al.* 1992a) and *P. fuscus* (Neira and Miskiewicz 1998). Larvae are pelagic, and characterised by a large depressed head with extensive spination, large, fan shaped pectoral fins and 25-28 myomeres (Neira and Miskiewicz 1998).

The lack of detailed early life-history studies on platycephalids has resulted in little information on patterns of spawning and larval distribution. Two unidentified species of platycephalids larvae were identified in Port Phillip Bay, Victoria, with larvae present in most months of the year (Jenkins 1986). The vertical distribution of *Platycephalus* spp. and *P. fuscus* larvae have been reported from coastal waters off New South Wales (Gray *et al.* 1992). In addition, little is known on the reproductive biology of platycephalids, with only limited data available on *Neoplatycephalus richardsoni* (Fairbridge 1951, Hobday and Wankowski 1987a, Jordan 1997), *P. speculator* (Hyndes *et al.* 1992a) and *P. bassensis*, *P. fuscus* and *P. speculator* (Brown 1978). In the most detailed study, Hyndes *et al.* (1992a) found *P. speculator* to be a multiple spawner, with males and females reaching maturity at the end of their first and second years respectively, with spawning occurring in estuaries in summer and early autumn (December to March).

Platycephalus bassensis is found from the central coast of New South Wales to eastern South Australia, but is most common in southern New South Wales, Victoria and Tasmania (Gomon *et al.* 1994). The species occurs on sandy and muddy substrates down to 100 m but are most common in shallow coastal waters less than

65 m. Brown (1978) reported spawning of *P. bassensis* to occur between August and October in Port Phillip Bay, with all fish mature by 22 cm. While *P. bassensis* are known to spawn in coastal embayments (Brown 1978), shelf spawning has not been previously identified.

Given the lack of information on the reproductive biology and early life-history of *Platycephalus bassensis,* the aim of this chapter is to (1) estimate the size at sexual maturity for male and female *P. bassensis*, (2) describe the pattern of gonadal and larval development (3) examine the spatial patterns of shelf hydrography and larval distribution, and (4) examine temporal patterns of juvenile recruitment.

3.2 Methods

3.2.1 Survey areas and sampling regime

Full details of survey areas and times, and sampling gear for both shelf and inshore surveys is presented in Chapter 2. In brief, *Platycephalus bassensis* were sampled seasonally on the inner-shelf (10-50 m) and mid-shelf (50-100 m) regions of Storm Bay and eastern Tasmania in eight out of the nine seasons between summer 1993 and summer 1995. *P. bassensis* were also sampled from inshore (0-12 m) soft-sediment habitats in three areas around the coast of Tasmania (Norfolk Bay, Prosser Bay, and Georges Bay) using a beam trawl and gill-nets. Six sites were sampled in Norfolk Bay every two months from February 1995 to December 1996 while two sites were sampled in Prosser Bay and four in Georges Bay seasonally from February 1995 to October 1995. During both shelf and inshore surveys all *P. bassensis* were retained and processed for biologicals in the laboratory.

In addition, the distribution of platycephalid larvae on the shelf of eastern Tasmania was determined from plankton samples collected at three fixed cross-shelf stations on five transects from Bicheno in the north (Transect 1) to Lagoon Bay in the south (Transect 5). Full details on survey design, and sampling gear and deployment is presented in Chapter 2. In brief, samples were collected from oblique tows with a 45cm diameter bongo net with 500 μm mesh on two occasions in January 1989 and 1990. The depth distribution of larvae was assessed at the mid-shelf station on Transect 5 in January 1989, where a series of six oblique tows was made in order of progressively shallower depths between 78 m and the surface.

The inshore distribution of platycephalid larvae was assessed during ichthyoplankton sampling conducted in October, November and December 1996 at four stations in Norfolk Bay. Samples were collected with a 100 cm diameter ring net with 500 μm mesh with each station consisting of a surface and oblique tow to a maximum depth of 15 m (bottom depth permitting), at a tow speed of ~3 knots. During shelf and inshore surveys, water temperature ($\pm$0.1°C) and depth ($\pm$0.1 m) were recorded with a temperature/depth probe which was attached to the net during each tow. Surface temperatures were recorded from the on-board temperature recorder ($\pm$0.1°C).

In addition, in order to monitor temporal patterns of recruitment, beam trawl sampling of juvenile *P. bassensis* was conducted at a single site in North West Bay every two months from March to July 1996, and then monthly until May 1997. The site was unvegetated and consisted of soft-mud between 3-10 m deep.

3.2.2 Laboratory procedures

Platycephalus bassensis from both shelf and inshore surveys were processed for biological data, including fork length (FL) (to the nearest millimetre), total weight (to the nearest gram) and sex, gonad stage and gonad weight (to the nearest gram).

Gonosomatic index (GSI) was calculated using the formula:

$$GSI = \frac{gonad\ weight}{somatic\ weight} \times 100$$

Gonads were staged macroscopically according to the criteria modified from Blackburn and Gartner (1954) (see Section 2.3, Table 2.4). Size at sexual maturity was defined as the fork length at which 50% of males and females collected over the spawning season were mature. Ovaries and testes were considered mature if their gonads were equivalent to Stage 3 or greater.

Sagittal otoliths were removed from all *P. bassensis* <12 cm, cleaned ,dried and stored in envelopes prior to processing. In addition, lapilli were removed from a sample of 20 fish <7 cm and mounted on a microscope slide in a drop of mounting medium. Lapilli were examined whole while 20 sagittae were transversely sectioned to ~100μm thick and viewed under transmitted light at x920 and x2360 magnification, using a video system fitted to a compound microscope. Full details of sagittal sectioning is presented in Chapter 5.

Platycephalid larvae were sorted from plankton samples in a rotatable sorting ring under a dissecting microscope. All unspecified body lengths refer to notochord length (NL) in preflexion and flexion larvae (tip of the snout to the posterior end of the notochord), and to standard length (SL) (i.e. tip of the snout to the posterior region of the hypural plate) in postflexion larvae and juveniles. All measurements are expressed as mean percentage of body length. Pre-anal length is defined as the horizontal distance from the tip of the snout to the anterior origin of the anal fin or anal-fin anlagen. Pectoral-fin length is defined as the distance from the pectoral-fin base to the posterior tip of the longest pectoral ray. Body depth at pectoral is equivalent to 'body depth' of Leis and Rennis (1983). Other definitions, such as body shape, follow Leis and Trnski (1989). Nomenclature of head spination follows that of Moser and Ahlstrom (1978). Larval measurements were made using an ocular micrometer, while juveniles were measured with vernier calipers. Larval drawings were made with the aid of a camera lucida.

3.3 Results

3.3.1 Size at maturity

Platycephalus bassensis were considered mature if macroscopic staging showed at least the presence of developing oocytes in females and developing testes in males (Stage 3 or greater). The smallest male and female *P. bassensis* to reach maturity were 19.0 and 20.0 cm, respectively (Fig. 3.1). All males larger than 24.5 cm and all females larger than 29.5 cm were mature. A comparison of the proportion of mature fish in each 0.5 cm size-class collected over the spawning season reveals that 50% of males and females were mature by 21.0 and 23.5 cm, respectively.
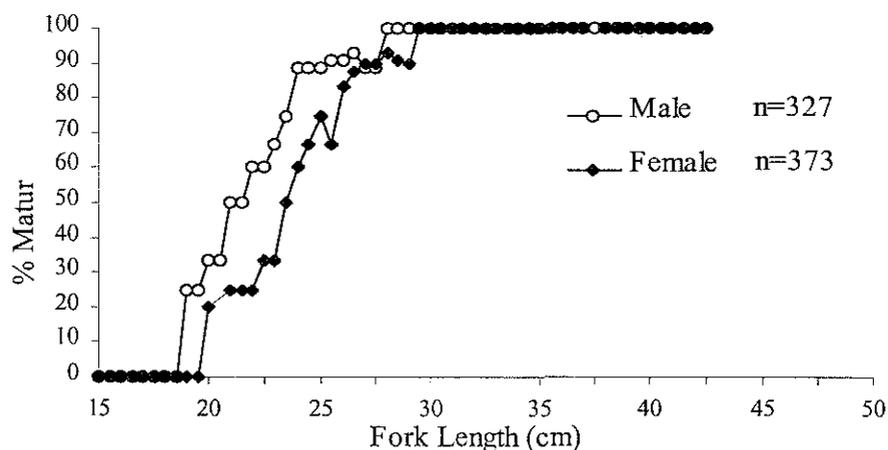
Fig 3.1 Proportion of mature male and female *Platycephalus bassensis* by 0.5 cm size-classes. n is sample size.

3.3.2 Gonadal development

Trends in mean gonadosomatic (GSI) for male and female *Platycephalus bassensis* were analysed seasonally from the shelf region between January 1993 and January 1995, and monthly from inshore regions from February 1995 to February 1997. Seasonal and monthly mean GSI's showed the same overall trend for both males and females (Fig. 3.2). Mean female GSI's rose from minimum values in May to a peak in October in both years before declining through to low values by March. Mean male GSI's exhibited similar trends. While values for males decreased rapidly from October to November in 1996 before increasing again in December, this trend reflects the small sample size in November in both years rather than indicating a period of reduced spawning activity in that month.
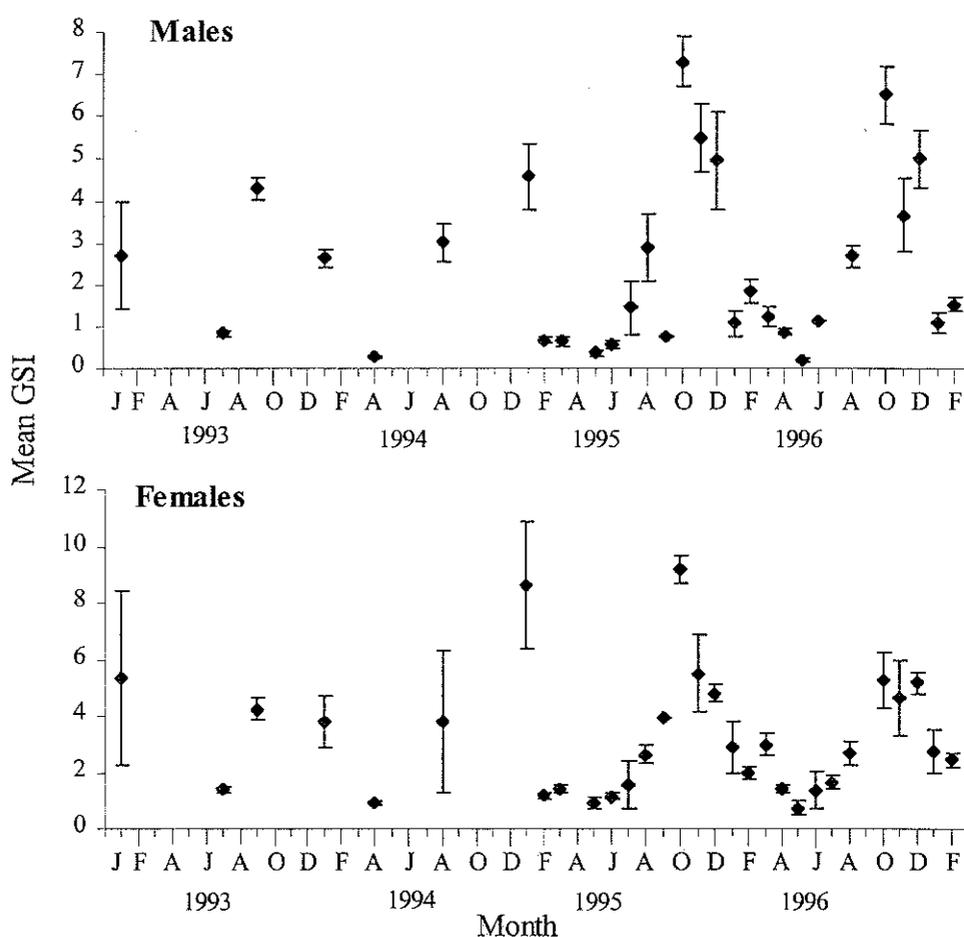
Fig. 3.2 Mean gonadosomatic indices (GSI) for male and female *Platycephalus bassensis* caught on the shelf between January 1993 and January 1995, and inshore between February 1995 and February 1997. Error bars are standard error.

The temporal patterns of spawning from the GSI's is also reflected in the monthly trend in gonad stages, with all males and females in the resting phase (stage 2) from

April to June, and ripe, running ripe and spent fish ($\geq$ stage 5) present from October to March (Fig. 3.3). The decrease in GSI's from October through to March reflects the increasing proportion of spent (stage 7) and recovering (stage 2) fish through these months and indicates that an increasing proportion of the population completes spawning after December. Mean GSI values for both males and females from the shelf in January 1993, 1994 and 1995 were consistently higher than those from inshore in January 1996 and 1997. Either the peak in spawning occurred earlier in the later two years or *P. bassensis* on the shelf spawn for longer than those inshore. Gonads reached a maximum of 10.2% and 18.7% of total body weight for males and females, respectively, during the spawning season.
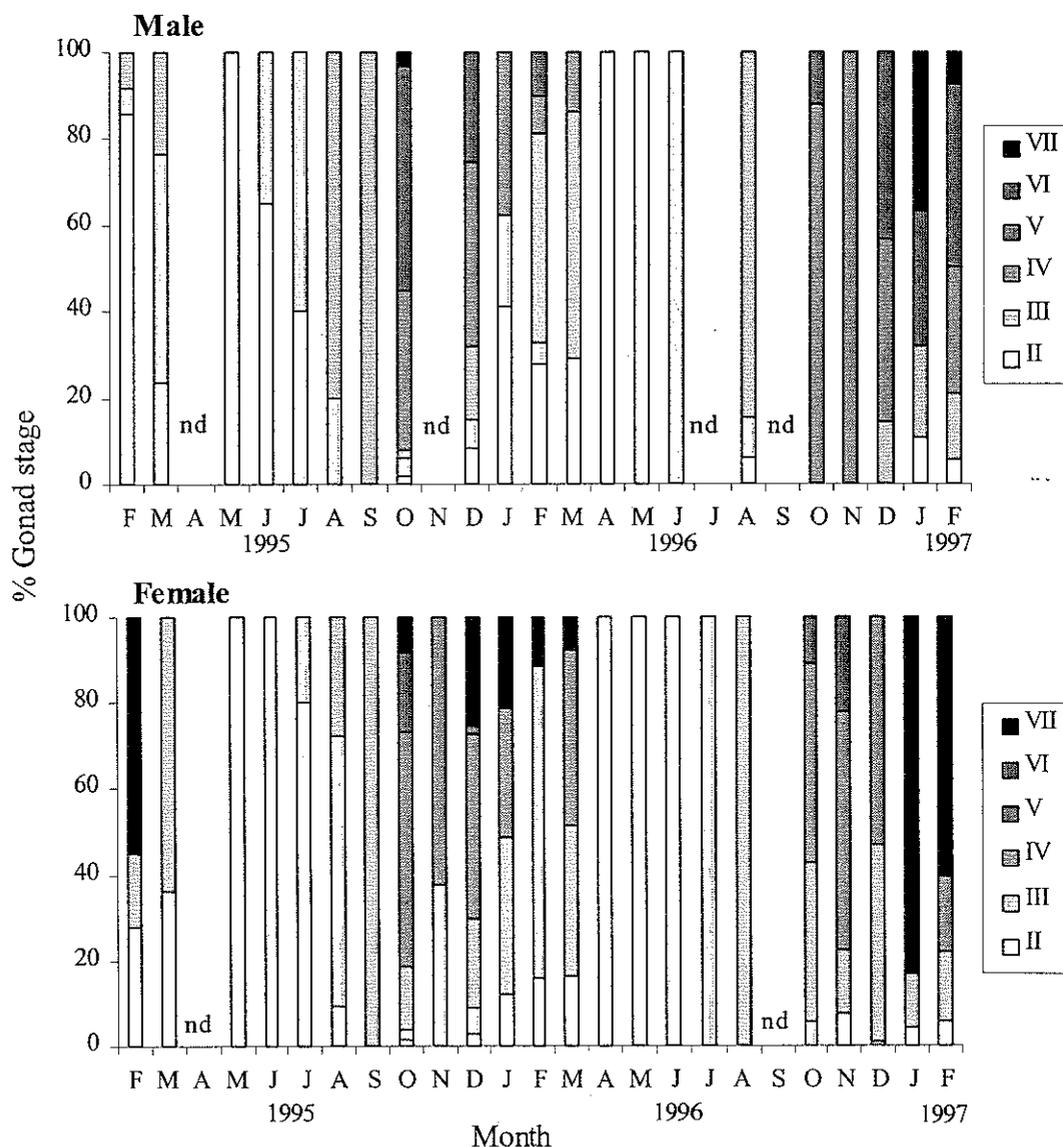
Fig 3.3 Monthly gonad stage percentages for male and female *Platycephalus bassensis* caught inshore between February 1995 and February 1997.

3.3.3 Shelf hydrography

Sea-surface temperatures on the shelf of eastern Tasmania during January of 1989 and 1990 reflected both seasonal warming, and the changing influence of warmer northerly, and cooler southerly water on the shelf (Fig. 3.4A-B). Temperatures showed variations both along the coast and across the shelf, reflecting the fact that warmer northerly waters originated offshore and at times moved south-west onto the shelf. In early January 1989, sea-surface temperatures ranged from 15.9° to 17.4° C, with warmest water on the outer shelf (Fig. 3.4A). By late January 1989, temperatures varied by up to 2.4° C across the shelf, with evidence of an influx of warm water over the shelf-break from the north-east. The warmer water of northerly origin is East Australian Current (EAC) water, characterised by the 17° C isotherm, and is clearly identified in satellite images of sea-surface temperature (Fig. 3.5). This image represents the distribution of sea-surface temperatures one week after the late January survey period and clearly indicates a continued onshore movement of warm EAC water which had flooded the entire shelf of eastern Tasmania by the end of January 1989.

In early January 1990, sea-surface temperatures on the shelf were between 16.0° and 17.1° C, with little variation along the coast (Fig. 3.4B). By late January most of the shelf was between 16.4° and 17.0° C, with evidence of warmer EAC water moving onto the shelf from the north-east. The satellite image for late January 1990 shows a filament of EAC water along most of the outer-shelf of the east coast with cooler waters of subantarctic origin dominating inshore (Fig. 3.5).

Vertical temperature structure of the shelf from Transect 5 in January of 1989 and 1990 reveals interannual differences in the extent of thermal stratification (Fig. 3.6A-B). In January 1989, a strong thermocline is evident across the entire shelf between warm water of northerly origin and cooler bottom water, forming a shallow (~30 m) mixed layer. In January 1990, shelf waters were only weakly stratified with evidence of a weak thermocline at around 60 m.
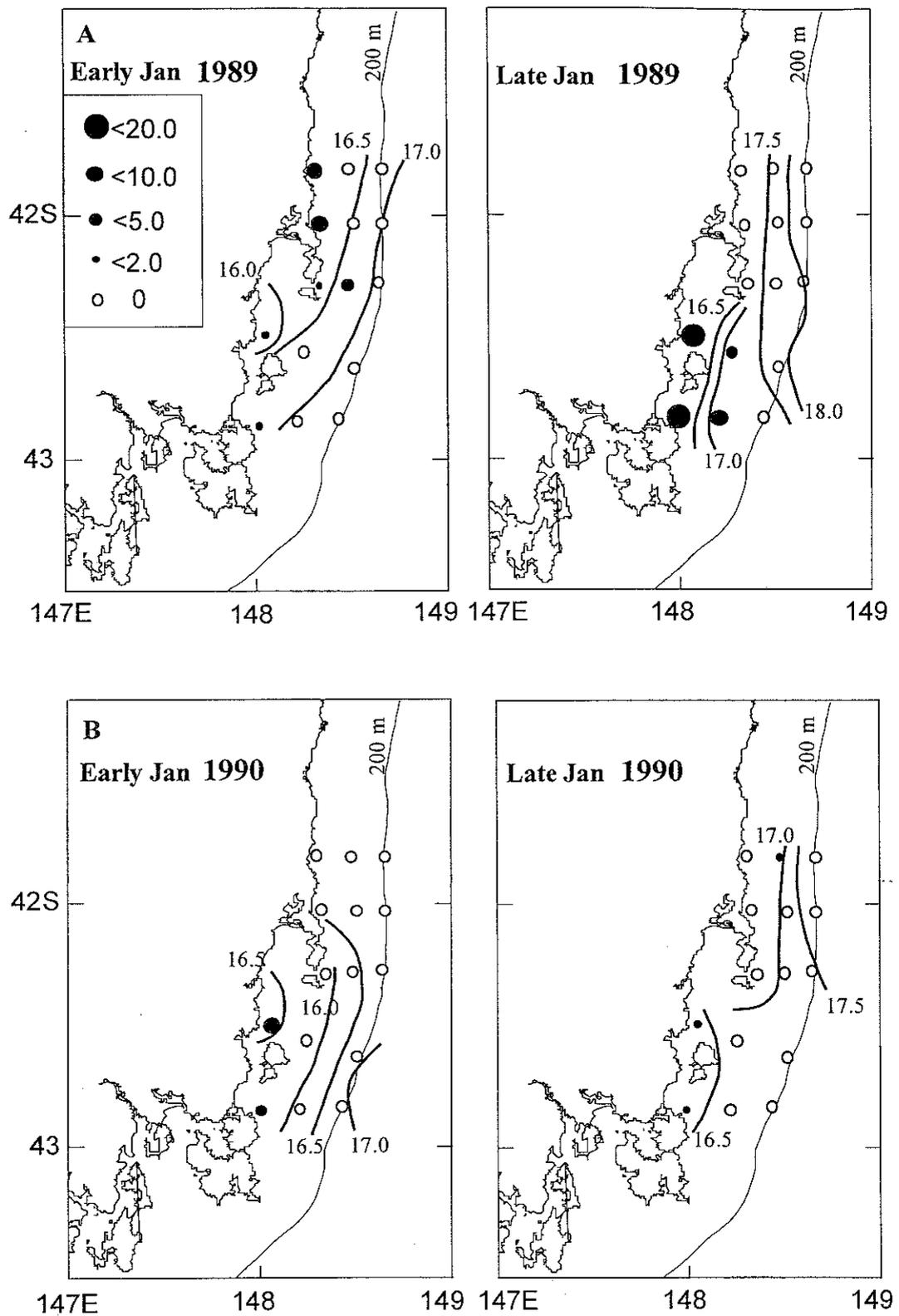
Fig. 3.4 *Platycephalus bassensis* larval concentrations (N.200m^{-3}) and sea-surface temperatures ($^{\circ}$ C) during early and late January of (A) 1989 and (B) 1990 on the shelf of eastern Tasmania.
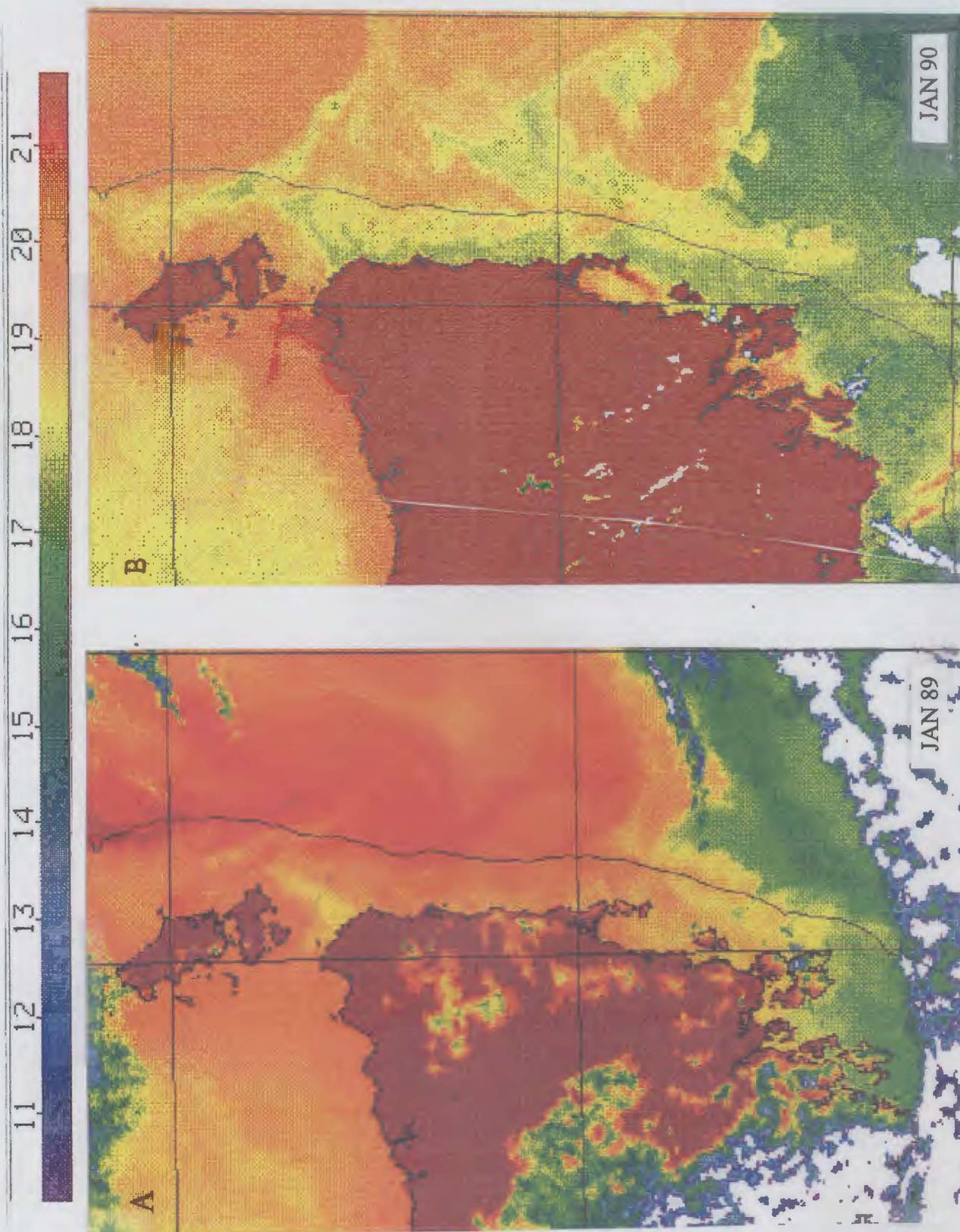
Fig. 3.5 Satellite image of sea-surface temperature of eastern Tasmania taken on (A) 29 January 1989 and (B) 23 January 1990. Land red; cloud white. The shelfbreak is represented by the dark line along the 200 m contour.
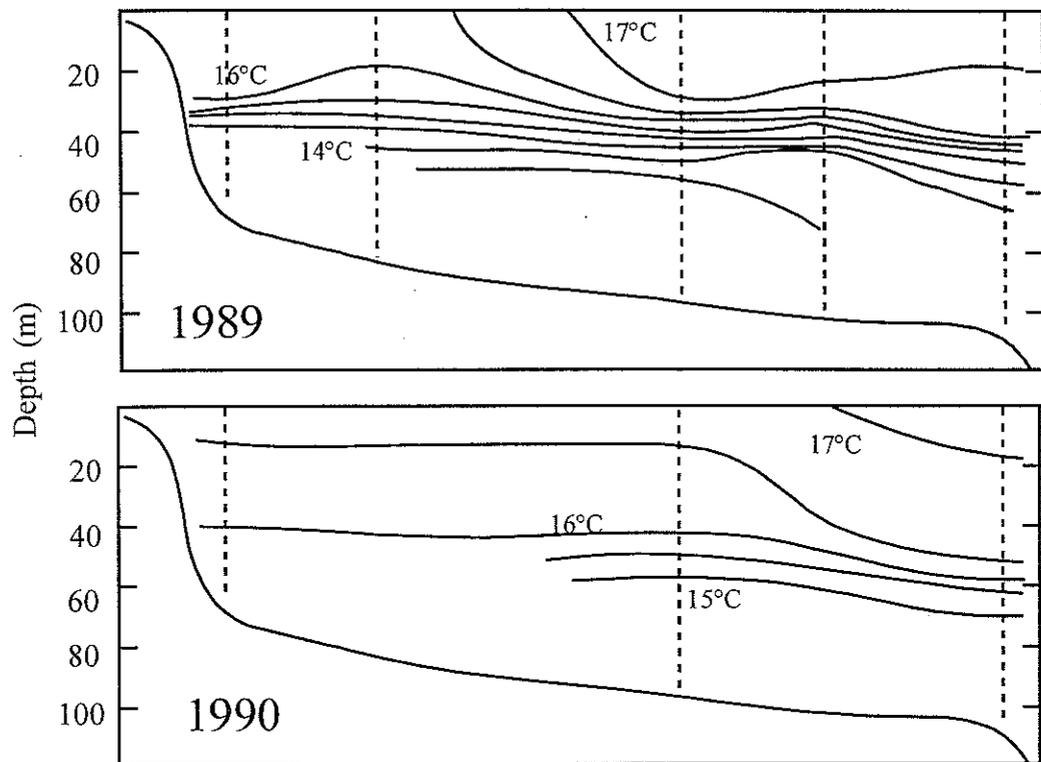
Fig. 3.6 Vertical sections of temperature(^{o} C) across Transect 5 in (A) early January 1989 and (B) early January 1990.
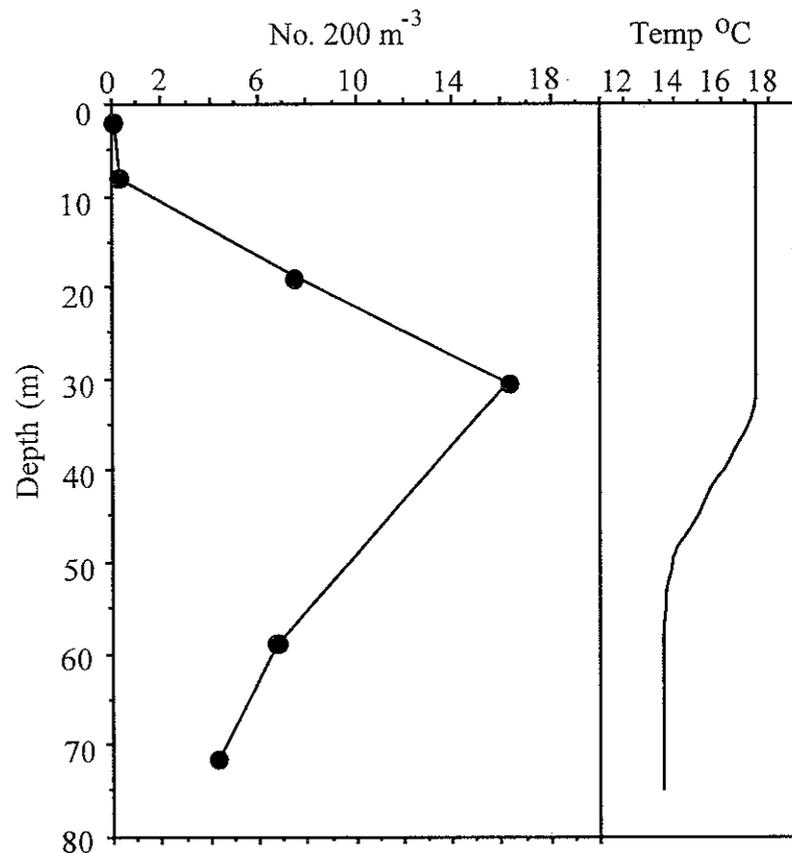
Fig. 3.7 Vertical distribution of *Platycephalus bassensis* larvae at the mid-shelf station on Transect 5 in late January 1989.

3.3.4 Shelf larval distribution

Platycephalus bassensis larvae were caught in January of 1989 and 1990 on the shelf of eastern Tasmania (Fig. 3.4A-B). Highest larval densities occurred almost exclusively at inshore stations on all transects in both years, with maximum densities of 14 larvae.200 m^{-3} at the inshore station on transect 4 in late January 1989. No larvae were caught at shelf-break stations in either year. Larvae in January 1989 were vertically stratified in the water column with highest densities occurring at 20-30 m, just above the thermocline (Fig. 3.7). The overestimate of abundances at depth due to contamination is expected to be minimal due to the small proportion of time the net sampled the non-targeted depths.

3.3.5 Inshore hydrography

Sea-surface temperatures in Norfolk Bay between February 1995 and 1997 reflected the seasonal cycle of warming and cooling. Mean temperatures reached a minimum of 8.2° C in August 1995, rising to a maximum of 17.4° C in February 1996 (Fig. 3.8). There was no indication of differences between years in either minimum or maximum temperatures.
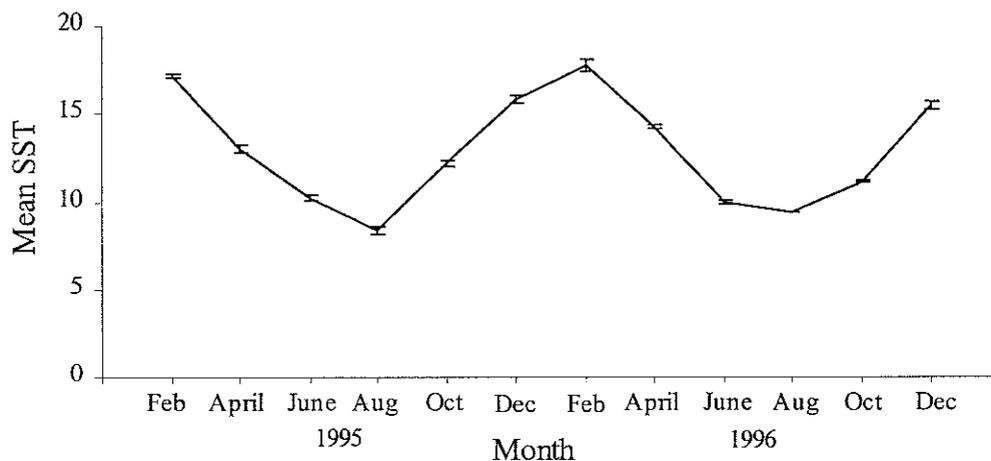
Fig. 3.8. Mean sea surface temperature (SST) (° C) of sampling sites in Norfolk Bay between February 1995 and December 1996. Error bars are standard error.

3.3.6 Inshore larval distribution

Despite sampling in Norfolk Bay during the three months of peak spawning activity (Oct-Dec), *P. bassensis* larvae were only caught in November 1996. At that time larvae were present at all four stations, although densities were highest in the middle of the bay peaking at 35 larvae.200m^{-3} (Fig. 3.9). All *P. bassensis* larvae were caught in oblique tows.
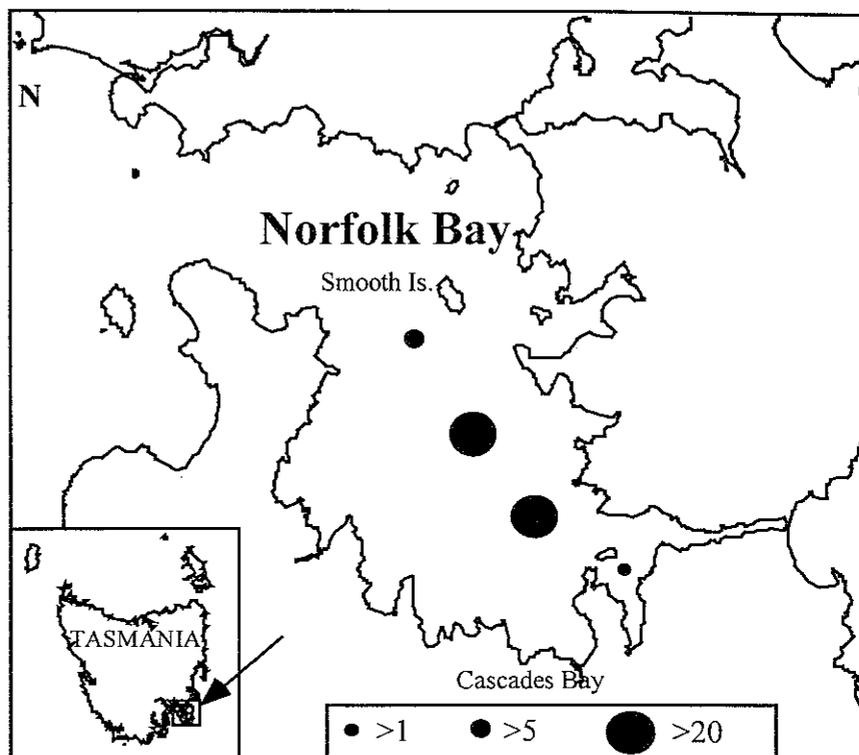
Fig. 3.9 *Platycephalus bassensis* larval concentrations (N.200m^{-3}) in Norfolk Bay in November 1996.

3.3.7 Larval development

3.3.7.1 Identification

Identification of larvae to the family Platycephalidae was based on a combination of characters including a large and wide head with extensive spination, moderate to large, fan shaped pectoral fins and the presence of 26-28 myomeres (Neira and Miskiewicz 1998). Identification to species using meristic characters is difficult as there are few differences between species (Table 3.1). Larvae were identified as those of *Platycephalus bassensis* by comparison with adult characters, distributions and spawning times, and the establishment of a developmental series.

Despite extensive sampling of shelf and inshore waters of southern and eastern Tasmania in the present study, no juvenile or adult specimens of *Neoplatycephalus aurimaculatus, Platycephalus speculator* and *P. laevigatus* were recorded, and these species appear to be restricted to waters of Bass Strait and northern Tasmania. While *N. richardsoni* are common on the shelf of southern and eastern Tasmania, spawning occurs during summer with no evidence of spring spawning (Jordan 1997). A single series of platycephalid larvae were present in samples taken in Norfolk Bay during the period of peak spawning activity of *P. bassensis* (November), strongly suggesting

they are the larvae of *P. bassensis*. A second developmental series of platycephalid larvae was present in the eastern Tasmanian shelf samples taken in January 1989 and 1990, and was characterised by melanophores on the dorsal surface of the trunk in all stages, and the presence of large teeth on the lower jaw and roof of the mouth in flexion and postflexion larvae. The presence of strong teeth is a diagnostic character of the genus *Neoplatycephalus* (Gomon *et al*. 1994), indicating that this second series were larvae of this genus.

Table 3.1   Meristic characters of platycephalid species present in Tasmanian waters. Collated from Gomon *et al*. (1994).

	D	A	P1	P2	C	Vertebrae
Neoplatycephalus richardsoni	VIII-IX,14	14	19-20	I,5	15	-
Neoplatycephalus aurimaculatus	IX,14	14	16-20	I,5	15	-
Platycephalus bassensis	VIII-IX,14	14	19-20	I,5	15	27
Platycephalus speculator	VIII,14	14	19-21	I,5	15	27
Platycephalus laevigatus	IX,14-15	14-15	18-21	I,5	15	27

3.3.7.2 Morphology

Larvae of *Platycephalus bassensis* are pelagic. The smallest *P. bassensis* larvae examined (3.0 mm) had a functional mouth and coiled gut with yolk absorption complete. The head is small and compressed in preflexion larvae (HL = 24%), but becomes moderate during flexion (Table 3.2, Fig. 3.10A-D). The mouth is large, reaching to approximately the centre of the eye in all larval stages, while the snout increases in length and becomes flatter during flexion. There are no strong teeth on the roof of the mouth or lower jaw in any stage. A small gas bladder was inflated and visible above the foregut in preflexion and flexion larvae. The body depth is moderate (BD=19-21%) with little change in body shape during larval development. Pectoral fins are moderate and fan shaped increasing in size during flexion. Notochord flexion commences at 6.0 mm and is almost complete in the largest larvae examined (8.4 mm). Larvae have 27 myomeres (10~11+16~17).

Table 3.2   Body proportions of *Platycephalus bassensis* larvae (expressed as mean percentage of body length, with standard deviations in parentheses; n = number of individuals). Specimens below dashed line are undergoing notochord flexion.

Size range (mm)	n	Pre-anal length	Body depth at pectoral	Head length	Pectoral-fin length
3.01-4.00	7	43.5 (3.5)	21.2 (2.8)	24.0 (1.3)	11.3 (0.9)
4.01-5.00	25	46.1 (3.0)	19.6 (0.9)	26.3 (1.7)	12.8 (1.1)
5.01-6.00	18	49.4 (2.0)	18.9 (0.4)	27.5 (1.5)	14.9 (1.0)
6.01-8.39	15	51.0 (1.4)	20.9 (1.4)	30.5 (1.8)	17.5 (0.9)

3.3.7.3 Fin development

Development of the pectoral fins is precocious with 1-2 incipient rays present in the smallest larvae examined (3.0 mm), ossification commencing in late preflexion larvae (5.4 mm) (Fig. 3.10). The pectorals have a full complement of 19-20 rays and reaching up to 17.5 % of body length during flexion (7.4 mm). Pelvic fin buds are visible in 5.9-6.0 mm larvae as small swellings either side of the gut. The pelvics develop rapidly, having a full complement of I,5 rays by 8.4 mm. Anlagen of both anal and second dorsal fins appear early during flexion with distinct bases present by 7.0 mm. Incipient rays first appear by 7.4 mm with up to 12 rays ossified in the largest larva examined (8.4 mm). The first dorsal fin anlagen first appears by 7.4 mm with 5 spines ossified by 8.4 mm. The caudal fin anlagen first appears on the ventral surface of the notochord immediately prior to flexion (5.8 mm) with a total of 10 rays ossified by 8.4 mm.

3.3.7.4 Spination

One small anterior preopercular spine was present in the smallest larvae examined (3.0 mm), with two present by 3.5 mm (Fig. 3.10). A single posterior preopercular spine is present by 3.5 mm, increasing to four immediately prior to flexion (5.9 mm), with the second and third spines becoming the longest. A single parietal spine develops at about 4.0 mm, with a further small spine appearing on the anterior portion of the spine by 5.1 mm. A small supraocular spine is visible by 5.8 mm and remains small after settlement.

3.3.7.5 Pigmentation

Pigment appears at the tip of the upper and lower jaws and snout by 3.5 mm and remains moderate during flexion (Fig. 3.10). Several scattered melanophores appear on the preopercle by 5.2 mm and on the dorsal surface of the head by about 5.9 mm. A single row of 13-17 melanophores is present on the ventral surface of the tail and 5-9 small melanophores on the ventral surface of the gut in all larval stages. Numerous small melanophores are present on the posterior portion of the gut in preflexion larvae, increasing in number during flexion. Pigment on the pectoral fin appears in early preflexion larvae and is restricted to the upper fin rays, with the lower rays remaining unpigmented. Internal pigment is present on the dorsal surface of the gas bladder during all larval stages.
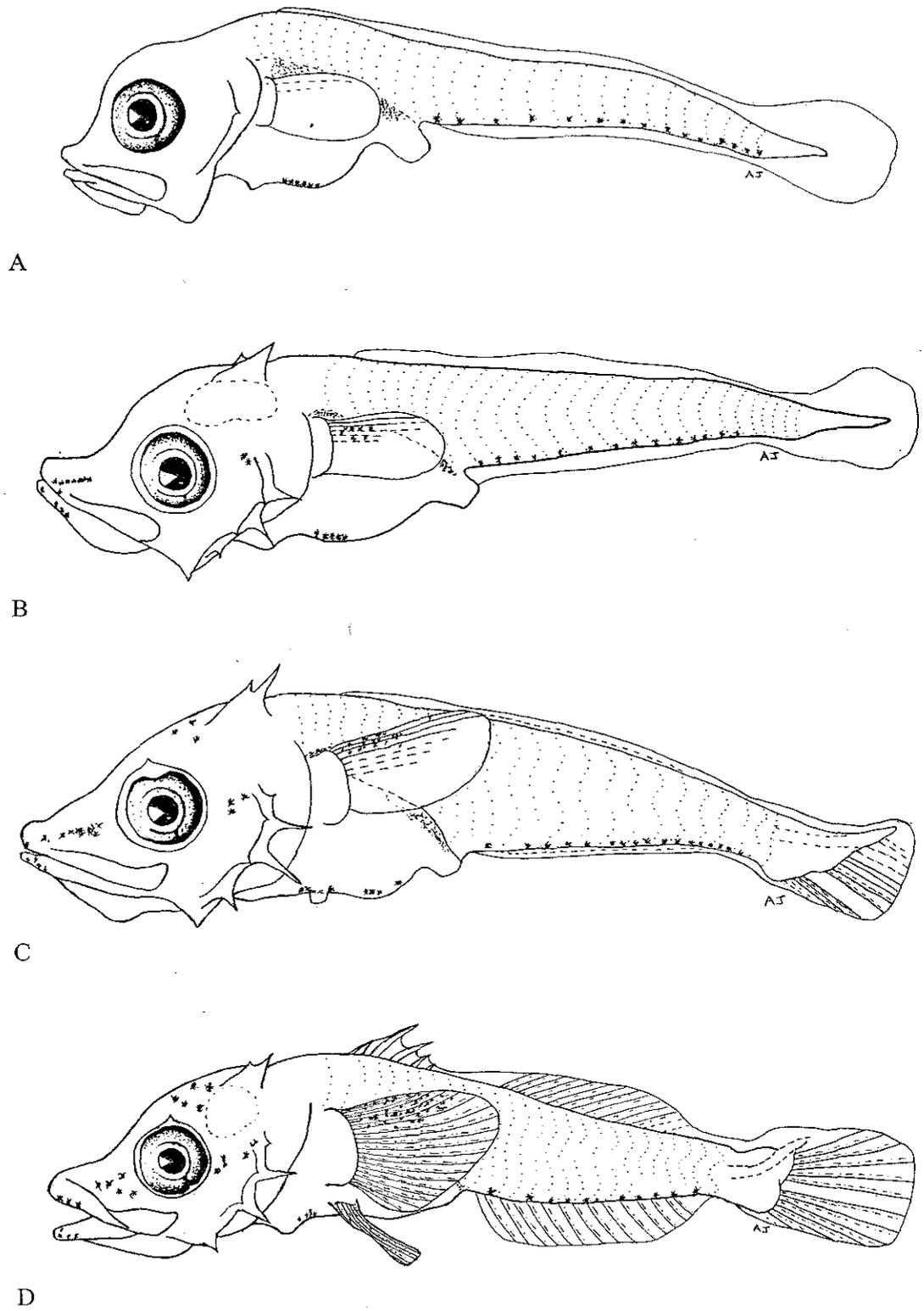
Fig. 3.10 Developmental stages of *Platycephalus bassensis* larvae: (A) 3.0 mm (B) 5.7 mm, (C) 7.1 mm and (D) 8.5 mm.

3.3.8 Recruitment

Length-frequency distributions of juvenile *Platycephalus bassensis* from North West Bay are dominated by a single cohort from March to December 1996, although in some months there is some evidence of bimodal distribution within this cohort (Fig. 3.11). This cohort had a mean length of 7.6 cm in March 1996 and represents 0+ fish from spawning that took place the previous spring and summer. The broad range of lengths (5.6 - 9.6 cm) suggests that settlement occurred over an extended period. The earliest month settlement was recorded was January, although lengths ranged from 2.3 to 7.4 cm in that month suggesting settlement had begun some time earlier. The lack of new recruits in December may reflect the smaller sample size in that month. Two additional cohorts with mean lengths of 13.7 cm and 19.0 cm were present in January 1997, representing the 1+ and 2+ age-classes. Modal progressions of the 0+ age-class in both years indicates growth is at a maximum until around May, with little increase in length until October when growth resumes (Fig. 3.11).

In order to provide a more detailed analysis on age at settlement, growth rates and backcalculated temporal distribution of spawning dates, the otolith microstructure from 40 0+ *P. bassensis* were examined. Despite detailed examination of both whole polished lapillus and transversely sectioned sagittae from fish ranging from 2.3 to 10.0 cm, no consistent increment structure could be read from either otolith. While small sections of microincrements could be discriminated, no consistent increment counts could be made from the primordium to the otolith edge.
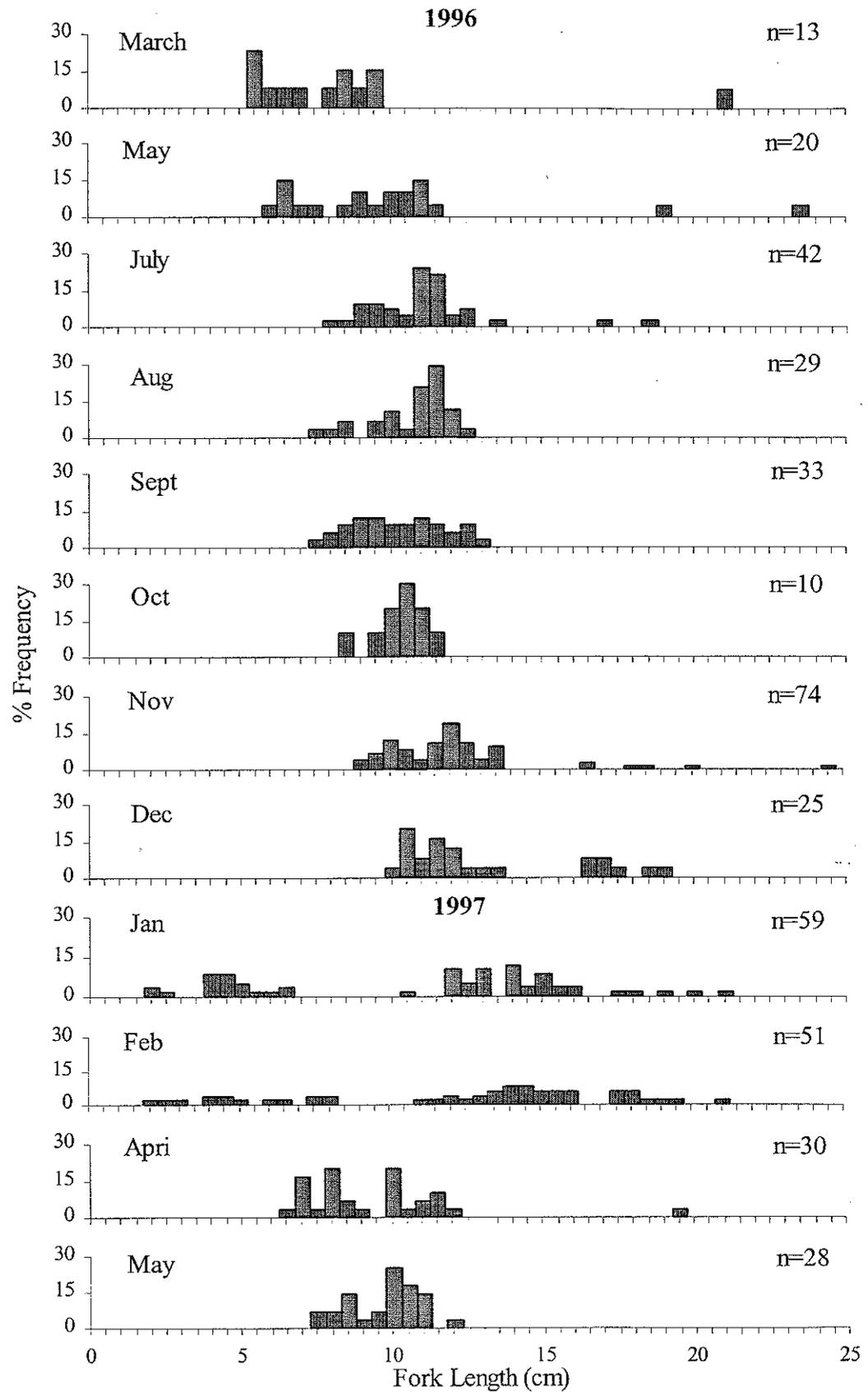
Fig. 3.11 Length-frequency distributions of juvenile *Platycephalus bassensis* from North West Bay between March 1996 and May 1997. n is sample size.

3.4 Discussion

3.4.1 Size at maturity

In the present study, the size at 50% maturity for male and female *Platycephalus bassensis* was 21.0 and 23.5 cm, respectively. While this is consistent with the size at maturity of *P. bassensis* in Port Phillip Bay, Victoria of around 20-21 cm (Brown 1978), this length was determined by comparing GSI and fork length, and hence represents the lower size limit. The difference between the smallest and largest *P. bassensis* to reach maturity (males 19.0-24.5 cm and females 20.0-29.5 cm), indicates a broad range of sizes at which sexual maturity may occur. Such variations in body size at first sexual maturity are common to fishes (Nikolskii 1969), and may be related to variations in size at age resulting from differences in juvenile growth rate or extended spawning seasons. Variations in size-at-age for juveniles, and age at sexual maturity is discussed in the Chapter 5.

3.4.2 Gonadal development

The presence of ripe, running ripe and spent *P. bassensis* ($\geq$ stage 5) from October to March clearly demonstrates that in southern and eastern Tasmania spawning occurs over an extended period lasting up to six months. The increased number of fish with resting stage gonads from January to March indicates, however, that the bulk of spawning occurs between October and December, with a lower level of spawning activity in the latter half of the spawning period. This is reflected in the highest GSI's between October and December. The high January GSI's for the shelf population, however, indicate that a larger proportion of the shelf population are spawning in that month compared to those inshore. As spawning commenced soon after water temperature rose in October this may be linked to the timing of the spring bloom in productivity in these waters which begins around mid-September (Harris *et al.* 1987).

In contrast, despite monthly sampling throughout the year the distribution of GSI's in *P. bassensis* in Port Phillip Bay indicated spawning occurred between August and October (Brown 1978). While some female fish with ripe ovaries were caught as late as December, Brown (1978) suggested that these fish did not spawn but reabsorbed their gonads. However, the timing and duration may vary from year to year as no The lack of platycephalid larvae in Port Phillip Bay during August or September

(Jenkins 1986), suggests that the timing of spawning may vary from year to year. While identification was only to family level, the fact the *P. bassensis* is the most abundant and earliest spawning flathead in Port Phillip Bay (Brown 1978), suggests that the 'type 1' larvae in Jenkins (1986) was most likely that of *P. bassensis*. The 'type 1' larvae were caught continuously from October through to April with abundances peaking in November and December. This spawning period is consistent to that found in the present study for *P. bassensis* in southern and eastern Tasmania.

There are several possible reasons to explain the differences in the duration of the spawning season. Firstly, Brown (1978) suggested that spawning in *P. bassensis* in Port Phillip Bay is restricted to spring months to reduce competition with the other sympatric species, *P. fuscus* and *P. speculator* that spawn in the bay from November to February. As *P. bassensis* is the only abundant platycephalid in coastal waters of southern and eastern Tasmanian, such sympatric competition is not evident. Variations in the spawning duration may also be related to differences in the seasonal cycle in water temperature with spawning in Port Phillip Bay occurring between 10.5° and 17.0° C (Brown 1978). However, while spawning in coastal waters of Tasmania occurred between 10.5° C and 17.4° C, maximum temperatures didn't occur until late February. The extended spawning period for *P. bassensis* in Tasmania may also be in response to the highly variable cycles in productivity that occur in these waters. While spring blooms occur primarily between September and November, the duration of the bloom can vary by as much as three months from year to year, with periods of increased westerly wind stress resulting in an increase in primary production right through the summer period (Harris *et al.* 1991). The spring and summer spawning of *P. bassensis* may therefore reflect a strategy to maximise the number of larvae encountering suitable feeding conditions.

The presence of spawning and spent male and female *P. bassensis* in all inshore and shelf areas sampled confirms that spawning occurs throughout their range in southern and eastern Tasmania. Spawning also occurred in a wide range of coastal and shelf environments including estuaries (Georges Bay), coastal embayments (Prosser Bay and Norfolk Bay) and on the shelf. This is further supported by the presence of small preflexion larvae in Norfolk Bay. While temperate platycephalid species have been found to spawn in estuaries (Hyndes *et al.* 1992a) and coastal embayment (Brown 1978), shelf spawning has not been previously identified, particularly in *P. bassensis*.

3.4.3 Larval distribution

The fact that *P. bassensis* larvae were most abundant at inshore stations in both 1989 and 1990 suggests that shelf spawning in eastern Tasmania is concentrated on the inner-shelf. This is further supported by the higher abundances of mature *P. bassensis* on the inner-shelf of the east coast during summer and their absence from outer-shelf waters (see Chapter 4). However, this conclusion will be influenced by the local hydrography and resultant transport of larvae from the spawning area. The oceanography of these waters during the spawning season is determined by a combination of the local westerly wind stress, and large scale oceanographic circulation dominated by the warm, stratified East Australian Current (EAC) water, and cool, well-mixed water of subantarctic origin (Harris *et al.* 1987). The relative influence of these water masses on the shelf of eastern Tasmania shows considerable interannual variability and has been coupled with interannual variations in westerly winds (Harris *et al.* 1988).

During January 1989, the shelf of eastern Tasmania was dominated by subtropical EAC water, coincident with a reduction in the westerly wind stress, this event being linked to a major La Niña 'cold event' in the southern hemisphere (Harris *et al.* 1991). The strong thermal stratification in January 1989 resulted in an upper mixed layer (~40 m) of EAC water that originated offshore and moved across the entire shelf resulting in an onshore flow of waters down to around 40 m. Hence, the concentration of *P. bassensis* larvae at inshore stations in January 1989 may reflect strong onshore transport in that year. A similar inshore distribution of eggs and larvae of jack mackerel (*Trachurus declivis*) in eastern Tasmania in January 1989 was attributed to a strong onshore flow of the EAC across the shelf at that time (Jordan *et al.* 1995). Warmer sea-surface temperatures were also present in January 1990, although the EAC water was mainly restricted to the outer-shelf with cooler waters dominating inshore. Therefore, the fact that *P. bassensis* larvae were concentrated inshore in January 1990 during a period of reduced EAC influence and onshore flow suggests that shelf spawning is concentrated on the inner-shelf and larvae are retained inshore by sub-surface currents.

There is little data available on the sub-surface currents of eastern Tasmanian shelf waters, although currents on the shelf-break are predominantly alongshore during spring and summer (Freeland *et al.* 1985). Movement of water is generally

northward coincident with flow of cold subantarctic water onto the shelf from the south (Cresswell *et al.* 1994). Sub-surface cross-shelf currents are considerably slower than the longshore currents and are mainly onshore (Freeland *et al.* 1985). In contrast, there is a consistent pattern of offshore flow of surface waters as suggested by the movements of satellite-tracked drifter buoys (Cresswell *et al.* 1994), although patterns of satellite drifter movement during years of reduced westerly wind stress and increased EAC influence have not been documented. The suggestion that the distributional patterns of *P. bassensis* larvae are influenced by the sub-surface currents on the shelf is further supported by the concentration of larvae in mid-water. Such vertical stratification has previously been documented for platycephalid larvae on the inner-shelf of New South Wales, where highest densities were present in mid-water (15-30 m) (Gray *et al.* 1992, Gray 1996). While no data are available on the vertical distribution of larvae during non-stratified conditions in the present study, Gray (1996) found that vertical stratification of platycephalid larvae were independent of the depth stratified layer and suggested that larval behaviour was the major influence determining the vertical distribution. Hence, this suggests that the vertical distribution observed in January 1989 may also reflect the distribution during non-stratified periods, thereby minimising the advective loss of larvae to offshore waters during periods of increased westerlies and offshore flow of surface waters.

Such variations in larval transport have been identified as a significant source of mortality (Nelson *et al.* 1977). The offshore transport of eggs and larvae in species whose larvae are distributed inshore and whose nursery areas are also inshore can play a major role in determining recruitment success (Bailey 1981). While such offshore advective losses of *P. bassensis* larvae spawned in coastal embayments (eg. Norfolk Bay) and estuaries (eg. Georges Bay) are unlikely as there was also no evidence of large scale replacement of coastal waters that would transport larvae away from suitable settlement areas, the significance of shelf spawning to overall egg production is yet to be determined. However, the concentration of shelf spawning on the inner-shelf region may also act to reduce offshore Ekman transport as such transport is often minimal directly adjacent to the coast (Parrish *et al.* 1981).

3.4.4. Larval development

Development of larvae of *P. bassensis* is similar to that described for other platycephalid larvae off southern Australia, *P. speculator* (Hyndes *et al.* 1992a), and

P. fuscus (Neira and Miskiewicz 1998) They are characterised by a large and wide head with extensive spination, moderate to large, fan shaped pectoral fins and 26-28 myomeres. However, *P. bassensis* larvae are distinguished from both *P. fuscus* and *P. speculator* by the larger size at both notochord flexion (6.0->8.4 mm) and pelvic (5.9-7.4 mm) and dorsal fin (6.2->8.4 mm) formation. In addition, the trunk and tail was only lightly pigmented in *P. bassensis* larvae, which contrasts the moderate to heavy pigment in larval *P. fuscus* and *P. speculator* (Neira and Miskiewicz 1998).

Small platycephalid larvae can be confused with scorpaenids and triglids that also have early developing fan-shaped pectoral fins and extensive spination. However, triglid larvae have more prominent posttemporal spines, a duck-bill shaped snout, 27-37 myomeres and lower two or three pectoral fin rays elongate and detached from the rest of the fin in larger larvae (Jordan *et al.* 1998a). Small scorpaenid larvae have a rounder head without a flattened, elongate snout, while larger larvae are easily distinguished by morphology, fin meristics and the presence of a single dorsal fin (Neira and Furlani 1998).

3.4.5 Recruitment

The size-class of juvenile *P. bassensis* present between March and November 1996 represents the 0+ cohort resulting from spawning that commenced the previous October. This is confirmed by the otolith radius of this cohort as presented in Chapter 5. There was a broad range of lengths in every month indicating that settlement occurred over an extended period reflecting the extended spawning period of *P. bassensis*. Newly settled *P. bassensis* were first caught in January, although the presence of fish up to 7 cm in that month suggests that initial settlement occurs some time earlier. The smallest new recruit was 2.1 cm indicating settlement to benthic habitats occurs close to this size. This is larger than the size at settlement of approximately 1.3 cm in *P. speculator* (Hyndes *et al.* 1992a), and may reflect selectivity of the beam trawl. However, the fact that the cod-end mesh size used by Hyndes *et al.* (1992a) was 9.5 mm, compared to 7.0 mm in the present study indicates that selectivity alone probably does not account for the lack of *P. bassensis* < 2.1 cm. The lack of smaller recruits may also reflect the fact that initial settlement does not occur into subtidal unvegetated habitats. A detailed examination of habitat preference of newly recruited *P. bassensis* in nearshore waters (0-12 m) is presented in Chapter 4.

Length-frequency distributions suggest the presence of two cohorts of 0+ *P. bassensis* in most months. The existence of multiple 0+ cohorts may reflect periodicity in the temporal pattern of spawning (Szedlmayer *et al.* 1990, Jordan 1994a), variability in larval supply (Jenkins and Black 1994) and larval duration (Cowen 1991, Jenkins and May 1994), or a combination of factors. While the monthly distribution of GSI's show no indication of distinct peaks in spawning, such monthly sampling may miss finer temporal patterns. The presence of several cohorts of *P. bassensis* may also reflect periodicity in larval survival through short-term variations in zooplankton production that is common in these waters (Clementson *et al.* 1989, Harris *et al.* 1991). This is supported by the absence of larvae in Norfolk Bay in October and December despite the presence of spawning fish in the bay in those months. It is clear that further work is needed to resolve the otolith microstructure of *P. bassensis* before the influence of temporal patterns of spawning and variations in larval survival and duration on the recruitment processes in this species can be fully evaluated.

Chapter 4 Spatial and temporal variations in abundance and distribution of sand flathead (*Platycephalus bassensis*)

4.1 Introduction

Coastal and continental shelf waters of southern Australia support diverse and abundant populations of platycephalids (Gomon *et al.* 1994, Kailola *et al.* 1993). However, there is little published information detailing the spatial and temporal variations in the abundance and distribution of flatheads in these waters. Wankowski and Moulton (1986) reported distinct seasonal and depth variations in abundance of *Platycephalus speculator*, *P. bassensis*, *Neoplatycephalus aurimaculatus* and *N. richardsoni* on the shelf of eastern Bass Strait, and attributed such variations to movement between depths and seasonal changes in vulnerability due to spawning. In contrast, no consistent spatial and temporal patterns were found for *P. longispinis* and *N. richardsoni* on the shelf of New South Wales (Gray and Otway 1994).

Most species of platycephalids common in temperate estuarine and coastal waters of Australia show a preference for unvegetated habitats (Gomon *et al* 1994, Edgar and Shaw 1995a). The lack of studies detailing patterns of abundance and distribution in these waters in some way reflects the emphasis on studies of fish communities associated with seagrasses (Young 1981, Middleton *et al.* 1984, Bell *et al.* 1992, Ferrell *et al.* 1993), the analysis of patterns at the community level (Potter and Hyndes 1994, Ayvazian and Hyndes 1995), and low abundances of individual species (Gray *et al.* 1990, Edgar and Shaw 1995a, Gray *et al.* 1996, Jenkins and Wheatley 1997). In addition, there is little published information on size compositions of platycephalids across their distribution.

Platycephalus bassensis are found on the inner shelf and coastal waters from the central coast of New South Wales to eastern South Australia, but are most common in southern New South Wales, Victoria and Tasmania (Gomon *et al.* 1994). Spatial and temporal variations in the abundance of *P. bassensis* in Port Phillip Bay, Victoria was reported by Brown (1978), who attributed variations to differences in bottom type and catchability. Edgar and Shaw (1995a) also found spatial variations in the abundance of *P. bassensis* in Western Port, Victoria, which they attributed to habitat type. In addition, *P. bassensis* showed no indication of a ontogenetic change in habitat preference in Western Port with both juveniles and adults preferring

unvegetated habitats (Edgar and Shaw 1995a). A similar habitat preference was noted for *P. bassensis* in coastal waters of Tasmania (Last 1983). However, both Last (1983) and Edgar and Shaw (1995a) primarily sampled shallow (<3 m) habitats, with only limited sampling of deeper subtidal unvegetated and seagrass habitats. Such deeper habitats form a substantial part of the coastal region of Tasmania, with beds of *Heterozostera tasmanica* common in depths down to 7 m and unvegetated habitats dominant in marine embayments and estuaries.

Therefore, in order to examine the factors influencing the variations in the abundance and distribution of juvenile and adult *P. bassensis* in southern and eastern Tasmania, this chapter aims to (1) describe the seasonal, interannual and depth variations in abundance and size composition of *P. bassensis* on the continental shelf (10-100 m), and (2) examine temporal variations in abundance, habitat preference and size composition in selected inshore embayments and estuaries (0-12 m) of southern and eastern Tasmania

4.2 Methods

4.2.1 Survey area and sampling regime

4.2.1.1 Shelf Region

Platycephalus bassensis were sampled on the shelf of eastern and south-eastern Tasmania seasonally in eight out of the nine seasons between summer 1993 and summer 1995. Full details of shelf sampling areas, survey design and gear and biological sampling is presented in Chapter 2. In brief, *P. bassensis* were sampled from the inner-shelf (10-50 m) and mid-shelf (50-100 m) regions in Storm Bay and on the east coast of Tasmania. Trawl stations were allocated proportional to the area of the stratum. Demersal tows were conducted at a maximum of 15 random stations on the east coast and 20 in Storm Bay, with stations designated to be a minimum of 2 Nm apart. At each station the net was towed for 30 minutes (bottom time) at a speed of 3.0 knots. Catch rates were calculated as the number of fish per tow (N.tow^{-1}). Details of stratum area, number of stations sampled in each stratum in each season and station density for shelf surveys are presented in Table 2.1.

4.2.1.2 Inshore Region

Platycephalus bassensis were also routinely sampled from three inshore areas in eastern and southern Tasmania (Norfolk Bay, Prosser Bay and Georges Bay). The

distribution of inshore sampling sites, site characteristics, survey times and sampling gear are detailed in Chapter 2. In brief, in each area, sites in the 1-12 m depth range were chosen to be representative of soft-sediment unvegetated (mud and sand) and seagrass habitats. Seagrass sites consisted almost exclusively of *Heterozostera*. Sampling was conducted at six sites in Norfolk Bay every two months from February 1995 to December 1996. Two sites in Prosser Bay and four in Georges Bay were also sampled seasonally from February 1995 to October 1995. At each site, three non-overlapping 3-min beam trawls were conducted at a tow speed of 2 knots. At a single seagrass and unvegetated site in each area, two multi-panel gillnets were set overnight on each sampling occasion. Catch rates were calculated as number of fish per tow for beam trawls and number of fish per hour for gill-nets.

In addition, *P. bassensis* were sampled with a 25 m beach seine from nearshore beach habitats (<1.5 m deep) monthly from December 1996 to February 1997 at 27 sites throughout south-eastern Tasmania (see Table 2.4, Fig. 2.9). In both shelf and inshore surveys the catch of *P. bassensis* was weighed at each station with a 15 kg or 40 kg clock face scale ($\pm$0.1 kg) and all individuals sampled for fork length (FL).

4.2.2 Statistical analysis

Spatial and temporal variations in the distribution of *Platycephalus bassensis* in all areas was assessed using analysis of variance (ANOVA). Variations in abundance (N.tow^{-1}) of *P. bassensis* on the inner-shelf were analysed for Storm Bay and the east coast separately using a two-way ANOVA with season and depth considered fixed factors. Separate analysis was conducted for beam trawl and gill-net data from inshore sampling. Variations in abundance in gill-nets (N.hr^{-1}) from Norfolk Bay were analysed using a two-way ANOVA with habitat considered fixed and time a random factor. Time was considered random, as there was no *a-priori* reason for choosing sampling dates and were chosen to give an even spread of samples throughout the year that didn't necessarily represent seasons. In Georges Bay and Prosser Bay, gill-net abundance (N.hr^{-1}) was analysed using a two-way ANOVA with season and habitat considered fixed factors. Analysis of variations in the abundance of *P. bassensis* from the beam trawl in Norfolk Bay was restricted to fish <18.0 cm using a two-way ANOVA with habitat considered fixed and time a random factor. *Platycephalus bassensis* < 18.0 cm have previously been identified as representing the 0+ and 1+ cohorts (see Chapter 3). Due to low and patchy abundance of

P. bassensis <18.0 cm in Georges Bay and Prosser Bay no statistical analyses were done.

All data were tested for conformity to the assumptions of ANOVA using the F_{max} test for heteroscedascity (Sokal and Rohlf 1981), and by examining normal probability plots. Transformation of abundance to ln(x+1) resulted in homogeneity of variances and even distribution of residuals. Ryans Q test was used to identify significant differences among means when there was significant main effects or interactions in the ANOVA. Ryans Q test is considered to be the most powerful post-hoc test which allows the user to control experiment-wise error rate (Day and Quinn 1989). Calculations were performed with the Peritz FORTRAN program (Martin and Toothaker 1989).

4.2.3 Size Compositions

Size compositions of *P. bassensis* on the shelf were firstly obtained by pooling lengths from all random trawl stations in a stratum in each season in both Storm Bay and east coast survey areas. The size composition of the total population in each area, season and stratum was then estimated by weighting each size class by the number of tows relative to the stratum area, using the formula of Davis and West (1992):

$$F_i = \sum_{j=1}^{j=3} f_{ij}A_j/n_j \qquad (4.1)$$

where F_i is the relative frequency of size class i in the population; f_{ij} is the frequency of size class i in stratum j; A_j is the area of stratum j; and n_j is the number of trawls in stratum j. Details of stratum areas and number of trawls in each stratum in each season are given in Table 4.1.

4.3 Results

4.3.1 Shelf region

4.3.1.1 Hydrography

The seasonal distribution of sea-surface temperatures on the shelf of south-east Tasmania between summer 1993 and 1995 reflected seasonal warming and the changing influence of warmer northerly, and cooler southerly water on the region (Fig. 4.1). Summer temperatures varied markedly between years, with 1995 being the warmest year, 1994 the coolest, and 1993 somewhat intermediate, while other

seasons showed little interannual variability. Temperatures varied both along the coast and across the shelf, reflecting the fact that warmer northerly waters originated offshore on the east coast and at times moved down the coast and onto the shelf while cooler water of subantarctic origin is driven up the coast from the south-west.

In summer 1993, sea-surface temperatures ranged from $16.7°$ to $17.2°$ C on the east coast and $14.4°$ to $17.0°$ C in Storm Bay (Fig. 4.1). By autumn 1993, temperatures were even along the coast at $16.0°$ to $16.6°$ C, cooling to around $11.5°$ to $12.0°$C by winter. In spring, temperatures were relatively even throughout the study area at around $11.5°$ to $12.5°$ C. Temperatures were cooler in summer 1994 at around $13.5°$ to $15.5°$ C, reflecting the increased influence of cooler southerly waters along the entire south-east coast. In autumn 1994, warmer water at around $17.0°$ C had advanced onto the shelf from the north-east, with cooler temperatures in the south.

The warmer water had retreated by winter, with cooler water of southerly origin dominating the entire shelf. In summer 1995, outer-shelf waters of the east coast were up to $17.7°$C, with a sharp gradient evident across both shelf areas, although in contrast warmer water was inshore in Storm Bay.
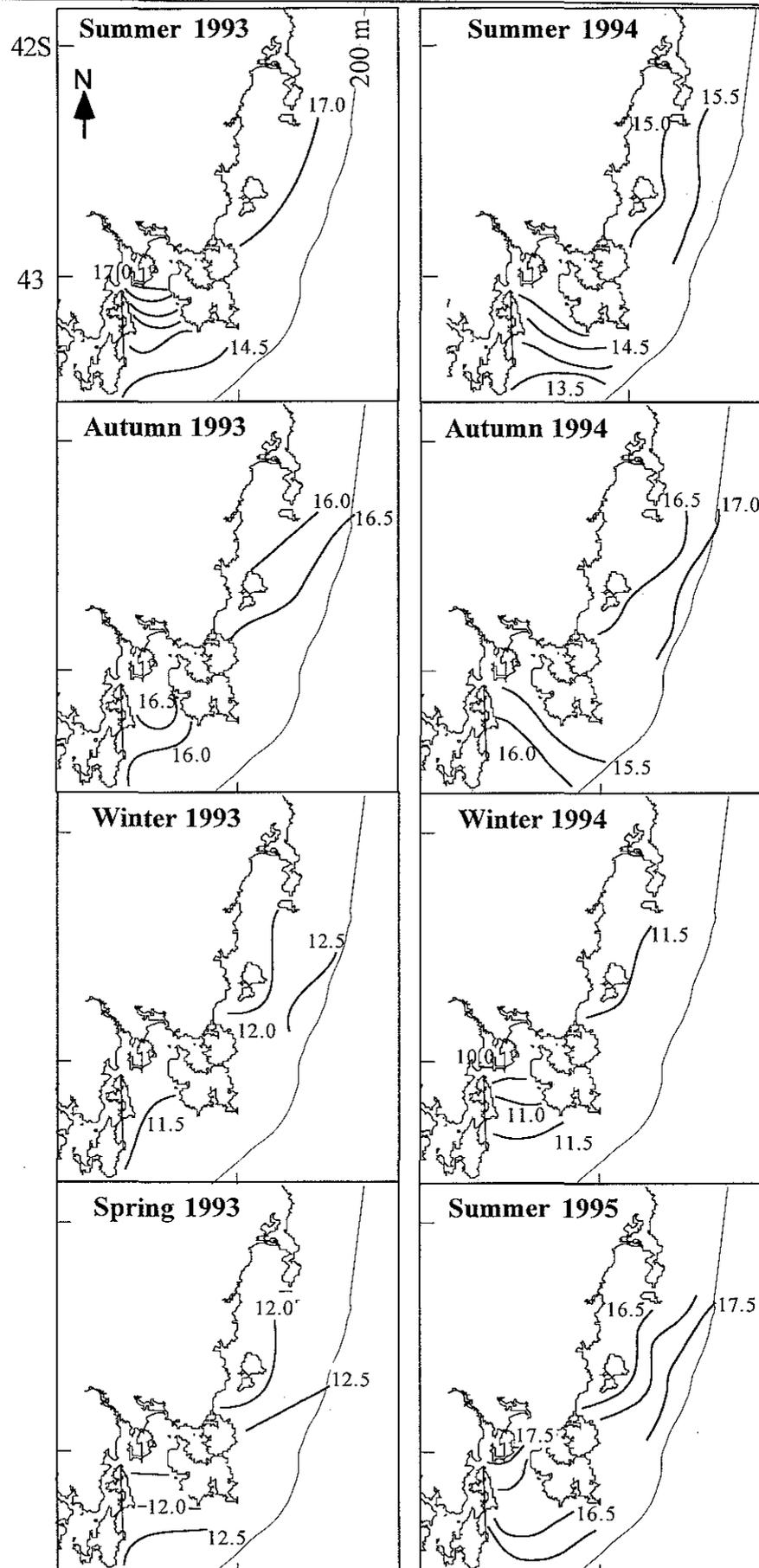
Fig. 4.1 Distribution of sea-surface temperatures ($^{\circ}$ C) in Storm Bay and the east coat of Tasmania seasonally between summer 1993 and summer 1995.

4.3.1.2 Catch rates

Abundances of *Platycephalus bassensis* on the shelf region of Storm Bay varied significantly between seasons and depths, and there was also a significant season and depth interaction (Table 4.1, Fig. 4.2). Post-hoc tests indicate that in terms of season, the major pattern was that on the inner-shelf, summer, winter and spring 1993 were significantly higher than all other seasons (Ryans Q-test; $p<0.01$). On the mid-shelf, winter 1993 was significantly higher than autumn 1993, autumn and winter 1994 and summer 1995, but not significantly different as all other seasons (Ryans Q-test; $p<0.05$). In terms of depths, abundances were significantly higher on the inner shelf only in summer, winter and spring 1993 (Ryans Q-test; $p<0.05$).

Table 4.1   Analysis of variance of $\ln(x+1)$ transformed abundance (N.tow^{-1}) of *Platycephalus bassensis* in two depth strata and eight seasons on the shelf region of Storm Bay.

Factor	Hypothesis	DF	MS	F	P
Season	a/r	7	6.911	14.410	<0.001
Depth	b/r	1	23.611	49.430	<0.001
Season*Depth	ab/r	7	1.985	4.140	<0.001
Residual	r	124	0.4796		
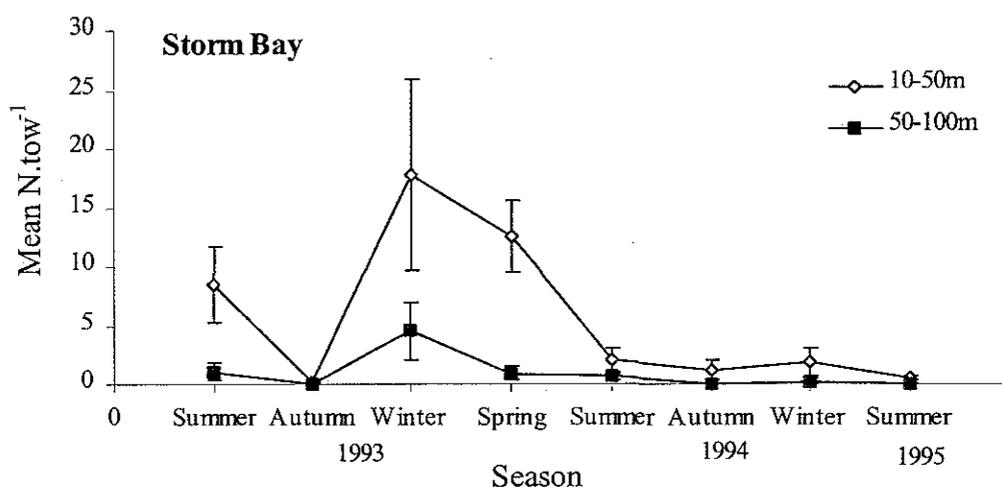
Fig. 4.2 Mean abundance (N.tow^{-1}) of *Platycephalus bassensis* collected from inner-shelf (10-50 m) and mid-shelf (50-100 m) strata in Storm Bay sampled seasonally in eight out of nine seasons between summer 1993 and summer 1995. Error bars are standard error.

Abundances of *P. bassensis* on the shelf region of the east coast varied significantly amongst seasons and depths (Table 4.2, Fig. 4.3). Post-hoc tests showed that abundances were significantly higher on the inner-shelf (Ryans Q-test; $p<0.05$). In

terms of season, abundances were significantly higher in spring 1993 than autumn 1993 and 1994 and winter 1994, but not significantly different as all other seasons (Ryans Q-test; p<0.05).

Table 4.2   Analysis of variance of ln(x+1) transformed abundance (N.tow^{-1}) of *Platycephalus bassensis* in two depth strata and eight seasons on the shelf of the east coast.

Factor	Hypothesis	DF	MS	F	P
Season	a/r	7	1.778	2.760	0.014
Depth	b/r	1	5.304	8.230	0.006
Season*Depth	ab/r	7	0.599	0.930	0.489
Residual	r	66	0.645		
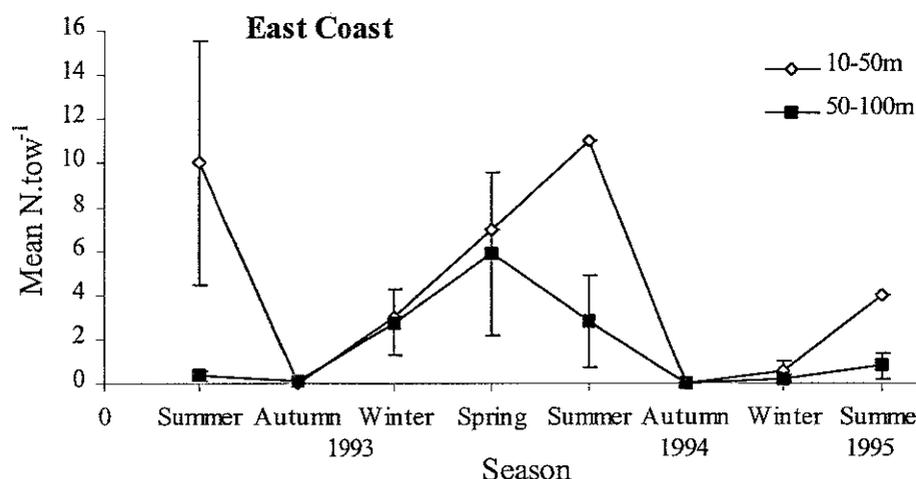
Fig. 4.3 Mean abundance (N.tow^{-1}) of *Platycephalus bassensis* collected from inner-shelf (10-50 m) and mid-shelf (50-100 m) strata on the east coast sampled seasonally in eight out of nine seasons between summer 1993 and summer 1995. Error bars are standard error.

4.3.1.3 Size composition

Platycephalus bassensis on the inner- and mid-shelf regions of Storm Bay ranged from 15.0 to 45.8 cm, with the distribution consisting of a single mode with a mean of 27.4 cm (Fig. 4.4). Few fish were below the size at maturity (21-23 cm) in Storm Bay, immature fish making up around 6% of the population. The size composition of *P. bassensis* on the east coast also consists of a single mode, although fish are larger on this shelf region compared to Storm Bay, ranging from 16.0 to 51.1 cm, with a mean of 32.6 cm (Fig. 4.4). Similar to Storm Bay, few immature fish were caught on the east coast, making up 4% of the population.
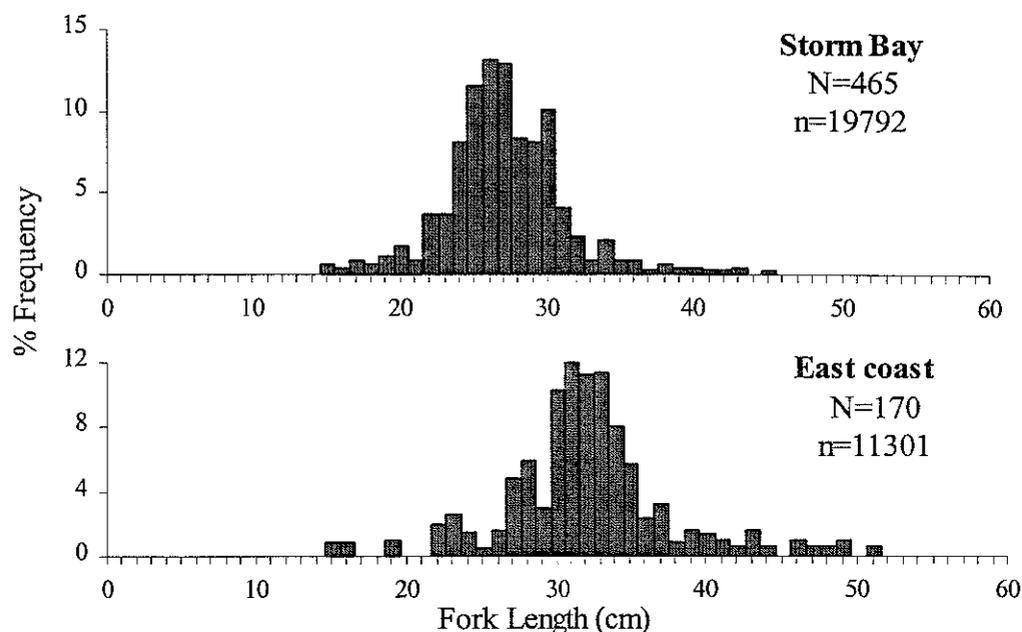
Fig. 4.4 Scaled length-frequency distribution of *Platycephalus bassensis* collected on the inner- and mid-shelf region of Storm Bay and the east coast between summer 1993 and 1995. N is measured sample size; n is scaled sample size.

Seasonal length-frequency distributions of *P. bassensis* in Storm Bay reveal little change in the size composition of the population throughout the year (Fig. 4.5). The size composition of fish varied little in 1993, although a slight increase in the proportion of fish >30.0 cm was evident during winter. Variations in the size composition evident during 1994 and summer 1995 resulted mainly from the low abundance of fish in those seasons.

Comparison of length-frequency distributions by depth in Storm Bay indicates an increase in the mean size of fish with increasing depth from 26.7 cm on the inner-shelf to 29.5 cm in the mid-shelf stratum (Fig. 4.5). This is particularly evident in winter and spring 1993 when no fish < 25 cm were present on the mid-shelf. This is also reflected in the smaller proportion of immature fish on the mid-shelf (1%) compared to the inner-shelf (5%).

Seasonal length-frequency distributions of *P. bassensis* on the east coast reveal little change in the size composition of the population throughout the year, or between years (Fig. 4.6). Comparison of length-frequency distributions by depth indicates little size structuring of the population across the shelf on the east coast with mean length increasing only slightly from 32.0 cm on the inner-shelf to 32.9 cm on the mid-shelf (Fig. 4.6). Few immature fish were caught on the east coast with only 5% of fish on the inner-shelf and 2% on the mid-shelf below the size at maturity.
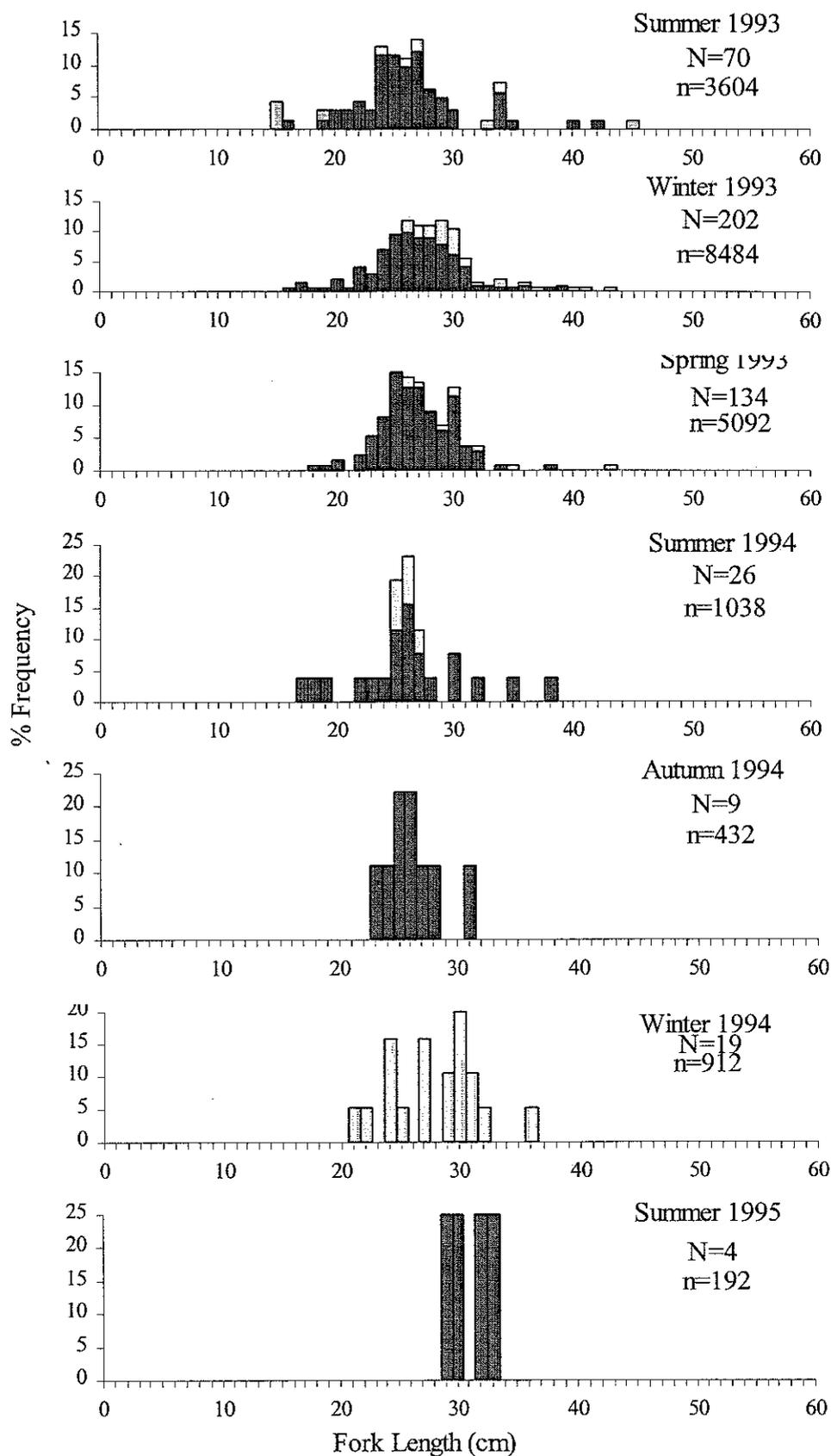
Fig. 4.5 Seasonal scaled length-frequency distribution of *Platycephalus bassensis* collected on inner-shelf (dark bars) and mid-shelf strata (light bars) of Storm Bay between summer 1993 and 1995. N is measured sample size; n is scaled sample size.
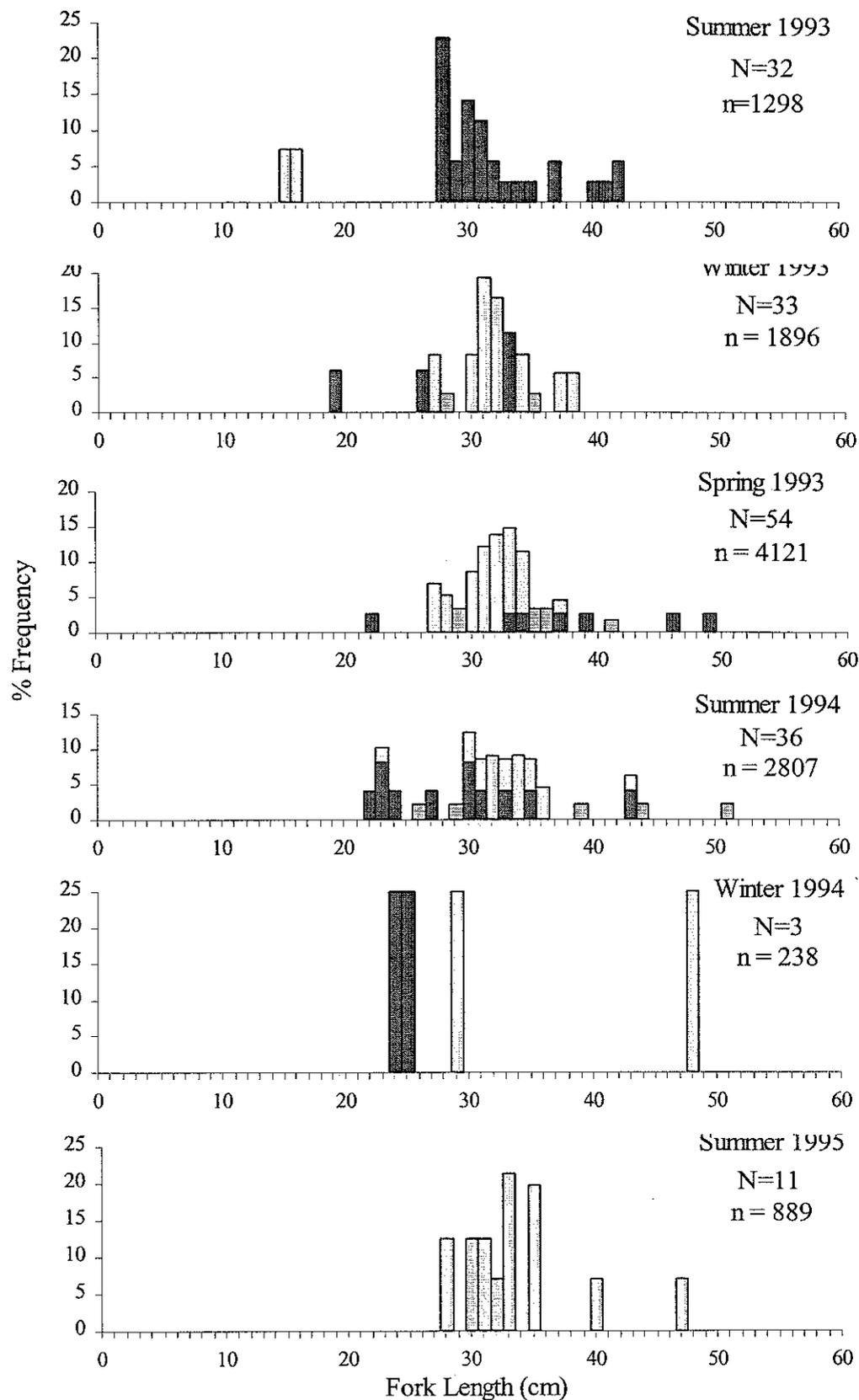
Fig. 4.6 Seasonal scaled length-frequency distribution of *Platycephalus bassensis* collected on inner-shelf (dark bars) and mid-shelf strata (light bars) of the east coast between summer 1993 and 1995. N is measured sample size, n is scaled sample size.

4.3.2 Inshore region

4.3.2.1 Catch rates

Abundances of *Platycephalus bassensis* from gillnets in Norfolk Bay varied significantly between sample dates, and there was also a significant habitat and date interaction (Table 4.3, Fig. 4.7). Post-hoc tests indicated that in terms of sample dates, abundance was significantly higher in *Heterozostera* compared to unvegetated habitat in October and December, 1995, but not significantly different as all other dates (Ryans Q-test; $p < 0.01$). In terms of habitats, post-hoc tests indicate that abundance in unvegetated habitats was significantly higher in February 1995, April 1995 and October 1996, than June 1995, August 1995 and June 1996, but not significantly different as all other dates (Ryans Q-test; $p < 0.05$). Abundance in *Heterozostera* was significantly higher in October 1995, December 1995 and December 1996, than June and August in both 1995 and 1996, but not significantly different as all other dates (Ryans Q-test; $p < 0.01$).

Table 4.3 Analysis of variance of $\ln(x+1)$ transformed abundance $(N.hr^{-1})$ of *Platycephalus bassensis* in gill-nets in *Heterozostera tasmanica* and unvegetated habitats in Norfolk Bay.

Factor	Hypothesis	DF	MS	F	P
Habitat	a/ab	1	0.155	1.918	0.147
Date	b/r	11	0.131	4.210	0.002
Habitat*Date	ab/r	11	0.081	2.600	0.024
Residual	r	24	0.031		
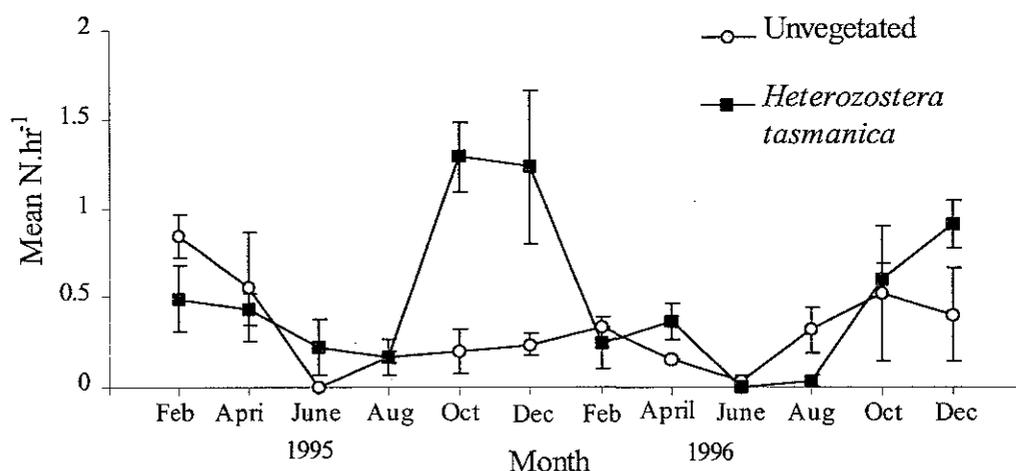
Fig. 4.7 Mean abundance $(N.hr^{-1})$ of *Platycephalus bassensis* collected in gill-nets from *Heterozostera tasmanica* and unvegetated habitats sampled every two months in Norfolk Bay between February 1995 and December 1996.

Abundance of 0+ and 1+ *P. bassensis* in Norfolk Bay was significantly higher in unvegetated compared to *Heterozostera* habitats throughout all sampling dates (Table 4.4, Fig. 4.8).

Table 4.4 Analysis of variance of ln(x+1) transformed abundance (N.tow^{-1}) of *Platycephalus bassensis* <18.0 cm in *Heterozostera tasmanica* and unvegetated habitats in Norfolk Bay.

Factor	Hypothesis	DF	MS	F	P
Habitat	a/ab	1	11.089	29.619	<0.001
Date	b/r	11	0.667	1.880	0.066
Habitat*Date	ab/r	11	0.374	1.060	0.415
Residual	r	48	0.354		
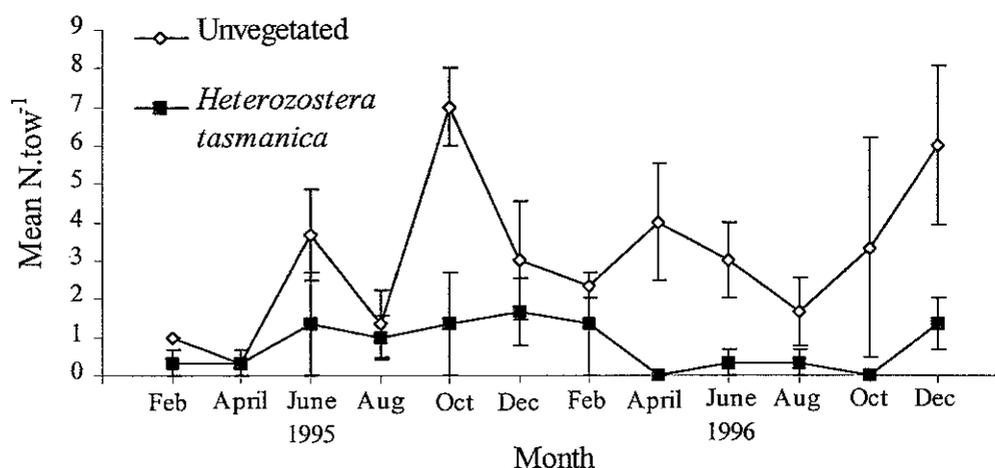
Fig. 4.8 Mean abundance (N.tow^{-1}) of 0+ and 1+ *Platycephalus bassensis* collected by beam trawl from *Heterozostera tasmanica* and unvegetated habitats in Norfolk Bay between February 1995 and December 1996.

Abundance of *P. bassensis* in Georges Bay indicates significant seasonal variability, with a significant habitat and season interaction (Table 4.5, Fig. 4.9). Post-hoc tests indicated that abundance was significantly higher in *Heterozostera* compared to unvegetated habitats in spring, but not significantly different in all other seasons (Ryans Q-test; p,0.05). In terms of seasons, abundance was significantly higher in spring than all other seasons in both *Heterozostera* and unvegetated habitats (Ryans Q-test; p<0.01).

Table 4.5 Analysis of variance of ln(x+1) transformed abundance (N.hr^{-1}) of *Platycephalus bassensis* in gill-nets in *Heterozostera tasmanica* and unvegetated habitats in Georges Bay.

Factor	Hypothesis	DF	MS	F	P
Season	a/r	3	0.076	37.540	<0.001
Habitat	b/r	1	0.001	0.450	0.523
Season*Habitat	ab/r	3	0.013	6.390	0.016
Residual	r	8	0.002		
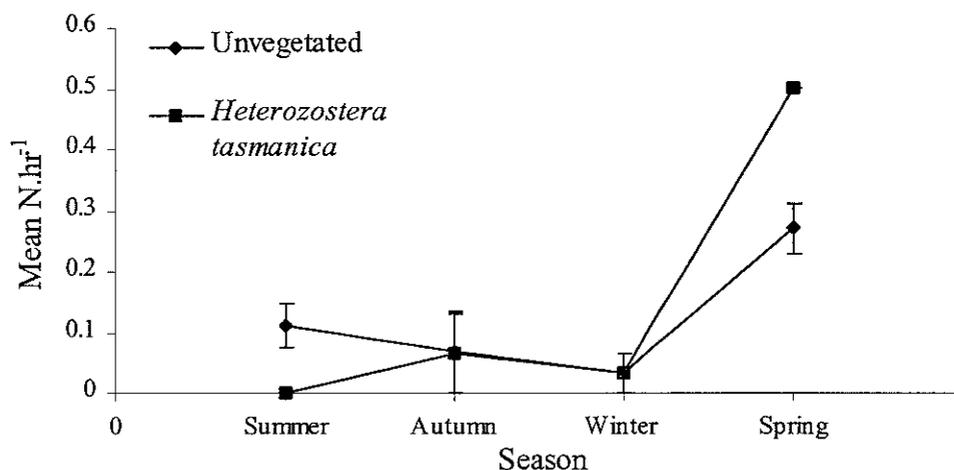
Fig. 4.9 Mean abundance (N.hr^{-1}) of *Platycephalus bassensis* collected in gill-nets from *Heterozostera tasmanica* and unvegetated habitats sampled seasonally in Georges Bay. Error bars are standard error.

Abundance of *P. bassensis* in Prosser Bay indicates significant seasonal variability, with a significant habitat and season interaction (Table 4.6, Fig. 4.10). Post-hoc tests reveal that abundance was significantly higher in unvegetated compared to *Heterozostera* habitats in spring, but not significantly different in all other seasons (Ryans Q-test; p<0.05). In terms of seasons, abundance was significantly higher in spring in *Heterozostera* than all other seasons (Ryans Q-test; p<0.01). In unvegetated habitats, abundances were significantly higher in spring than summer and autumn, which were significantly higher than winter (Ryans Q-test; p<0.05).

Table 4.6 Analysis of variance of ln(x+1) transformed abundance (N.hr^{-1}) of *Platycephalus bassensis* in gill-nets in *Heterozostera tasmanica* and unvegetated habitats in Prosser Bay.

| Factor	Hypothesis	DF	MS	F	P
Season	a/r	3	0.173	89.030	<0.001
Habitat	b/r	1	0.007	3.580	0.095
Season*Habitat	ab/r	3	0.009	4.490	0.040
Residual	r	8	0.002		
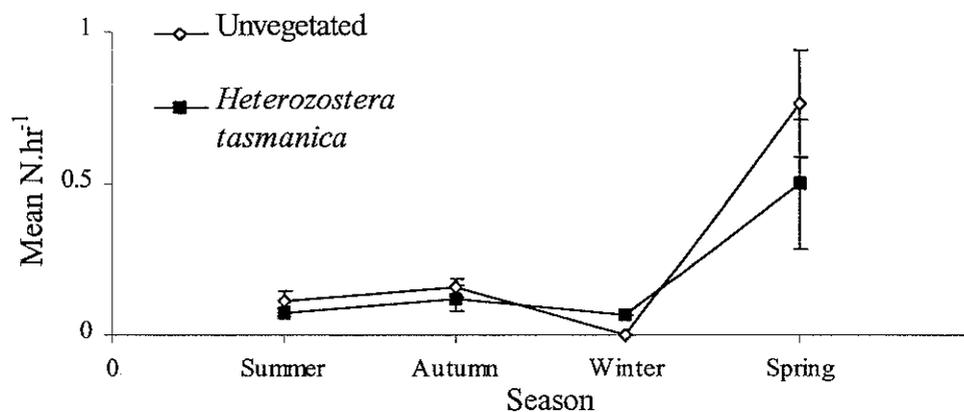
Fig. 4.10 Mean abundance (N.hr^{-1}) of *Platycephalus bassensis* collected in gill-nets from *Heterozostera tasmanica* and unvegetated habitats sampled seasonally in Prosser Bay.

4.3.2.2 Size composition

Platycephalus bassensis in Norfolk Bay ranged from 2.1 to 46.6 cm, with evidence of two distinct modes in the distribution, one at around 9 and the other at 33 cm, with a smaller mode at 15 cm (Fig. 4.11). The size-classes > 23 cm represents fish caught by gillnet, with the increase in the proportion of fish > 28 cm reflecting the increased selectivity of the 64 mm gill-mesh for *P. bassensis* above that length. There was a considerable difference in the gillnet size compositions between habitats, with fish >35 cm making up 40% of the sample from *Heterozostera* compared to 8% from unvegetated habitats (Fig. 4.11).   There is little change in the seasonal size composition of the gillnet size-classes (> 23 cm), throughout the year (Fig. 4.12).
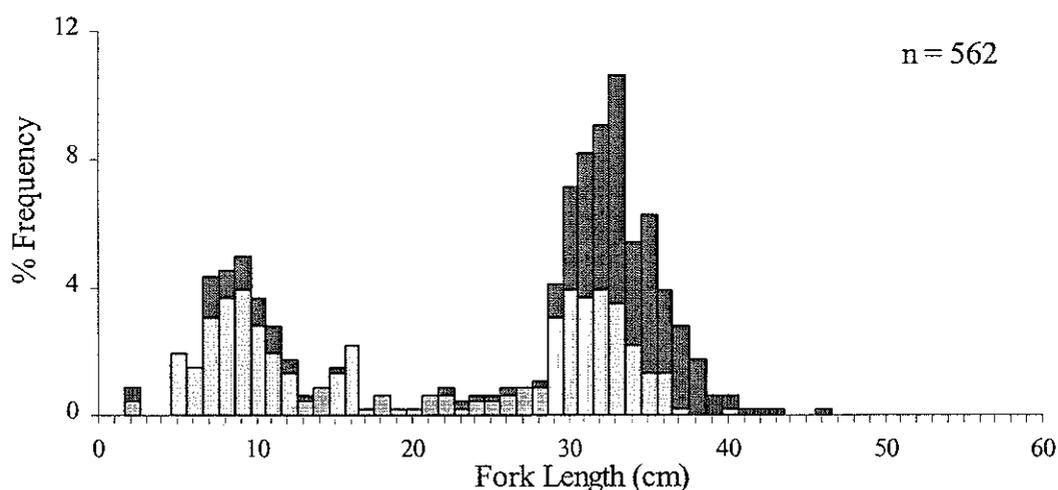
Fig. 4.11 Length-frequency distribution of *Platycephalus bassensis* collected by beam trawl and gill-nets from *Heterozostera tasmanica* (dark bars) and unvegetated habitats (light bars) in Norfolk Bay between February 1995 and December 1996. n is sample size.

The smaller modes at 9 and 15 cm represents *P. bassensis* caught by beam trawl. Within this size range the overall size composition was similar for *Heterozostera* and unvegetated habitats, although fish < 6 cm were restricted to unvegetated sites (Fig. 4.11). Seasonal length-frequency distributions show progression of the smallest size-class, previously identified as the 0+ cohort, in both 1995 and 1996 (see Chapter 3) (Fig. 4.12). The appearance of the smallest new recruit occurred in February of both years at a length of 2-3 cm. The 0+ cohort in 1995 had progressed to a mean size of 7.5 cm by August and 10.1 cm by December. Few 1+ and 2+ fish were present in beam trawl samples in Norfolk Bay in both years, although the 15 cm mode in the total length-frequency distributions represents the 1+ age-class.
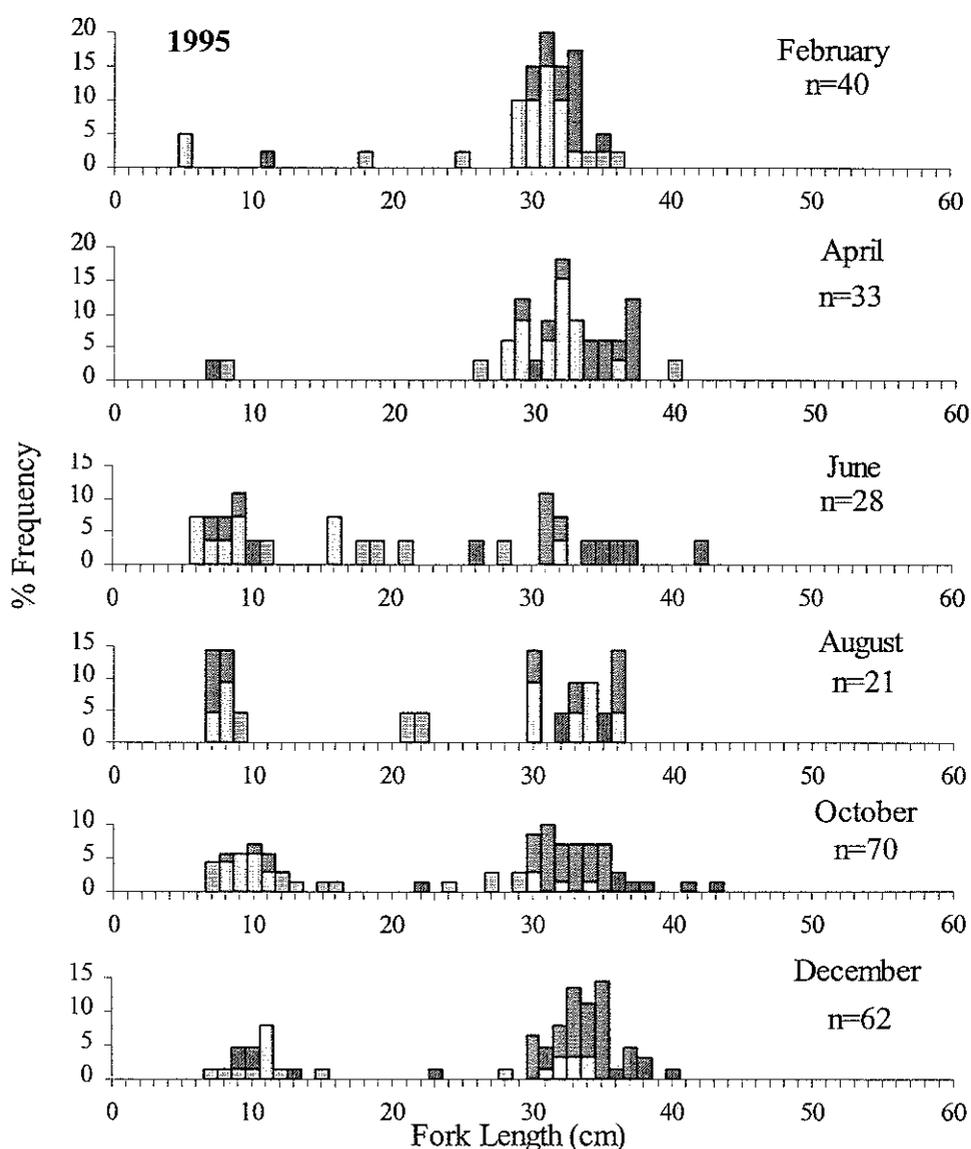
Fig. 4.12 Bi-monthly length-frequency distribution of *Platycephalus bassensis* collected by beam trawl and gill-nets from *Heterozostera tasmanica* (dark bars) and unvegetated habitats (light bars) in Norfolk Bay between February 1995 and December 1996. n is sample size.
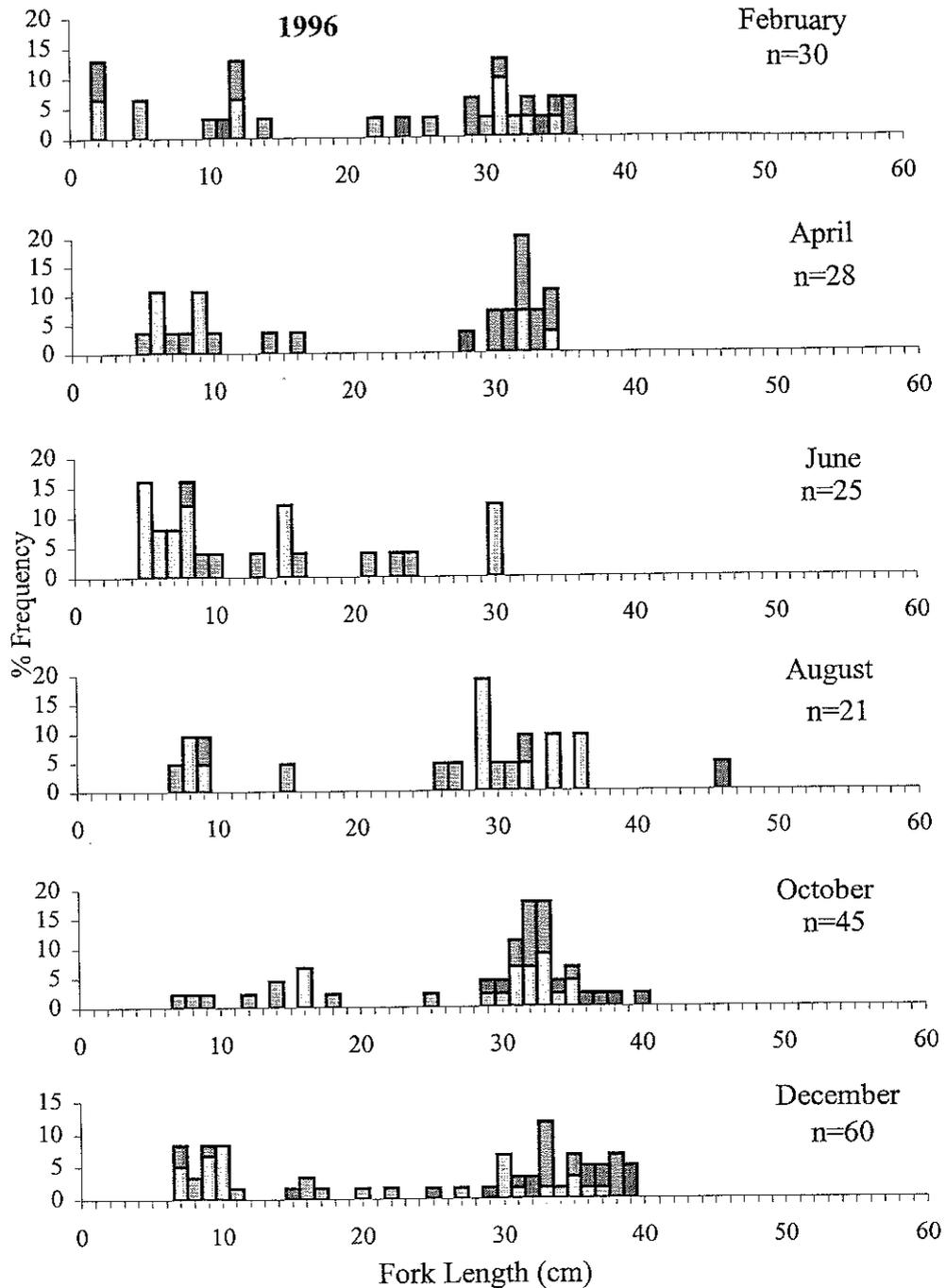
Fig. 4.12 (Cont). Bi-monthly length-frequency distribution of *Platycephalus bassensis* collected by beam trawl and gill-nets from *Heterozostera tasmanica* (dark bars) and unvegetated habitats (light bars) in Norfolk Bay between February 1995 and December 1996. n is sample size.

4.3.2.3 Nearshore beach survey

Very few *P. bassensis* were caught in nearshore beach habitats in south-eastern Tasmania, occurring in only 8% of hauls. All fish were caught at unvegetated sites which were represented by different levels of exposure. Catches consisted

exclusively of small juveniles in the 0+ age-class, ranging in size from 4.4 to 9.7 cm (Fig.4.13).
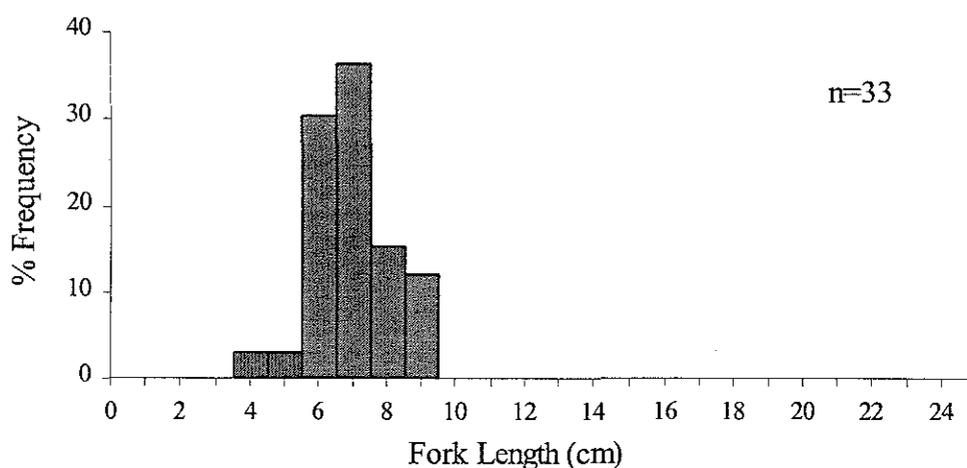
Fig. 4.13   Length-frequency distributions of *Platycephalus bassensis* sampled from nearshore beach habitats in south-east Tasmania. n is sample size.

4.4 Discussion

The present study revealed a generally low abundance of *Platycephalus bassensis* on the shelf of southern and eastern Tasmania, with some evidence of seasonal variability. The variations were primarily driven by the large decrease in abundance on the inner-shelf during autumn when *P. bassensis* essentially disappeared from the shelf region. Differences in abundance were most apparent during winter, spring and summer, with overall catch rates peaking in Storm Bay in winter and the east coast in spring. These seasonal variations are consistent with those for *P. bassensis* in eastern Bass Strait where catch rates were highest in winter and spring and lowest in autumn (Wankowski and Moulton 1986). As similar seasonal trends occur across the shelf regions of both southern and eastern Tasmania and eastern Bass Strait, the variations do not appear to result from movement of fish between these areas. However, the extent of the seasonal variations in abundance indicates some movement of fish onto the shelf during winter. Such seasonal variability could also be influenced by recruitment of juveniles, but the lack of seasonal change in the size composition of the population confirms that variations in abundance resulted from the movement of the mature fish onto the shelf. This contrasts that of tiger flathead (*Neoplatycephalus richardsoni*) in eastern Tasmania shelf waters where seasonal variations in

abundance resulted mainly from a movement of a distinct size class of large fish into the area during summer (Jordan 1997).

Distinct seasonal variations in abundance were also apparent in inshore regions of southern and eastern Tasmania. In Norfolk Bay, abundances were consistently highest in spring and summer and lowest in winter, while in Georges Bay and Prosser Bay abundances peaked in spring and were lowest in winter. The low abundances inshore in winter contrast the high abundance on the shelf at that time, suggesting that throughout southern and eastern Tasmania a large proportion of mature *P. bassensis* move from inshore waters onto the shelf at the end of autumn. The shift in distribution appears to be unrelated to the seasonal decrease in water temperature, which varies little between inshore and shelf regions. As prey abundance in inshore soft-sediment habitats in south-eastern Australia have been shown to be at their lowest during winter (Edgar *et al.* 1994), the movement into shelf waters may be in response to decreased food availability inshore. However, the lack of data on seasonal variations in prey abundance on the shelf precludes an assessment of its influence in determining seasonal patterns of *P. bassensis* distribution.

While the variations in abundance of *P. bassensis* in winter appears to be related to changes in distribution, spring abundances were found to be high in both inshore and shelf areas. One explanation is that the observed variations in catch rates represents seasonal changes in catchability rather than changes in abundance. Brown (1978) attributed the significant seasonal differences in abundance of *P. bassensis* in Port Phillip Bay, Victoria to variations in catchability. Such catchability through the herding of fish by trawl gear has been shown to be proportional to water temperature (Byrne *et al.* 1981, Foster *et al.* 1981), although in this study highest catch rates on the shelf occurred at the time of minimum water temperatures. Catch rates inshore also peaked significantly earlier than maximum water temperatures. It is more likely that variations in catch rates are influenced by changes in schooling behaviour related to spawning as high spring catch rates occurred at the time of peak spawning activity (see Chapter 3).

Overlying the seasonal trends in the shelf abundance of *P. bassensis* were interannual variations that were at least an order of magnitude in difference. Whilst these

variations were most evident in Storm Bay in summer 1994 and 1995, both shelf areas had significantly lower catch rates in winter 1994 compared to winter 1993. Large interannual variations in shelf productivity are common in Storm Bay and the east coast, and are related to variations in the zonal westerly wind strength and changing influence of subtropical, nutrient poor East Australian Current (EAC) water and nutrient rich water of subantarctic origin (Harris *et al.* 1987, Clementson *et al.* 1989, Young *et al.* 1993). Micronekton biomass on the shelf of eastern Tasmania during winter 1994 was found to be less than half that of winter 1993 (Young *et al.* 1996), suggesting that the lack of movement of *P. bassensis* back onto the shelf in winter 1994 may be in response to the lower shelf productivity in that year. However, the reasons for the low abundance of *P. bassensis* in Storm Bay in summer 1994 are less clear given the same trends did not occur on the east coast. The hydrographic data shows an increase in subantarctic influence in both shelf areas over this period which generally results in higher nutrient concentrations leading to an increase in shelf productivity (Clementson *et al.* 1989, Harris *et al.* 1991). In addition, as subtropical waters moves down from the north, the shelf of the east coast would be expected to show reduced productivity at the same time as Storm Bay. As a trend of declining abundance was evident for all demersal species in Storm Bay during 1994 and summer 1995 (Jordan 1997), it is apparent that the decline in abundance of *P. bassensis* over this period reflects an localised ecosystem wide response, although the factors causing such variations are yet to be determined.

A depth related trend in *P. bassensis* abundance on the shelf was also found in the present study, with catch rates significantly higher on the inner-shelf, although this was only apparent in Storm Bay in summer, winter and spring 1993 and on the east coast consistently in summer. This reflects the higher abundance of mature fish on the inner-shelf in those seasons as little difference was detected in the size composition between depth strata in either Storm Bay or the east coast. The lack of distinct size structuring of the population by depth contrasts that of the majority of commercially important demersal fish common on the shelf of southern and eastern Tasmania, including tiger flathead (*Neoplatycephalus richardsoni*), jackass morwong (*Nemadactylus macropterus*), silver dory (*Cyttus australis*) and latchet (*Pterygotrigla polyommata*) (Jordan 1997). All of these species had size-dependent depth distributions, with the inner-shelf dominated by juveniles, the mid-shelf containing both juveniles and adults and the outer-shelf dominated by mature fish. This reflects

the fact that these species are predominantly shelf species whose juveniles utilise the inner-shelf region as a nursery area with most undergoing an age-based migration across the shelf.

The low number of juvenile *P. bassensis* in shelf samples indicates that close to the size at maturity a proportion of the population move from the inshore to the inner- and mid-shelf region, although the seasonal trends indicate that such movements are not permanent. The lack of significant numbers of juveniles on the shelf, the smallest being 15.0 cm, may however reflect mesh selectivity of the demersal trawl. The length at 50% selection for tiger flathead (*Neoplatycephalus richardsoni*) with 25 mm codend mesh was estimated to be 16 cm, with 0% selection at 11.0 cm (Wankowski 1986). Given the similarity in morphology between *P. bassensis* and *N. richardsoni* selectivities would be expected to be similar. Therefore, as a 20 mm codend was used in the present study, the lengths at 50% and 0% selection would be expected to be less than 16 cm and 11 cm, respectively. These size-classes represent 0+, 1+ and 2+ fish (see Chapter 3), indicating that the inner- and mid-shelf regions of southern and eastern Tasmania are not an important nursery area for these age-classes and confirms that the size compositions reflect some seasonal movement of fish onto the shelf close to the size at maturity.

Adult *P. bassensis* were found to be common in both unvegetated and *Heterozostera* habitats in all inshore regions in the present study. Relative abundances changed through time, reflected by the significant habitat and time interaction in all three areas. Distinct differences in habitat preference were apparent only in spring, with abundances higher in *Heterozostera* compared to unvegetated habitats in Norfolk Bay and Georges Bay, whereas in Prosser Bay abundances were higher in unvegetated habitats. These differences between inshore regions are possibly related to the differences in habitat distributions. Beds of *Heterozostera* in Prosser Bay are only small and sparse, a function of the high degree of exposure and the significant loss of *Heterozostera* habitat that has occurred over the past 20-30 years (Rees 1993). Such losses have not been apparent in Georges Bay or Norfolk Bay (Rees 1993). The use of *Heterozostera* beds by adult *P. bassensis* contrasts other studies where there was no strong association with seagrass habitats (Last 1983, Edgar and Shaw 1995a).

In contrast to the lack of habitat preference identified for adult *P. bassensis*, juvenile abundances were consistently higher in unvegetated compared to *Heterozostera* habitats. The low abundance of juveniles in shallow intertidal beach habitats also suggests that the unvegetated subtidal zone is a more significant nursery area for the species. This is supported by the low abundance of *P. bassensis* in shallow beach habitats during extensive beach seine surveys of Tasmania (Last 1983). A number of studies have also identified unvegetated habitats as a nursery areas for platycephalids (Bell *et al.* 1984, Hyndes *et al.* 1992, Edgar and Shaw 1995a, Ayvazian and Hyndes 1995). The significance of unvegetated habitats as a nursery area for temperate Australia platycephalids is also supported by the lack of juveniles in vegetated habitats, despite extensive surveys of both seagrass (Burchmore *et al.* 1984, Ferrell *et al.* 1993, Bell and Westoby 1986a) and reef-algal beds (Jenkins and Wheatley 1997).

The preference for unvegetated habitats by juvenile *P. bassensis* in the present study is consistent with results from studies in Western Port, Victoria (Edgar and Shaw 1995a) and Tasmania (Last 1983). It is likely that *P. bassensis* use unvegetated habitats as a nursery area, as camouflage allows them some protection from predators. In addition, while benthic invertebrate production is generally higher in seagrass beds (Edgar 1990, Edgar *et al.* 1994), enhanced food production in unvegetated habitats can occur through regular phytoplankton blooms (McLachlan *et al.* 1981) and organic enrichment of sediments due to the presence of detached macrophytes (Robertson and Lenanton 1984, Shaw and Jenkins 1992). Similar patterns of recruitment to unvegetated habitats is common in families such as Pleuronectidae (flounders) that are also protected by camouflage (Crawford 1984, Connolly 1994, Jenkins *et al.* 1997b).

Initial settlement and growth of *P. bassensis* was found to occur exclusively into subtidal unvegetated habitats, with some post-settlement movement into beds of *Heterozostera* occurring around 7 cm (approximately 3-5 months old) (see Chapter 5). There was no indication that this represented an ontogenetic habitat shift in juvenile *P. bassensis*, as only small numbers of 0+ and 1+ fish were present in *Heterozostera* beds compared to unvegetated sites. The present study supports the findings of Edgar and Shaw (1995a), who found no indication of a change in habitat preference with growth in juvenile *P. bassensis* in Western Port, Victoria. Size dependant shifts in habitat, however, are common to many species that initially

recruit to both seagrass beds (Robertson 1977, Middleton *et al.* 1984, Love *et al.* 1991, Worthington *et al.* 1992) and sandy beaches (Bennett 1989, Hyndes *et al.* 1996). While a complete shift in habitat is not apparent in *P. bassensis*, close to maturity they increasingly utilise both *Heterozostera* beds and inner- and mid-shelf waters.

Chapter 5 Age, growth and interannual and spatial trends in age composition of sand flathead (*Platycephalus bassensis*)

5.1 Introduction

The determination of age of temperate fish is necessary to understand the dynamics of their populations and define many life-history parameters including growth and age at maturity. It is also an essential component of establishing the age composition of a population in order to estimate mortality and year-class variability, and examine spatial structuring of populations. Many of these parameters are also a necessary part of developing age based stock assessments.

As assessments of stocks often rely on age composition, an important component of ageing studies is validation of presumed annual increments. In addition, for validation to be considered complete, annual periodicity of increment formation must be established on otoliths with differing numbers of increments (Beamish and McFarlane 1983). A commonly used method to establish annual increment formation is by examining trends in marginal increments (Beckman *et al.* 1989, Massey and Horn 1990, Hyndes and Potter 1996).

Platycephalids are common and widespread throughout coastal and continental shelf waters of southern Australia supporting significant commercial and recreational landings (Gomon *et al.* 1994, Kailola *et al.* 1993). Despite this, there is little published information detailing the age and growth of flatheads in these waters with studies limited to *Neoplatycephalus richardsoni* (Fairbridge 1951, Montomery 1985, Jordan 1997), *Platycephalus speculator* (Hyndes *et al.* 1992b) and *P. bassensis*, *P. fuscus* and *P. speculator* (Brown 1978). While all of these studies were based on whole sagittal otoliths, Hyndes *et al.* (1992b) compared estimates of age and growth of *P. speculator* using both whole and sectioned sagittae and found whole otoliths underestimated age by as much as six years in older fish. These findings are consistent with previous studies where age estimates were lower from whole otoliths compared to those sectioned or broken and burnt (Beamish 1979, Campana 1984, Collins *et al.* 1988).

The only previous ageing study on *P. bassensis* estimated maximum ages from whole sagittae to be 7 years for males and 9 years for females (Brown 1978). The

population consisted of two distinct modes, the first representing 2 year old fish and the second dominated by 3 and 4 year olds. As this study was restricted to fish from Port Phillip Bay, Victoria no studies have detailed the age composition of shelf populations of *P. bassensis*.

Given the lack of information on age and growth of *P. bassensis* from Tasmanian waters, particularly using sectioned otoliths, the aims of this chapter are to (1) determine the validated age and describe the growth of *P. bassensis* from sectioned sagittal otoliths, and (2) examine the interannual and spatial trends in age composition from inshore and shelf waters of southern and eastern Tasmania in order to assess the extent of age-dependant migration and recruitment variability.

5.2 Methods

5.2.1 Study locality and sampling regime

Length-frequency data and otolith samples of *Platycephalus bassensis* were obtained from research sampling conducted between January 1993 and May 1997. Initially, samples were obtained from demersal trawl surveys of the inner-shelf (10-50 m) and mid-shelf (50-100 m) regions of eastern Tasmania and Storm Bay conducted seasonally in eight out of the nine seasons between summer 1993 and 1995. Full details of shelf sampling areas, survey design, gear and biological sampling is presented in Chapter 2. In brief, demersal tows were conducted at a maximum of 15 random stations on the east coast and 20 in Storm Bay with stations designated to be a minimum of 2 Nm apart. Depth strata were allocated stations proportional to the area of the stratum. At each station the net was towed for 30 minutes (bottom time) at a speed of 3.0 knots.

Platycephalus bassensis were also routinely sampled from inshore habitats in three areas around the coast of Tasmania (Norfolk Bay, Prosser Bay, and Georges Bay). Full details of the distribution of inshore survey sites, survey times and sampling gear is presented in Chapter 2. In brief, sampling was conducted at six sites in Norfolk Bay every two months from February 1995 to December 1996. Two sites in Prosser Bay and four in Georges Bay were also sampled seasonally from February 1995 to October 1995. In addition, beam trawl sampling of juvenile *P. bassensis* was conducted at a single site in North West Bay every two months from March to July 1996, and then monthly until May 1997. All individuals were sampled for fork

length (FL), with on-board measurements rounded down to the nearest half centimetre. During both shelf and inshore surveys all *P. bassensis* were retained and processed for biologicals in the laboratory.

5.2.2 Laboratory procedures

All fish processed for biologicals were measured to the nearest millimetre fork length (FL) (length of the middle caudal ray), and weighed to the nearest gram. Sex was determined by macroscopic examination of the gonads (see Table 2.4). Sagittal otoliths from *P. bassensis* caught during shelf surveys were removed from a random sample of 20 fish in each depth strata each season, while otoliths were removed from all *P. bassensis* from inshore surveys. Once removed, sagittae were cleaned, dried, weighed to the nearest 0.001 grams and stored in envelopes prior to processing.

Sagittae were transversely sectioned through a three stage process of embedding into polyester resin, sectioning to ~300μm thick and mounting on glass slides. Transverse sections of sagittae from *P. bassensis* <12 cm were made by mounting the central part of the sagittae on the edge of 1 mm thick glass slide with resin and grinding from anterior and posterior ends until a 1 mm section was obtained. Sections were then mounted on the surface of a glass slide and both surfaces ground with sequentially finer grades of carborundum paper until ~300μm thick and viewed at either 12, 25 or 50 times magnification using a dissecting microscope with transmitted light and displayed on a personal computer. A customised image analysis system was used to enable on-screen digitising and enhancing of each section.

Age estimates were derived by counting the presumed annual increments (opaque or dark zones) from the primordium to the edge of the otolith section on the ventral sector of the proximal side. Along this same axis the distance from the primordium to the outer edge of each opaque zone and the edge of the section was measured to the nearest 0.1 μm. The section with the clearest increments and most discernible primordium was used for counts and measurements. The opaque zones considered true annuli were distinguished from false checks as they extended down both the ventral and dorsal sides of the medial groove and were continuous from the ventral edge to the sulcus. An increment was considered complete when a distinct opaque zone was visible across the proximal face of the otolith section immediately inside a

narrow discernible edge of translucent material. All counts and measurements of increments were made without knowledge of fish size, sex or date at capture. A total of 12.6% of otoliths were rejected due to the poor quality of sections. There was no relationship between fish size or sampling region in the rejection of otoliths.

5.2.3 Age validation

The periodicity of increment formation was determined from analysis of the temporal pattern of marginal increment development (distance between the outer edge of the outermost opaque zone and the otolith periphery). This was calculated as the index of completion [C] using the formula of Tanaka *et al.* (1981):

$$C = W_n/W_{n-1} \qquad (5.1)$$

where W_n = marginal increment and W_{n-1} = previous complete increment. Mean monthly index of completion values were plotted separately for otoliths with 1-8 and >8 opaque zones with months pooled over different years.

5.2.4 Precision of age estimates

To compare the precision of age estimates a random subsample of 275 sagittae were read a second time by the main reader, and a second subsample of 100 sagittae by a second reader. The average percent error (APE) was calculated for both the within and between reader age estimates using the formulae of Beamish and Fournier (1981).

$$\text{APE} = \frac{100}{N} \sum_{j=1}^{N} \left[\frac{1}{R} \sum_{i=1}^{R} \frac{|Xij - Xj|}{Xj} \right] \qquad (5.2)$$

where   N is the number of fish aged

        R is the number of times fish are aged

        X_{ij} is the ith determination of the jth fish

        X_j is the average estimated age of the jth fish

In addition, the percentage agreement of the within and between reader age estimates was calculated as another means of evaluating precision.

5.2.5 Growth

An absolute age was assigned to *P. bassensis* using a birth date of 1 December, which corresponds to the mid-point of the spawning season (see Chapter 3). Von Bertalanffy growth curves were fitted to the individual length-at-age data for males

and females separately and combined by direct non-linear least-squares estimation using a routine in *Genstat* statistical package. For both males and females, juveniles were ranked by size, with successive juveniles assigned an alternate sex and included in the calculation of sex specific growth curves. This was done to eliminate the bias of excluding slow growing juveniles that take longer to reach a size that can be sexed. The von Bertalanffy equation is defined as:

$$L_t = L_\infty \{1 - \exp[-K(t-t_0)]\} \qquad (5.3)$$

where L_t is the length at age t (years), L_∞ is the asymptotic length, K is the growth coefficient and t_0 is the hypothetical age at which the fish would have zero length if growth had followed that predicted by the equation. The growth curve derived for males and females was compared using an F-test on the ratio of the mean square for the combined fit and the sum of the error mean square for males and females fitted separately (Ratkowsky 1983). Using the estimated ages, mean lengths-at-age were calculated for males and females separately and combined.

5.2.6 Age composition

The age composition of *P. bassensis* was estimated separately for the 1993, 1994 and 1995 samples, with the number of fish aged proportional to the number in each 2 cm size-class from the scaled population size composition of the same year. Year-class distributions were also examined separately for 1993, 1994 and 1995, with the year-class referring to the year in which the fish was spawned. Age composition of the inshore and shelf population was also examined separately, with the number of fish aged proportional to the number in each 2 cm-size class from the scaled population size compositions in each region across years. The 1993 and 1994 samples were taken on the shelf with demersal trawl gear, while those in 1995 were sampled in inshore waters with gill-nets.

5.3 Results

5.3.1 Size and sex compositions

Length-frequency distributions were determined separately for males and females from shelf and inshore regions (Fig. 5.1). The overall distribution of *P. bassensis* inshore was dominated by a single mode at around 33 cm, although a broad range of smaller beam trawl caught fish around 15 to 20 cm was also evident. Lengths ranged

from 12.6 to 42.7 cm (mean 28.5 cm) for males and 12.0 to 47.5 cm (mean 31.1 cm) for females. The distribution of *P. bassensis* on the shelf consisted of single mode at around 33 cm. Lengths ranged from 15.0 to 46.1 cm (mean 28.4 cm) for males and 15.3 to 51.1 cm (mean 30.4 cm) for females.

A direct comparison of size compositions between regions is difficult as fish from inshore were caught with gill-nets and beam trawl, while those on the shelf were caught by demersal trawl. The small proportion of fish less than around 28 cm in the inshore region may reflect the decreased selectivity of these size-classes in the gill-nets rather than distinct differences in size-compositions between regions. The small proportion of fish <22 cm on the shelf reflects the low abundance of these size-classes in that region as fish move onto the shelf close to the size at maturity (22-24 cm) (see Chapter 4).
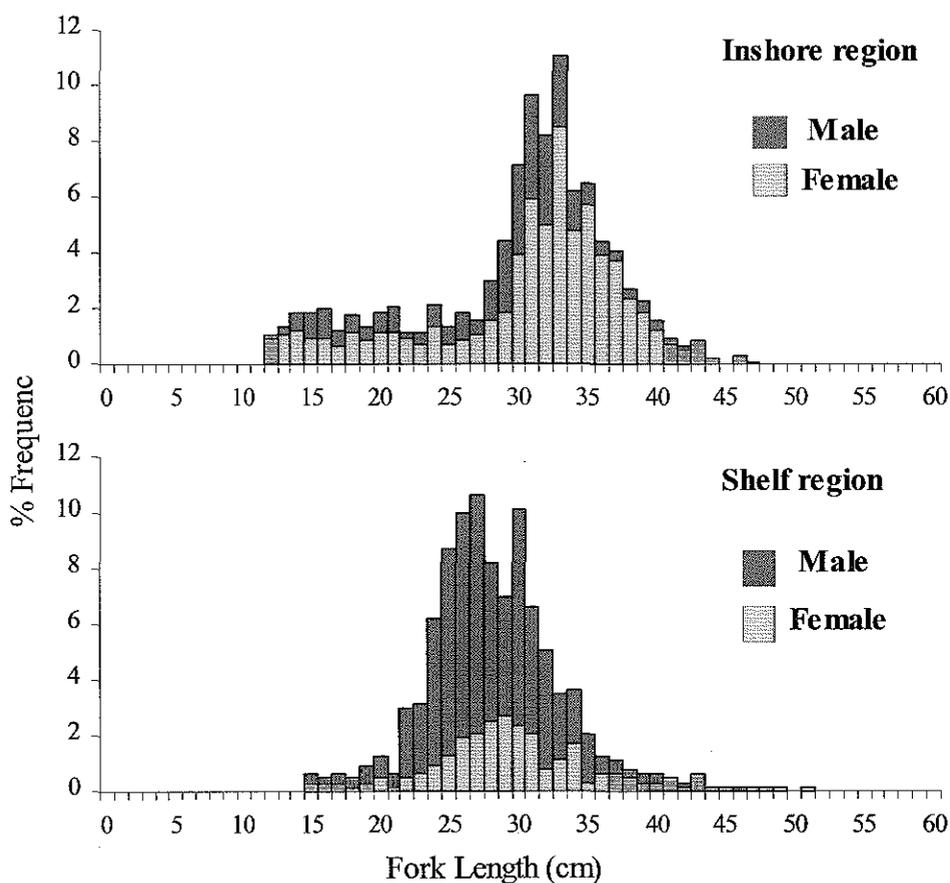
Fig. 5.1 Length-frequency distributions of male and female *Platycephalus bassensis* from inshore and shelf regions of southern and eastern Tasmania.

Sex ratios were determined for inshore and shelf populations of *P. bassensis* >20 cm, with the proportion of females significantly higher inshore contrasting the dominance of males on the shelf (Table 5.1). This pattern was consistent in all seasons on the shelf, and all seasons except winter inshore where the sex ratio did not differ from 1:1. Sex ratios varied considerably by size in both regions (Fig. 5.2). In inshore waters a significantly higher proportion of females were present above 32 cm (Chi-square, $P>0.5$). On the shelf a significantly higher proportion of males occurred up to around 35 cm, no difference in sex ratios up to 40 cm, and females dominating most larger size-classes.

Table 5.1 Sex ratios of *Platycephalus bassensis* >20 cm, based on proportion of female (prop. F) by season for shelf and inshore regions. P is probability of sex ratios varying from 1:1 based on Chi-square tests, n is sample size.

Season	Shelf region		Inshore region	
Summer				
prop. F	30.5	$p<0.001$	71.4	$p<0.001$
n	305		402	
Autumn				
prop. F	25.0	$p<0.001$	62.6	$0.01<p<0.05$
n	12		99	
Winter				
prop. F	32.0	$p<0.001$	50.5	$p>0.5$
n	257		109	
Spring				
prop. F	20.7	$p<0.001$	74.6	$p<0.001$
n	188		67	
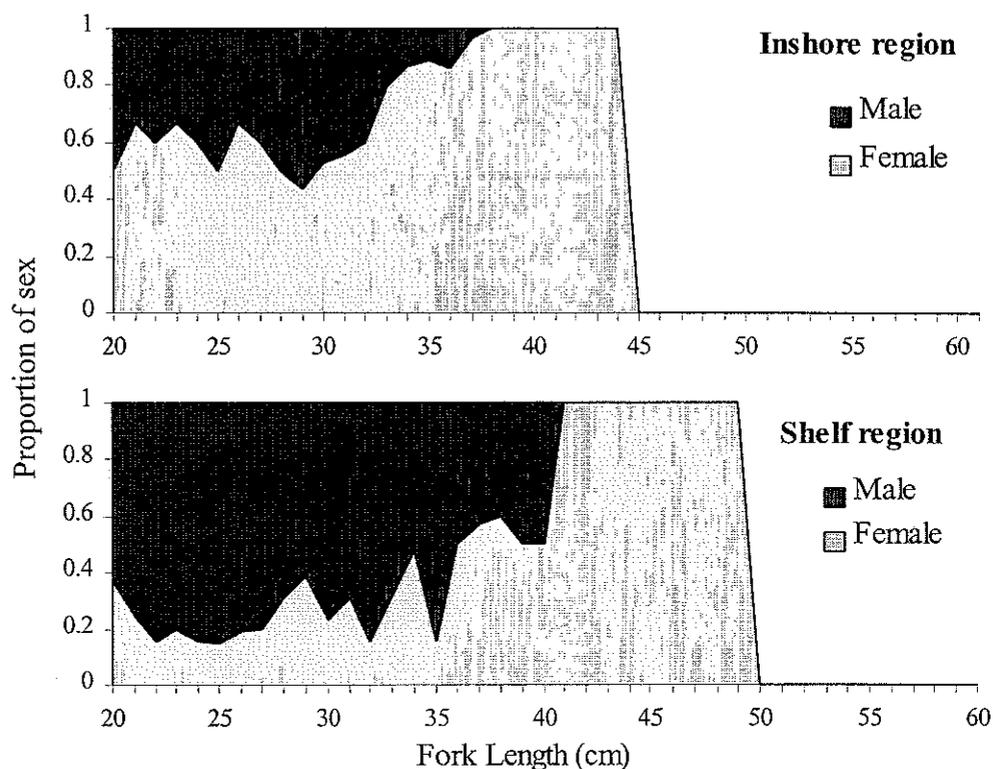
Fig. 5.2 Proportion of male and female *Platycephalus bassensis* >20 cm by 1 cm length-class for shelf and inshore regions of southern and eastern Tasmania.

5.3.2 Otolith structure and interpretation

Sagittal sections of *P. bassensis* showed clear and distinctive alternating opaque and translucent zones seen under transmitted light (Fig. 5.3). The increment banding pattern remained relatively easy to read in older fish despite the narrowing of translucent zones. The primordial area of all otoliths consisted of an opaque region with no obvious increment structure. Immediately adjacent to this was a broad opaque zone with a mean radius ($\pm$s.d.) of 525 $\pm$54 μm that occurred in 25.2% of all sagittae examined (Fig. 5.3). This zone was characterised by being fainter than adjacent opaque zones and not being continuous around the distal face of the otolith. A second broad opaque zone with a mean radius of 877 $\pm$78 μm occurred in 72.2% of all sagittae (Fig. 5.3). The structure of the otolith differed outside this second zone with all sagittae of sufficient radius having a consistent narrow opaque zone with a mean radius of 1200 $\pm$87μm. Beyond this, there were clear and distinctive opaque zones, initially 310 $\pm$68μm apart but generally decreasing in width towards the margin.

Given the variability in the structure and consistency of the opaque zones in the region of the primordium, the definition of the first annual increment was based on

A

500 microns

B

500 microns
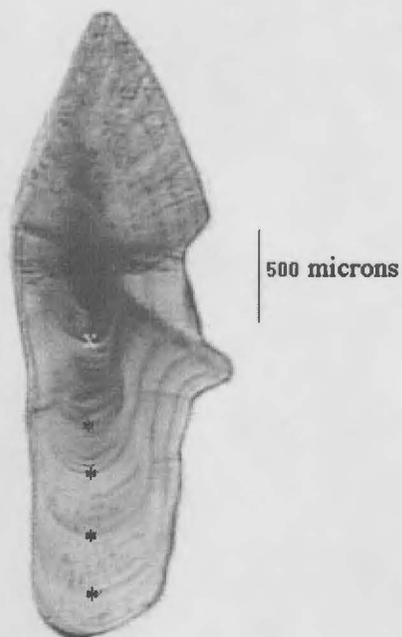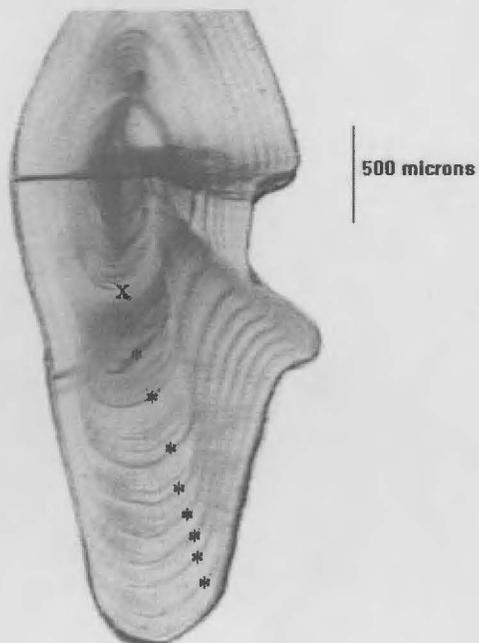
Fig. 5.3   Transverse sections of *Platycephalus bassensis* sagittal otolith viewed with transmitted light: (A) 4 year old and (B) 8 year old. Annual increments marked as *; inner increment seen in 25% of otoliths marked as x.

the relationship between the otolith radius and length of the 0+ cohort. Monthly progression of juvenile size-composition show *P. bassensis* first appeared in samples in January at around 2-7 cm and progressed rapidly through summer to around 9 cm by May (Fig. 5.4). This cohort had reached a mean length of around 11cm by the following November. These lengths are consistent with that previously described as the 0+ age-class from spawning that peaked the previous spring and summer (see Chapter 3). By December this cohort progressed into the 1+ age-class, given the birth date of 1 December, which corresponds to the mid-point of the spawning season.

The monthly progression of the otolith radius of these two age-classes is shown in Fig. 5.5. The otolith radius of the smaller cohort increased from around 546 μm in February to 692 μm in May. By December the mean radius was 872 μm, a radius consistent with the second broad opaque zone visible in the primordial region of most otoliths, and hence defined as the first annual increment. Both the modal length and otolith radius increased in the larger cohort to around 16 cm and 1207 μm respectively by the following November. This is consistent with the radius of the first distinct narrow opaque zone seen in all otoliths and hence defined as the second annual increment.
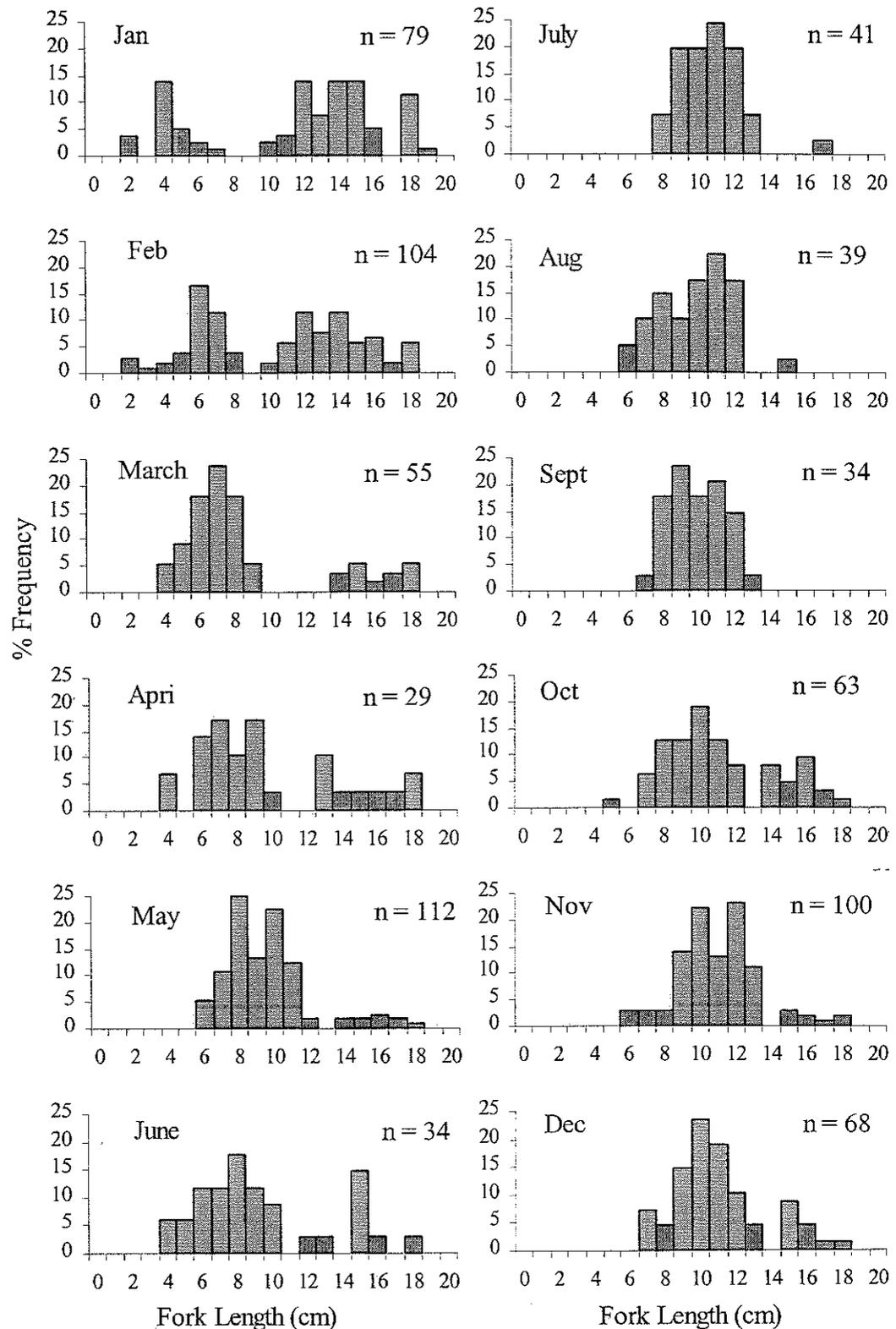
Fig. 5.4 Monthly length-frequency distributions of juvenile *Platycephalus bassensis* from southern and eastern Tasmania pooled from sampling conducted between February 1995 and May 1997. n is sample size.
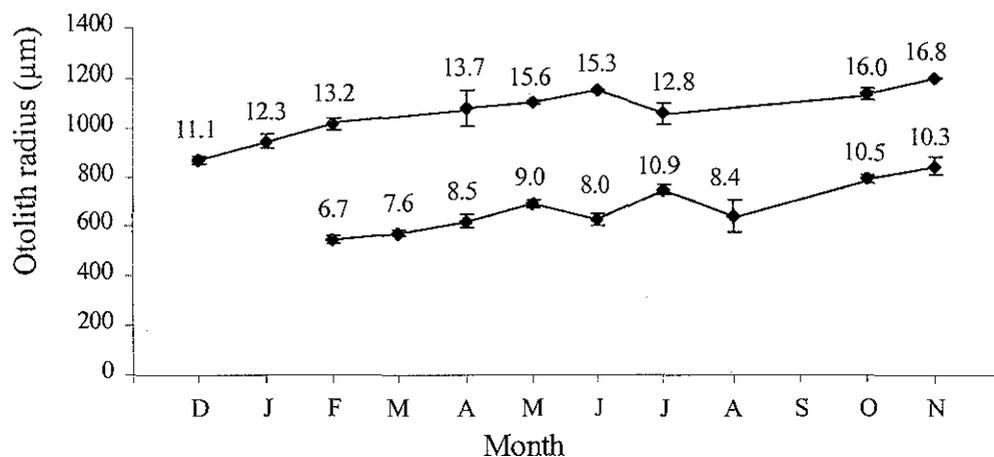
Fig. 5.5 Monthly mean progression of otolith radius of juvenile *Platycephalus bassensis* from southern and eastern Tasmania pooled from sampling conducted between February 1995 and May 1997. Values labels are corresponding mean fish lengths (cm). Error bars are standard error.

5.3.3 Validation

Trends in the monthly pattern of marginal increment development was used to determine the periodicity of annulus formation. For otoliths with one opaque zone the marginal increment rose to a peak in November before decreasing rapidly in December and increasing again over the following months before levelling off in winter (Fig. 5.6). Similar monthly trends were apparent in otoliths with two or more opaque zones with marginal increments falling rapidly in December and January (summer). The rapid drop in marginal increments in summer indicates that translucent material has started to form at that time, with opaque material forming between about July and November. The above trends showing a decline in marginal increments to occur only once in a year indicate that the first eight opaque zones in sectioned otoliths of *P. bassensis* are formed annually. Given that the same trend was displayed in the data pooled for the ninth and subsequent opaque zones, these results indicate that the zones are also formed annually.
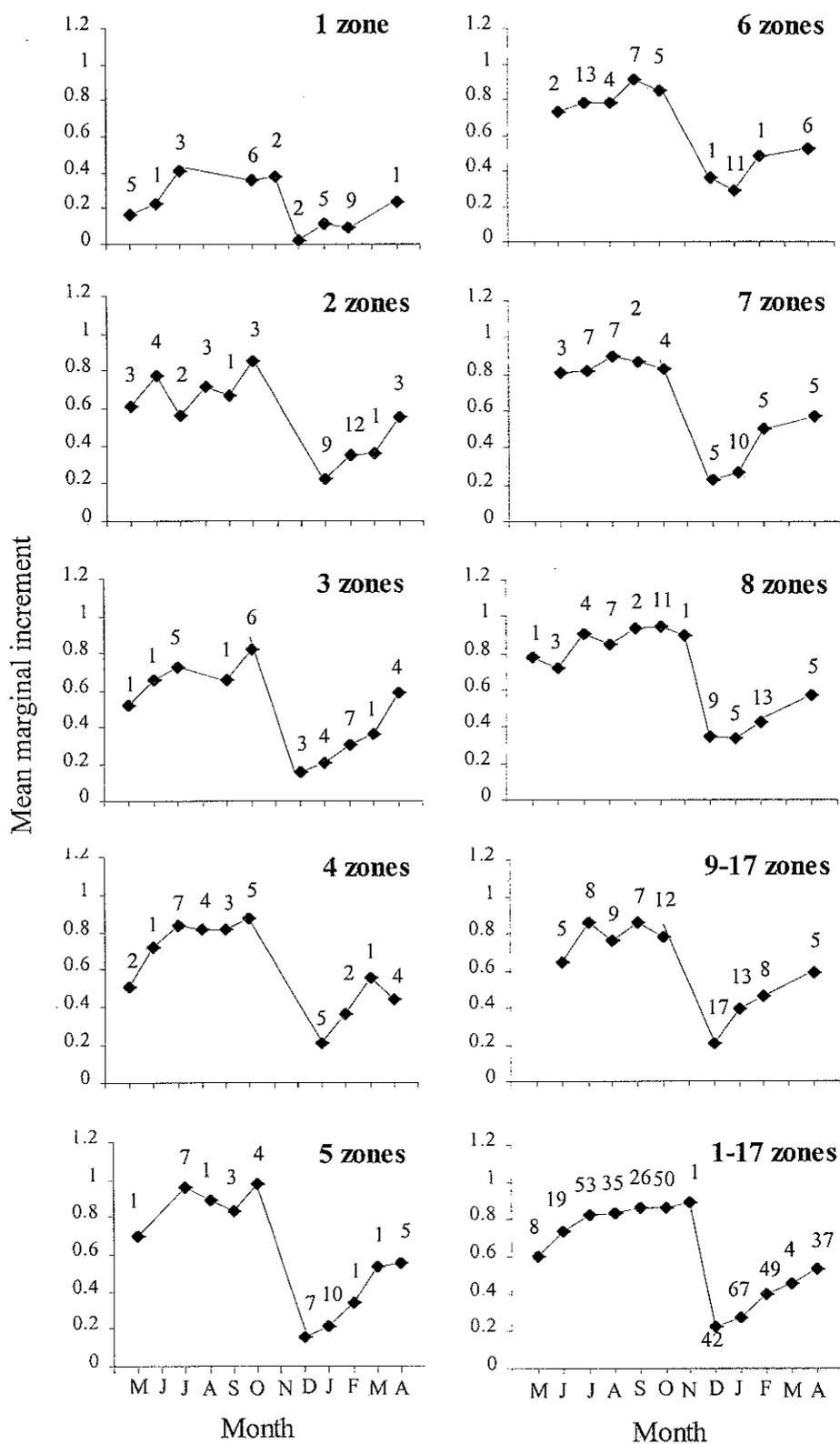
Fig. 5.6 Monthly trends in mean marginal increment for sagittal otoliths of *Platycephalus bassensis*. Value labels are sample size. Error bars are standard error.

5.3.4 Precision of age estimates

The index of average percent error (APE) calculated for repeat readings by the main reader was 0.70 % indicating a high consistency of similarity between readings. This is reflected in the distributions of differences revealing that around 84% of first and second readings were the same (Fig. 5.7). There was no indication of a skewed distribution that would result from consistently assigning higher or lower estimates on the second reading. The index of APE for estimates between the main and second reader was slightly higher at 2.35% reflecting less consistency between readers. Age estimates were the same 46% of the time, with clear evidence of the second reader overestimating age by one year in 42% of all fish.
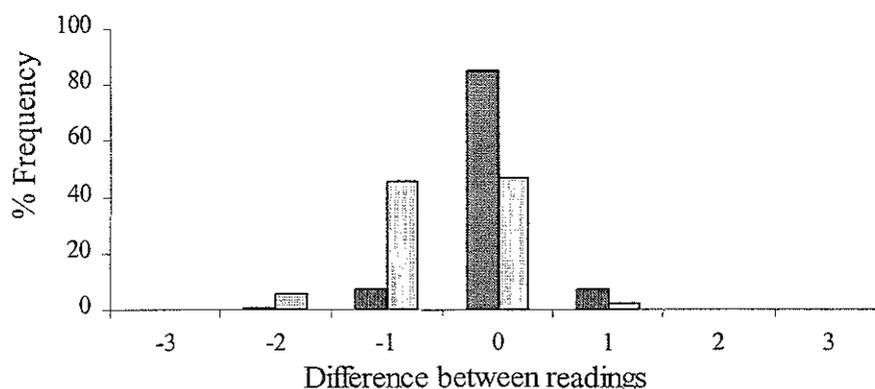
Fig. 5.7 Distribution of differences in estimated ages of *Platycephalus bassensis* for repeat readings by the same reader (dark bars) and a second reader (light bars).

5.3.5 Growth

Von Bertalanffy growth curves were fitted to male and female individual length-at-age data separately and combined (Fig. 5.8). Growth curves were found to be significantly different between males and females (F = 39.9, df 3,591, P<0.001). The von Bertalanffy growth parameters are presented in Table 5.2. The respective asymptotic lengths (L_∞) for males and females were 36.6 cm and 40.5 cm respectively. Mean lengths-at-age for males and females estimated separately, and combined are presented in Table 5.3. The mean length of females is consistently higher than that of males for all age-classes up to 16 years, the oldest age-class consisting of only one fish. There was a broad range of lengths within individual age-classes with a maximum of 7 age-classes present in a 1 cm size-class. Growth is

rapid until around 3 years old and 22-25 cm and then slows appreciably. Maximum ages for males and females were 17 and 16 years old respectively.
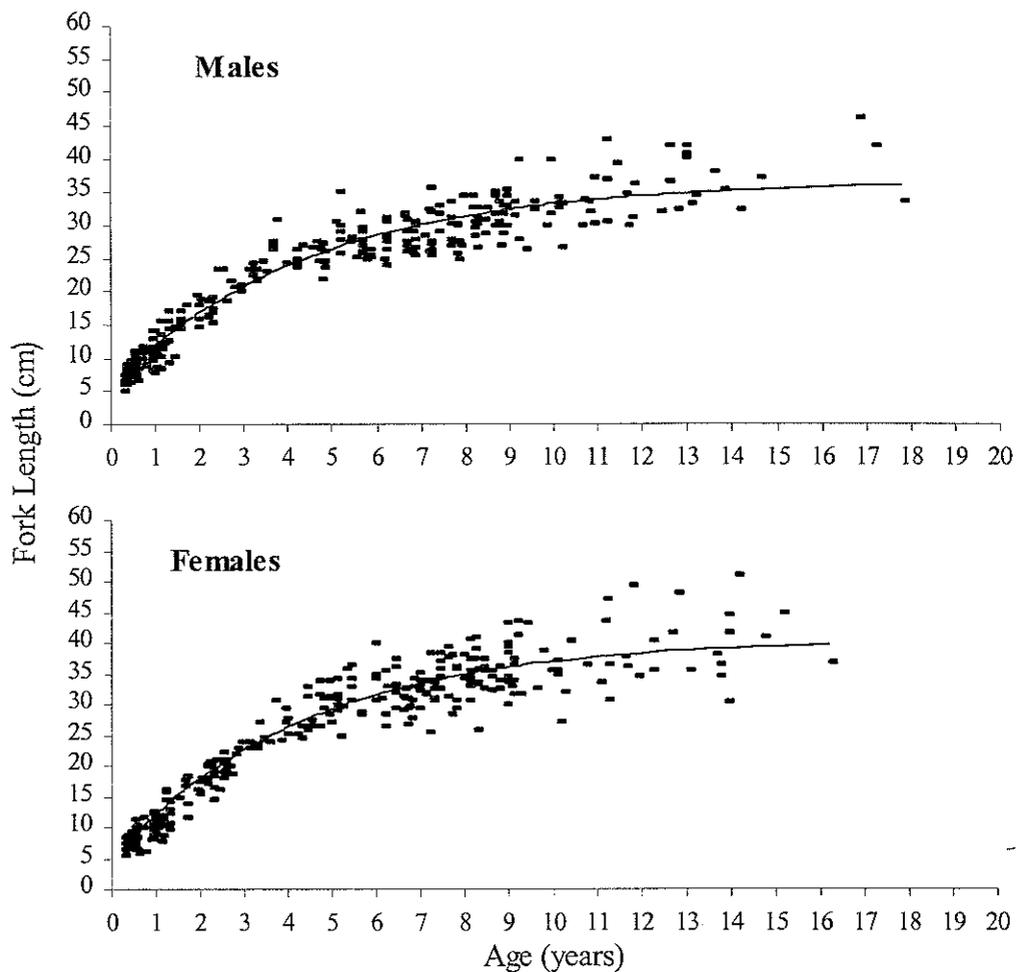
Fig. 5.8 Fitted von Bertalanffy growth curves for male and female *Platycephalus bassensis* from southern and eastern Tasmania.

Table 5.2 Von Bertalanffy growth parameters derived from length at age data for *Platycephalus bassensis* from southern and eastern Tasmania. n is sample size, s.e. is standard error.

		von Bertalanffy growth parameters					
	n	L_∞	s.e.	K	s.e.	to	s.e.
All	597	38.46	0.57	0.23	0.01	-0.63	0.07
Females	307	40.45	0.78	0.23	0.01	-0.52	0.08
Males	290	36.60	0.72	0.22	0.01	-0.79	0.09

Table 5.3 Mean lengths at age for male and female *Platycephalus bassensis* separately, and combined, from southern and eastern Tasmania. n is sample size, s.d. is standard deviation.

Age	Females - Males - Juveniles			Females - Juveniles			Males - Juveniles		
	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.
0	119	8.84	1.87	119	8.84	1.87	119	8.84	1.87
1	63	13.74	2.90	48	12.99	2.73	52	13.23	2.81
2	45	19.37	2.28	30	19.38	2.30	19	18.68	2.45
3	33	24.83	2.37	16	25.27	2.39	17	23.41	2.35
4	35	27.39	3.02	19	28.96	3.06	16	25.53	1.61
5	42	29.72	3.69	19	31.02	3.51	23	27.82	2.65
6	53	30.05	3.12	30	32.54	2.85	23	28.12	2.31
7	53	31.61	3.94	28	33.71	3.42	25	29.25	3.08
8	64	33.43	3.53	35	35.11	3.49	29	31.40	2.32
9	22	34.74	4.73	12	36.45	4.43	10	32.69	4.43
10	19	33.45	3.38	8	34.76	3.91	11	32.49	2.74
11	18	36.94	5.61	10	38.29	6.24	8	35.26	4.51
12	11	39.20	4.73	4	41.40	5.20	7	37.94	4.33
13	11	36.58	3.93	7	37.29	4.68	4	35.35	2.09
14	4	40.38	7.99	2	46.05	7.14	2	34.70	3.39
15	1	44.80		1	44.80		0		
16	2	41.45	6.58	1	36.80		1	46.10	
17	2	37.75	6.01	0			2	37.75	6.01

The relationship between length and weight was examined for males and females with the slopes of the regression of log weight against log length showing no significant difference (ANCOVA, F 2.919, df 1,1204, P>0.1). Given a common slope, there was no significant difference in the intercepts for the two sexes (ANCOVA, F 0.714, df 1,1205, P>0.1). Hence, both sexes and juveniles were combined to produce the relationship between fork length and weight shown in Fig. 5.9 and Table 5.4.
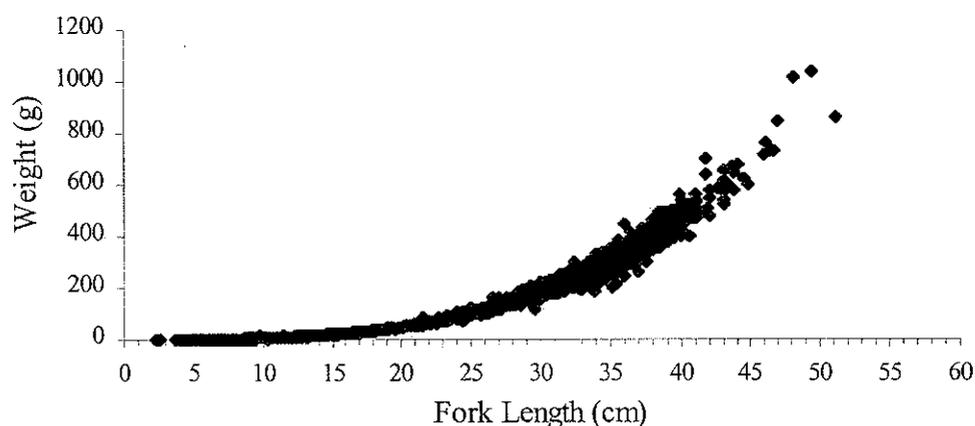
Fig. 5.9 Relationship of fork length (cm) against weight (g) for *Platycephalus bassensis* from southern and eastern Tasmania.

The relationship between otolith weight and age was examined for male and female *P. bassensis* from all years (Fig. 5.10). An examination of the distribution of residuals from the linear regression shows that variance in otolith weight increased with age for both sexes, thereby violating the assumption of homogenous variances. The problem of heteroscedasticity was best solved by logarithmic transformation of otolith weight and age, with the residual plots showing no increase in variance with age. The regression of log otolith weight against log age were significantly different for males and females (ANCOVA, $F=8.186$, df 1,329, $P<0.01$). Hence, the relationship between otolith weight and age was calculated separately for males and females (Table 5.4).
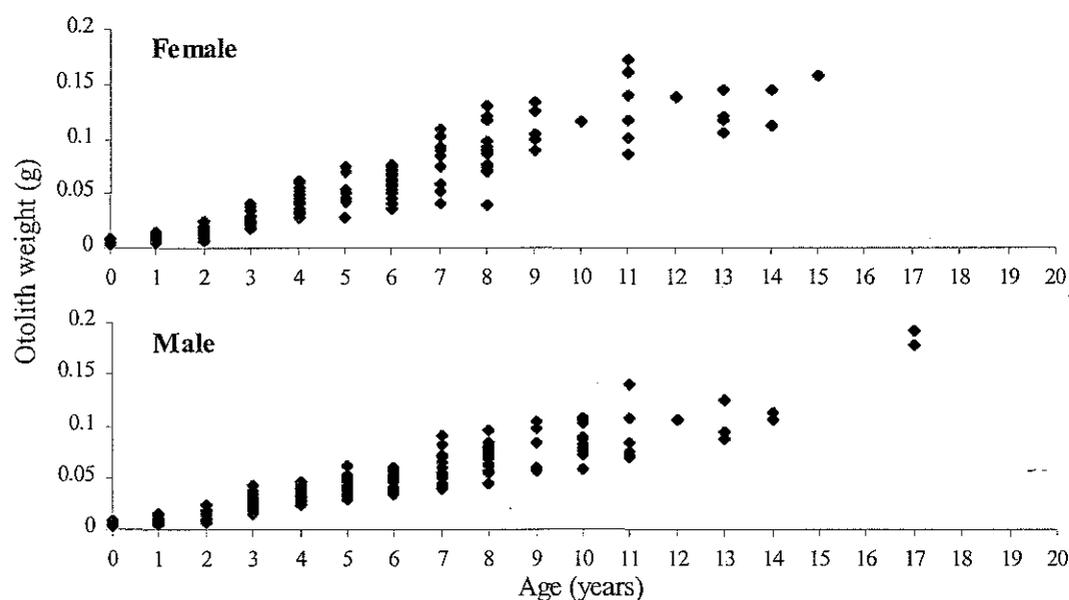
Fig. 5.10 Relationship of otolith weight against age for female and male *Platycephalus bassensis* from southern and eastern Tasmania.

Table 5.4 Length (FL)-weight (WT) and otolith weight (OT)-age regressions for *Platycephalus bassensis* from southern and eastern Tasmania. n is sample size.

Y	X	n	Y = a+bX a	b	r^2
$\log_{10}$WT	$\log_{10}$FL	1743	-2.479	3.207	0.99
Female $\log_{10}$OT	$\log_{10}$AGE	170	-5.367	2.754	0.95
Male $\log_{10}$OT	$\log_{10}$AGE	203	-5.505	2.874	0.94

5.3.6 Age composition

The age composition of male and female *P. bassensis* combined from inshore and shelf regions of southern and eastern Tasmania between 1993 and 1995 is presented in Fig. 5.11. A maximum of 16 age-classes of females and 15 age-classes of males occurred in the samples, dominated by 2 to 8 year old fish, which made up 88% of the sampled population. There was no significant difference in the age composition of males and females (KS test, P>0.5). The high proportion of 6 to 8 year olds in the samples reflects the pooling of age compositions over three years.

This is demonstrated in the separate age compositions for all three years, with 6, 7 and 8 year-old fish dominating in 1993, 1994 and 1995 respectively. These age-classes represent the 1986 year-class indicating that strong recruitment occurred in that year (Fig. 5.12). The high proportion of this year-class in 1995, from samples taken inshore, indicates that this strong recruitment was evident in both the inshore and shelf populations. There is also evidence of the 1989 year-class being weak, particularly in the 1993 and 1995 samples, the higher proportion of this year-class in 1994 reflecting the smaller sample size in that year.

Fig. 5.11 Age composition of male and female *Platycephalus bassensis* from inshore and shelf regions of southern and eastern Tasmania between 1993 and 1995. n is sample size.
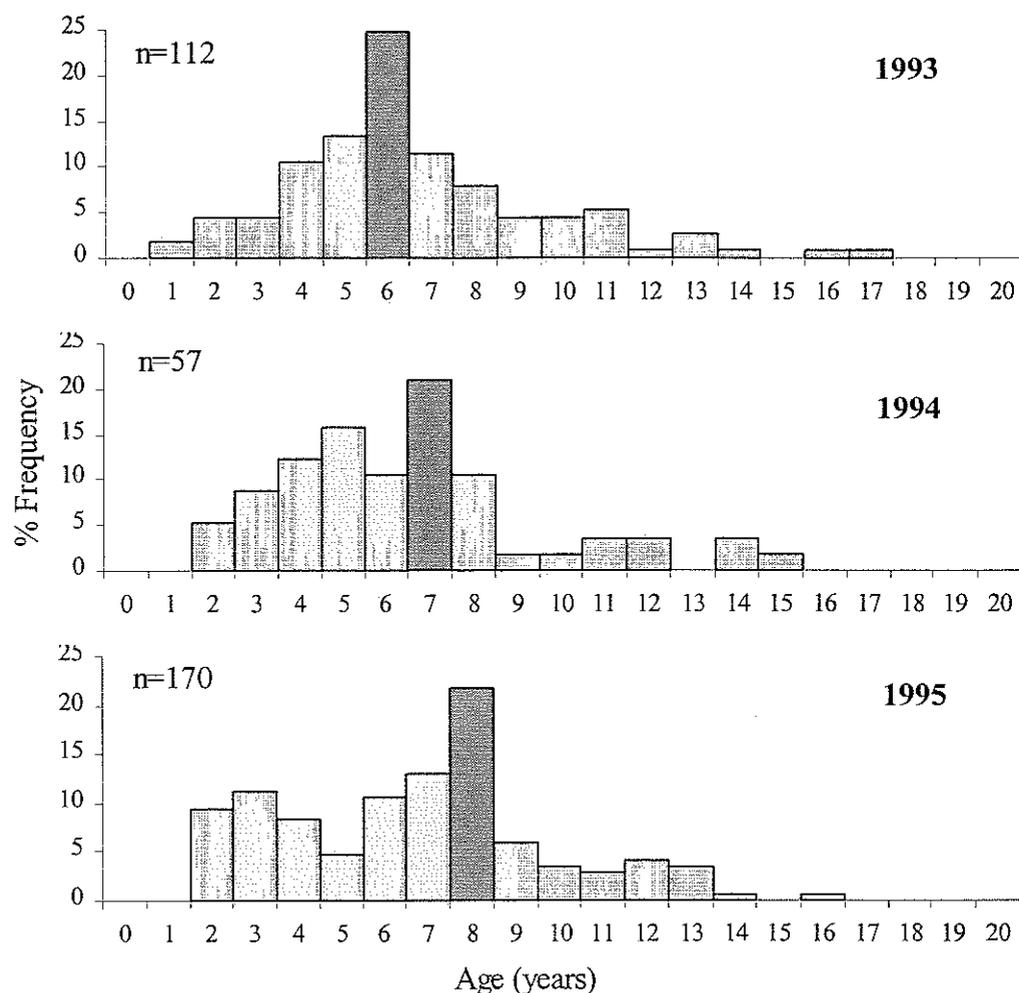
Fig. 5.12 Year-class distribution of male and female *Platycephalus bassensis* from inshore and shelf regions of southern and eastern Tasmania in 1993, 1994 and 1995. Dark bar represents the 1986 year-class. n is sample size.

The age composition of male and female *P. bassensis* caught inshore with gill-nets and beam trawl and by demersal trawl on the shelf is presented in Fig. 5.13. The distribution of 0+ fish and unsexable 1+ fish appear to be restricted to inshore waters and are not included in this analysis (see Chapter 4). As discussed earlier with size compositions, a direct comparison of overall age composition by depth is biased due to selectivity of 1+ and 2+ males and females in gill-nets in inshore samples, although the inclusion of beam trawl samples may act reduce this bias, although the catchability of these age-classes by beam trawl is uncertain. The small proportion of 1+ and 2+ males and females on the shelf reflects the low abundance of these age-classes in that region as fish move onto the shelf close to the size at maturity (22-24 cm) (see Chapters 3 and 4). There was a significant difference in the age composition between inshore and shelf regions (KS test, P<0.001), although this is

strongly influenced by the high abundance of 6+ and 7+ fish that was sampled on the shelf in 1993 and 1994 respectively, and 8+ fish inshore in 1995, all representing the strong 1986 year-class. Overall, there was no evidence of age-structuring of males and females between inshore and shelf regions with most age-classes present in both regions and no clear increase in age with depth resulting from an age-based migration.
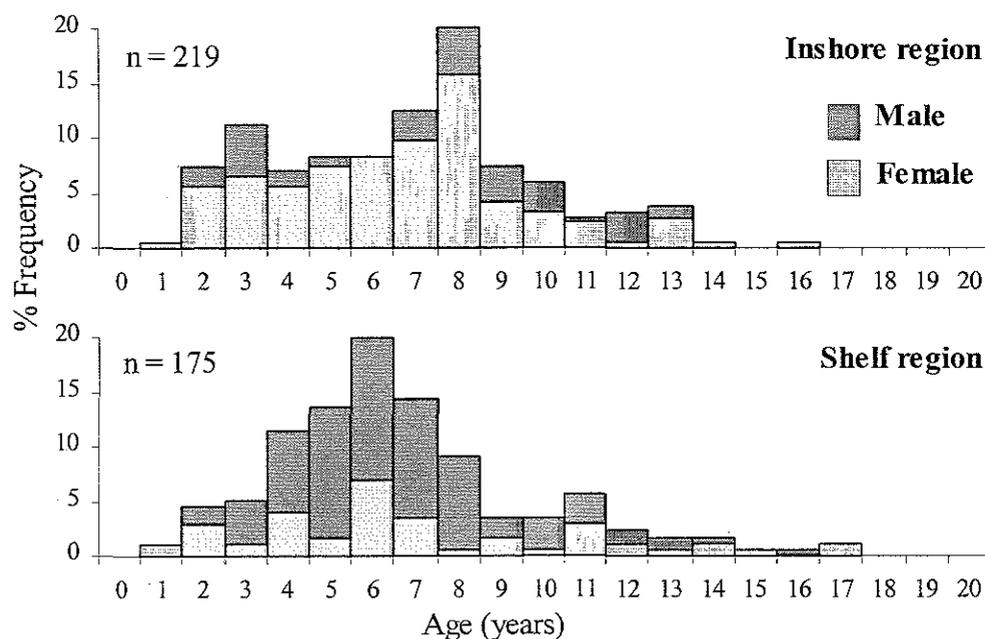
Fig. 5.13. Age composition of male and female *Platycephalus bassensis* from inshore and shelf regions of southern and eastern Tasmania between 1993 and 1995. n is sample size.

5.4 Discussion

5.4.1 Validation

For validation to be considered complete annual periodicity of increment formation must be established on otoliths with differing numbers of increments (Beamish and McFarlane 1983). Trends in marginal increments have been commonly been used to establish that increments are formed annually (Beckman *et al.* 1989, Massey and Horn 1990, Hyndes and Potter 1996). In the present study, annual trends in marginal increments of sagittae of *P. bassensis* were consistent regardless of the number of opaque zones, confirming that one increment is formed each year throughout growth. The consistent decrease in marginal increments in December indicates that translucent material starts to form in early summer. These trends in marginal increments are consistent with that observed in sagittae of *P. speculator* where one

increment was formed each year, irrespective of the number of increments, although increment formation in *P. speculator* is complete in early spring (Hyndes *et al.* 1992b), some months earlier than *P. bassensis*. The difference in timing may be related to the later increase in water temperatures in southern and eastern Tasmania. There was no indication of variability in the timing of annuli formation with increasing age.

5.4.2 Growth

The monthly progression of the 0+ cohort indicates rapid growth during summer and autumn (Jan-May) when water temperatures are at a maximum. Growth then slows appreciably during winter and spring (June-Nov) to reach approximately 7-13 cm after one year. The absence of a distinct opaque zone in the otoliths of this cohort is consistent with the conclusion that this represents the 0+ age-class. A single opaque zone became discernible in otoliths of this cohort by December, now the 1+ age-class. This cohort progressed to a mean length of around 17 cm by the following December when otoliths possessed two opaque zones, therefore representing 2+ fish. These mean lengths-at-age for 1+ fish are consistent with that of *P. bassensis* from Port Phillip Bay as defined from modal progressions, but are considerably larger than the 15 cm defined for 2+ fish (Brown 1978). The smaller size of 2+ fish in Port Phillip Bay can be attributed to the fact that sampling of this age-class was restricted to winter before the period of faster growth in late spring an early summer. Such growth rates are slower and less variable than those of the corresponding age for *P. speculator* which reach 19-31 cm after one year and 21-40 cm after two years (Hyndes *et al.* 1992b). Despite the inclusion of considerable numbers of juveniles in the present study, the values for t_0 for males and females were -0.52 and -0.79 respectively, indicating that the von Bertalanffy growth curve poorly is a reasonable representation of growth of juvenile *P. bassensis*.

Growth of male and female *P. bassensis* is relatively rapid for the first 3 years, slowing appreciably at around 22-25 cm which is consistent with the onset of maturity. After 3-4 years there was an increasing variation in size-at-age with fish at the minimum legal length of 30 cm ranging from 4 to 11 years old. Females are larger than males at corresponding ages, with growth curves diverging with increasing age after reaching maturity. A larger female size appears to be a life-history strategy to increase reproductive potential through increased fecundity in

larger fish (Roff 1984). As there was little difference in the overall age composition between sexes, the larger female size can be attributed to significantly higher growth rates and not greater longevity. However, as there was some evidence of a higher proportion of females in the older age-classes, the predominance of larger females in the population may also result from a higher rate of mortality of older males. The dominance of males on the shelf reflects the smaller proportion of fish above 35 cm in that region.

The maximum ages of 17 years for males and 16 years for females found in the present study is significantly higher than that of 7 years for males and 9 years for females reported for *P. bassensis* from Victorian waters (Brown 1978). The lower maximum ages may reflect either spatial variations in the age structure or underestimates of age in older fish due to the use of whole otoliths by Brown (1978). Firstly, the presence of older fish in inshore waters in the present study indicates that such age-classes are not restricted to shelf waters, and are likely to occur in Port Phillip Bay. Secondly, a comparison of whole and sectioned sagittae in *P. speculator* found whole otoliths underestimated age by as much as six years in old fish (Hyndes *et al.* 1992b). This is consistent with previous studies where ages estimates were lower from whole otoliths compared to those sectioned or broken and burnt (Beamish 1979, Campana 1984, Collins *et al.* 1988, Hyndes *et al.* 1992b). The consistent marginal increment trend in fish aged 9-16 also supports the maximum ages found in the present study. The use of whole otoliths and smaller representation of juveniles in the study of Brown (1978) also resulted in considerable differences in the von Bertalanffy growth parameters compared to those in the present study.

5.4.3 Age Composition

There was some evidence of differences in the age composition of larger juvenile and adult *P. bassensis* between inshore and shelf regions of southern and eastern Tasmania. The relative abundance of the youngest age-classes will be influenced, however, by the decreased catchability of small fish to the particular sampling gear, with the age compositions of shelf samples reflecting fish caught by demersal trawl with a codend mesh size of 20 mm. As detailed in Chapter 4, the use of this mesh size would result in lengths at 50% and 0% selection to be somewhat less than 11 cm and 16 cm, respectively, indicating that the 2+ and older age-classes were fully recruited to the demersal trawl and therefore representatively sampled. The small

proportion of 2+ and 3+ fish on the shelf therefore reflects the low abundance of these age-classes in that region as fish move seasonally onto the shelf close to the size at maturity (22-24 cm) (see Chapter 4). Overall, there was no evidence of age-structuring of males and females between inshore and shelf regions. Most adult age-classes were present in both regions and there was no distinct increase in age with depth that would result from an age-based migration of fish from a inshore nursery area into adult grounds in deeper water.

A maximum of 17 age-classes of *P. bassensis* were present in inshore and shelf waters of southern and eastern Tasmania, dominated by 2 to 10 year old fish which made up around 88% of the population. There was clear evidence of variable recruitment in the population of *P. bassensis*, with the 1986 year-class representing around 20% of the population in all three years sampled. While this age composition will be influenced by size/age dependant gear selectivity, as previously discussed, 3+ and older age-classes were fully recruited to the demersal trawl and therefore representatively sampled in 1993 and 1994. As the 1995 samples were from the inshore region, it is evident that this strong year-class was present both inshore and on the shelf.

The data also suggests there were few 3+ fish present on the shelf in 1993, representing the 1989 year-class. This poor year-class was also apparent in 1995 which consists exclusively of inshore fish caught by gill-net. While there was evidence of selectivity in the gill-nets of the fish <28 cm (see Chapter 4), the low abundance of the 1989 year-class in 1995, representing 5+ fish, is unlikely to be biased given the mean length-at age of 5+ male and female *P. bassensis* is 28 cm and 32 cm, respectively. This is further supported by the higher proportion of younger age-classes in the gill-net samples in that year despite their lower catchability. An examination of the likely causes of the recruitment variations evident in the population of *P. bassensis* in southern and eastern Tasmanian waters is presented in Chapter 9.

Chapter 6   Reproductive biology and early life-history of jackass morwong (*Nemadactylus macropterus*)

6.1 Introduction

Jackass morwong (*Nemadactylus macropterus*) is a demersal species commonly found in coastal and continental shelf waters of southern Australia, New Zealand and South America (Gomon *et al.* 1994). In Australia, the species is distributed from about Sydney (New South Wales) to Perth (Western Australia), including Tasmania. Spawning occurs in shelf waters of southern New South Wales and Victoria between January and June, with the peak in spawning activity from April to June (Hobday and Wankowski 1987b). In Tasmania, spawning peaked between March and May (Lyle and Ford 1993), which is consistent with *N. macropterus* in New Zealand where spawning commences and finishes earlier at higher latitudes (Tong and Vooren 1972). The estimated size at maturity for *N. macropterus* in southern New South Wales and Tasmania is around 28 cm for males and 31 cm for females (Hobday and Wankowski 1987b, Lyle and Ford 1993) and equates to an age at maturity of 3 years (Smith 1989).

While spawning occurs throughout the species distributional range in south-eastern Australian shelf waters, the finer spatial distribution of spawning has not been examined in detail in this region. In New Zealand, spawning is reported to occur on the outer-shelf at a number of distinct spawning areas, with eggs concentrated in surface waters (Tong and Vooren 1972, Robertson 1978). In eastern Tasmanian waters, *N. macropterus* larvae were concentrated at the surface in waters offshore suggesting a rapid advection of larvae off the shelf due to the predominance of westerly winds in the region (Bruce *et al.* 1997). Such transport, however, is likely to vary from year to year as the regional hydrography of eastern Tasmanian shelf waters show considerable interannual variability often associated with El Niño/Southern Oscillation (ENSO) events (Harris *et al.* 1987). The influence of these oceanographic variations on egg and larval transport of *N. macropterus* has not been documented.

As only limited information is available on the reproductive biology of *N. macropterus* from southern and eastern Tasmania, the aim of this chapter is to estimate the size at sexual maturity for male and female *N. macropterus* and describe

the seasonal pattern of gonadal development from these waters. In addition, the intra- and interannual variations in sea-surface temperature and thermal stratification of eastern Tasmanian shelf waters during the spawning period are described and the subsurface distribution of larval *N. macropterus* examined. The influence of variations in hydrography on larval distributions is discussed.

6.2 Methods

6.2.1 Study locality and sampling regime

Nemadactylus macropterus were sampled seasonally on the inner- (10-50 m), mid- (50-100 m) and outer-shelf (100-200 m) waters of eastern Tasmania and inner- and mid-shelf waters of Storm Bay in eight out of the nine seasons between summer 1993 and summer 1995. Demersal tows were conducted at a maximum of 23 random stations on the east coast and 20 in Storm Bay. In each season, a maximum of 50 fish were retained in each stratum in each sampling area and processed for biologicals back at the laboratory. At each station sea-surface temperatures were recorded from the on-board temperature recorder ($\pm$0.1° C). Full details of shelf sampling areas, survey design and gear and biological sampling is presented in Chapter 2. In addition, *N. macropterus* were sampled from the commercial trawl fishery off eastern Tasmania in October 1994 and processed for biologicals.

The distribution of cheliodactylid larvae on the shelf of eastern Tasmania was examined from plankton samples collected at three fixed cross-shelf stations on five transects from Bicheno in the north (Transect 1) to Marion Bay in the south (Transect 5). Full details on ichthyoplankton survey design, sampling gear and deployment is presented in Chapter 2. In brief, samples were collected from oblique tows with a 45 cm diameter bongo net with 500 μm mesh on two occasions in January 1989 and 1990. The depth distribution of larvae was assessed in January 1989 on Transect 5, where a series of six oblique tows was made in order of progressively shallower depths between 78 m and the surface. Temperature ($\pm$0.1°C) and depth ($\pm$0.1 m) were recorded with a temperature/depth probe which was attached to the net during each tow. Sea-surface temperature and thermal stratification of the shelf of eastern Tasmania was assessed from cruises conducted monthly from January to April 1989 to 1991.

6.2.2 Laboratory methods

Nemadactylus macropterus were processed for biological data, including fork length (FL) (to the nearest millimetre), total weight (to the nearest gram) and sex, gonad stage and gonad weight (to the nearest gram).

Gonosomatic index (GSI) was calculated using the formula:

$$GSI = \frac{gonad\ weight}{total\ weight} \times 100$$

Gonads were staged macroscopically according to the criteria modified from Blackburn and Gartner (1954) (see Section 2.3, Table 2.4). Size at first sexual maturity was defined as the fork length at which 50% of males and females collected over the spawning season were mature. Ovaries and testes were considered mature if their gonads were equivalent to Stage 3 or greater.

Cheilodactylid larvae were sorted from plankton samples in a rotatable sorting ring under a dissecting microscope. All unspecified body lengths refer to notochord length (NL) in preflexion and flexion larvae (tip of the snout to the posterior end of the notochord), and to standard length (SL) (i.e. tip of the snout to the posterior region of the hypural plate) in postflexion larvae and juveniles. Larval measurements were made using an ocular micrometer.

6.3 Results

6.3.1 Size at maturity

Nemadactylus macropterus were considered mature if macroscopic staging showed at least the presence of developing oocytes in females and developing testes in males (Stage 3 or greater). The smallest male and female *N. macropterus* to reach maturity were 25.0 and 23.0 cm, respectively (Fig. 6.1). All males larger than 29.0 cm and all females larger than 27.0 cm were mature. A comparison of the proportion of mature fish in each 1 cm size-class collected over the spawning season reveals that 50% of males and females were mature by 27.0 and 25.0 cm, respectively.
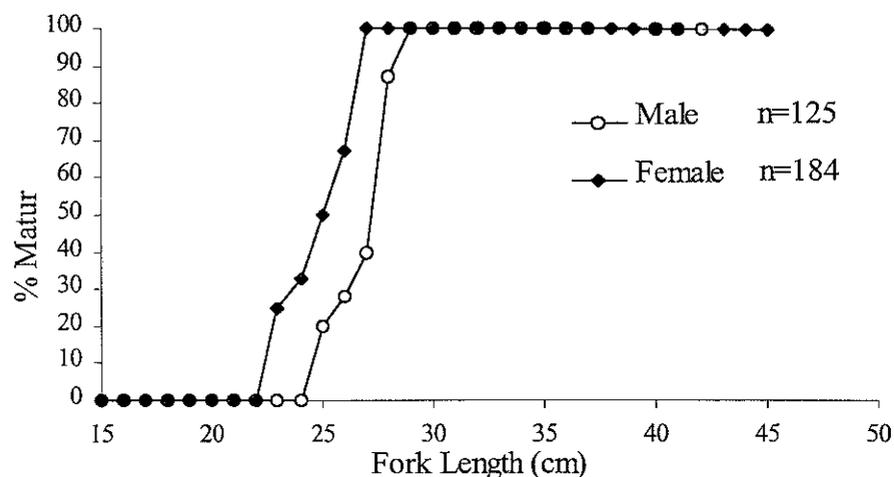
Fig 6.1 Proportion of mature male and female *Nemadactylus macropterus* by 1.0 cm size-classes. n is sample size.

6.3.2 Gonadal development

Trends in mean gonadosomatic index (GSI) for male and female *N. macropterus* were analysed seasonally from summer 1993 to 1995. Seasonal mean GSI's showed the same overall trend for both males and females increasing from a low in winter (July 1993 and August 1994) and spring (September 1993 and October 1994) to a peak in summer (January) before declining again in autumn (April) (Fig. 6.2). The decrease in GSI's in autumn from the summer peak reflects the increasing proportion of fish with stage 2 gonads indicating that a proportion of the population had finished spawning by that time. There was little difference in the summer GSI's between years. This cycle is also reflected in the seasonal trend in gonad stages with all males and females in the resting phase (stage 2) in winter and most fish late developing, ripe or running ripe ($\geq$stage 4) in summer and autumn (Fig. 6.3). Gonads peaked at 9% and 12% of total body weight for males and females, respectively, in January.

6.3.3 Hydrography

Sea-surface temperatures on the shelf of eastern Tasmania during summer and autumn of 1989 to 1991 and 1993 to 1994 reflected seasonal warming and the changing influence of warmer northerly, and cooler southerly water on the region. Temperatures varied markedly between years, with 1989 being the warmest period, 1991 and 1994 the coolest, and 1990 and 1993 somewhat intermediate. Temperatures showed variations both along the coast and across the shelf, reflecting the fact that warmer northerly waters originated offshore and at times moved south-west onto the shelf.
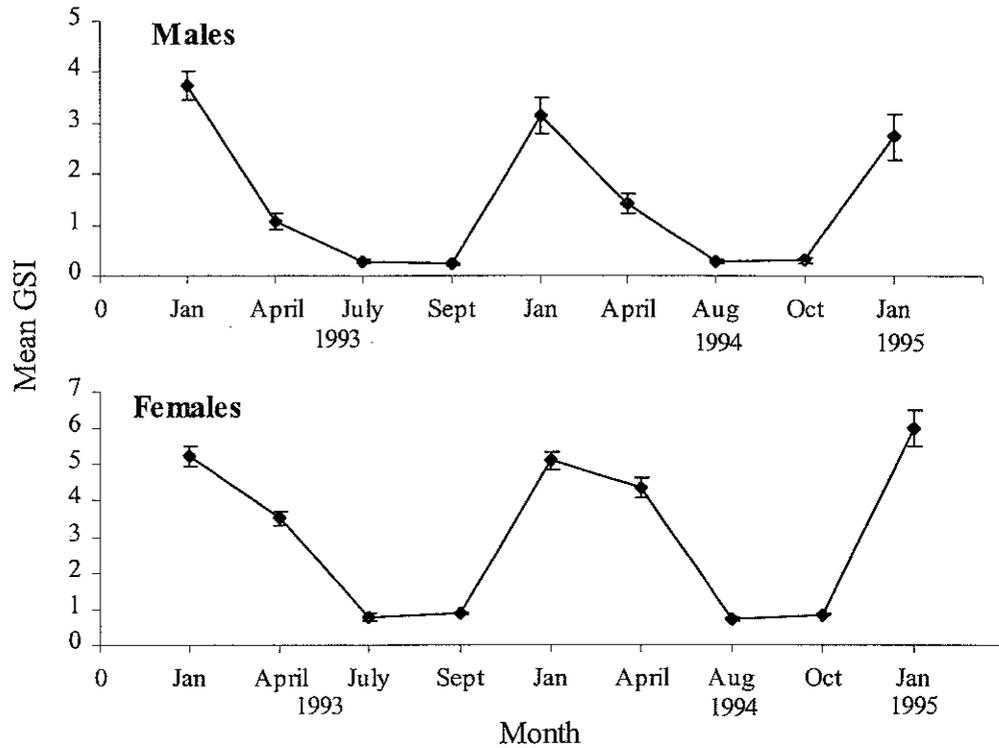
Fig. 6.2 Mean gonadosomatic indices (GSI) for male and female *Nemadactylus macropterus* caught on the shelf between January 1993 and January 1995. Error bars are standard error.
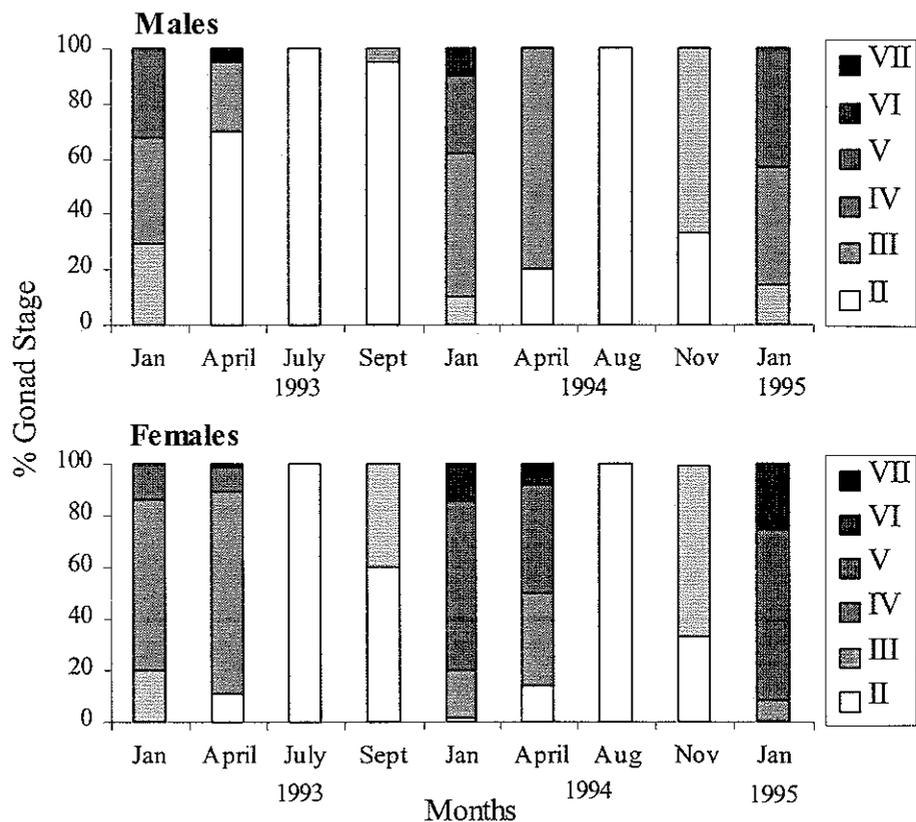
Fig. 6.3 Percentage of gonad stages for male and female *Nemadactylus macropterus* caught on the shelf between January 1993 and January 1995.
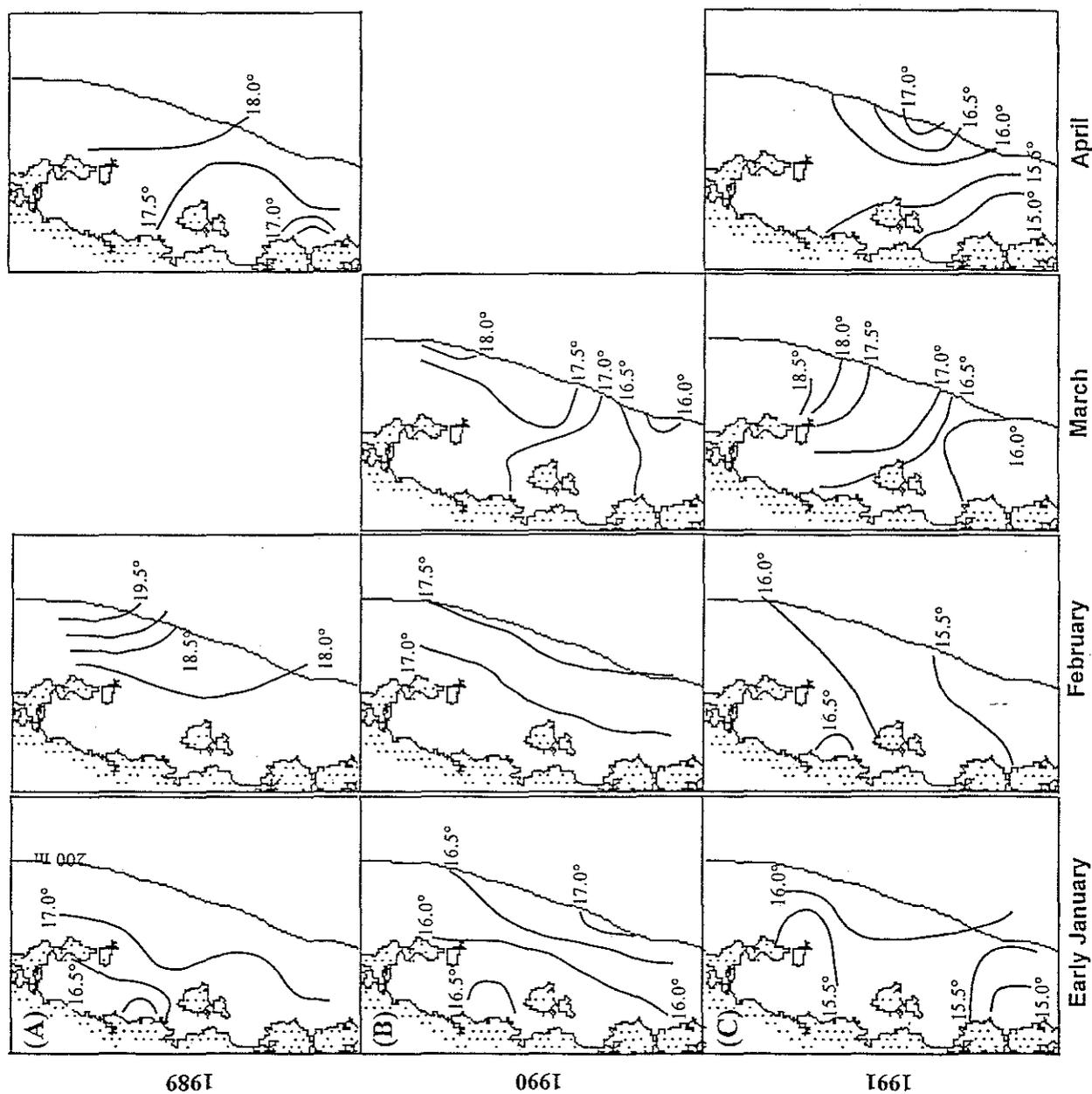
Fig. 6.4 Monthly sea-surface temperatures ($^\circ$ C) between January and April of (A) 1989, (B) 1990 and (C) 1991 on the shelf of eastern Tasmania.

The hydrography of Tasmanian east coast shelf waters in the summer and autumn 1989 to 1991 is described from on-board measurements of sea-surface temperature from the Maria Island area (Fig. 6.4A-C), and broader satellite images (Fig. 6.5A-C). In January 1989, sea-surface temperatures on the southern part of the shelf ranged from $16.0°$ to $17.4°$ C with warmest water on the outer-shelf (Fig. 6.4A). The warmer water is East Australian Current (EAC) water, characterised by the $17°$ C isotherm, and is clearly visible in satellite images moving over the shelf-break from the north-east (Fig. 6.5A). By mid February, EAC water had flooded the entire shelf of the east coast, with temperatures between $17.8°$ C and $19.7°$ C. Warm EAC water still dominated the shelf in April, although some cooling inshore was apparent.

In January 1990, sea-surface temperatures in the vicinity of Maria Island were between $16.0°$ and $17.0°$ C (Fig. 6.4B), with evidence in the satellite image of warmer EAC water moving over the shelf in the north (Fig. 6.5B). By February, warm EAC water up to $17.6°$ C was present on the outer-shelf in the south with cooler water inshore. The satellite image confirms that this pattern was consistent along the entire east coast at that time. Cooler water of southerly origin had advanced onto the southern part of the east coast by March resulting in a strong thermal gradient between warmer EAC water north of Maria Island (Fig. 6.4B). Several thermal fronts were evident along the east coast in April, with filaments of EAC water dominating the shelf in the north and cooler water of subantarctic origin dominant in the south (Fig. 6.5B).

Sea-surface temperatures were consistently cooler during 1991 reflecting the reduced influence of warmer northerly EAC water (Fig. 6.4C). In January, water was between $14.8°$ and $16.1°$ C with little variation by February when temperatures were up to $3.2°$ C cooler than for the same period in 1989. The satellite images confirm the dominance of cooler water of subantarctic origin along the entire east coast in these months, although a very warm filament of EAC water is present in the far north in February (Fig. 6.5C). This EAC water had moved on the shelf as far south as Maria Island by mid March, with temperatures up to $2.6°$ C cooler in the south. The satellite image of late March confirms that this EAC water was present on the shelf for several weeks. By mid April, the EAC water had retreated onto the outer-shelf as cooler water was driven up from the south.
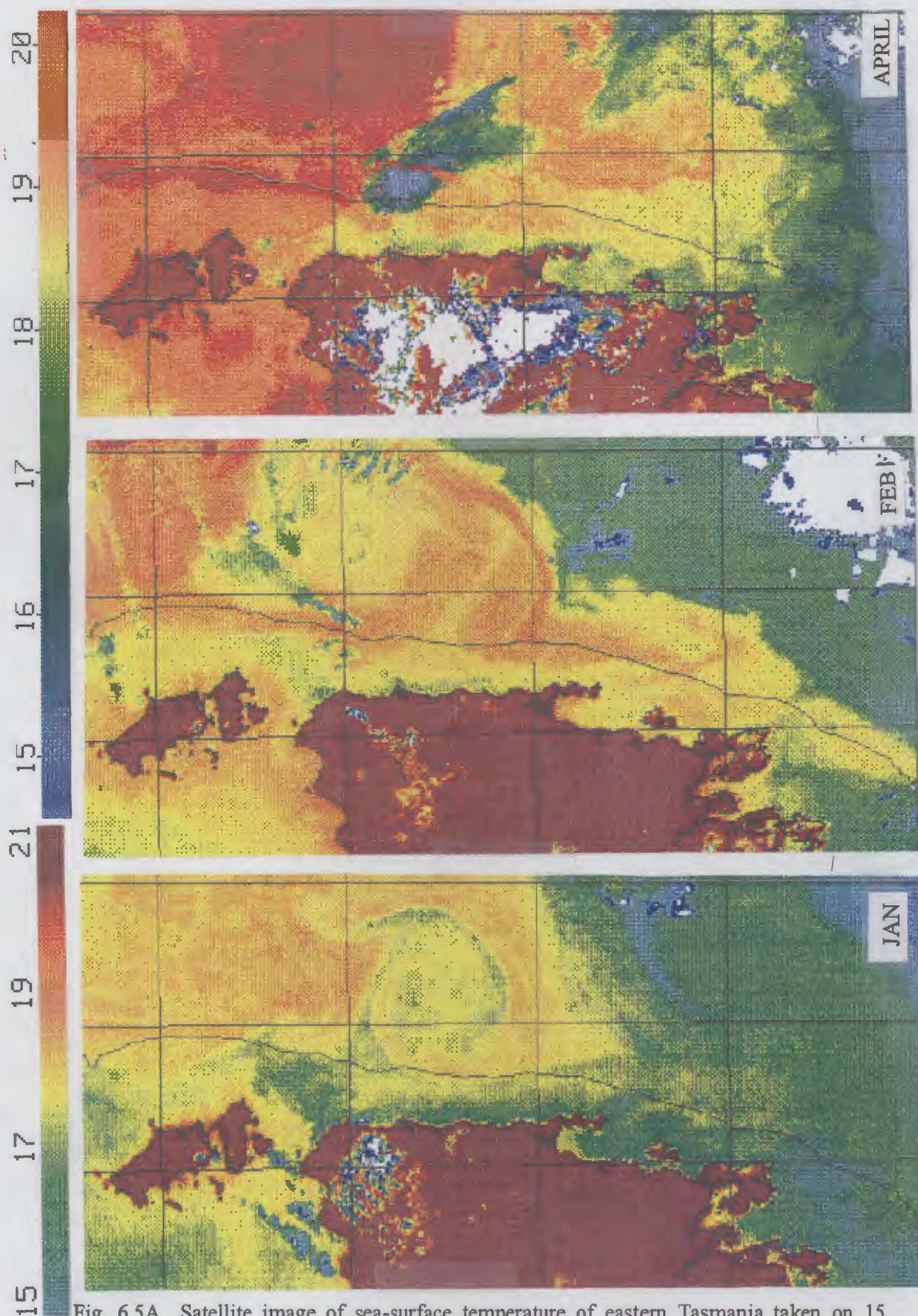
Fig. 6.5A Satellite image of sea-surface temperature of eastern Tasmania taken on 15 January 1989, 11 February 1989 and 4 April 1989. Land red; cloud white. The shelfbreak is shown by the dark line along the 200 m contour. Note the difference in temperature scale for image from 15 January 1989.
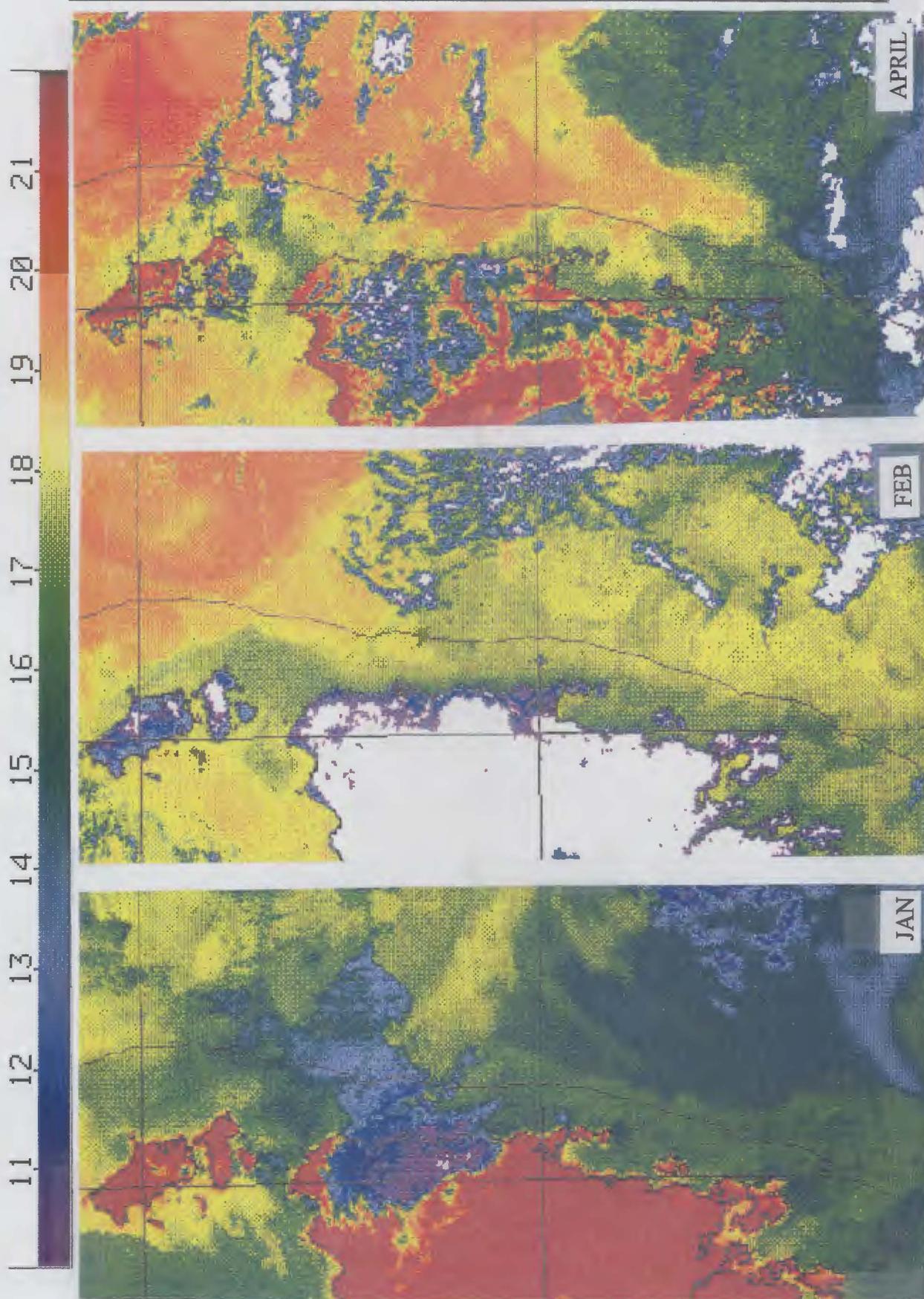
Fig. 6.5B Satellite image of sea-surface temperature of eastern Tasmania taken on 10 January 1990, 17 February 1990 and 19 April 1990. Land red; cloud white. The shelfbreak is shown by the dark line along the 200 m contour.
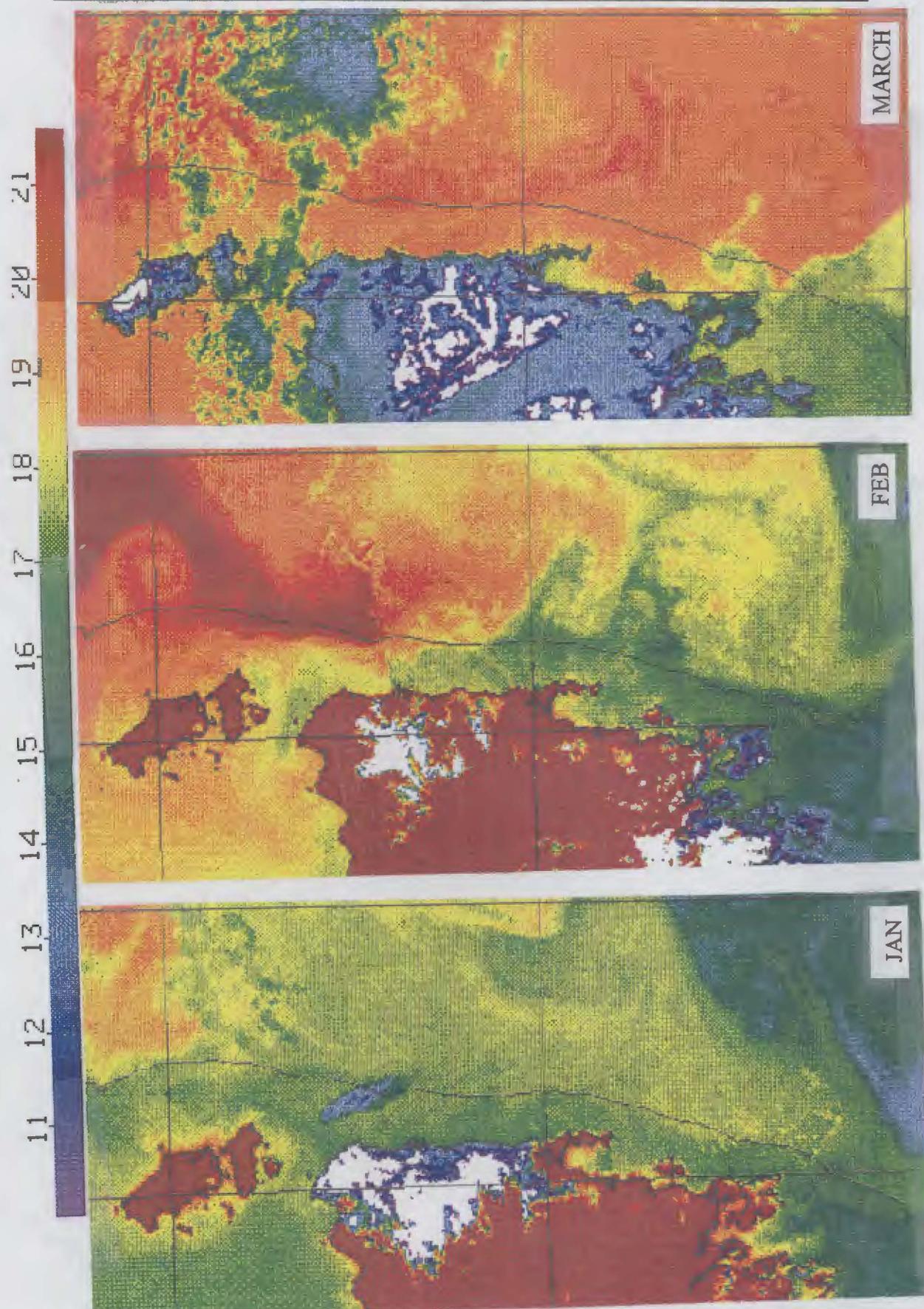
Fig. 6.5C Satellite image of sea-surface temperature of eastern Tasmania taken on 12 January 1991, 20 February 1991 and 26 March 1991. Land red or blue; cloud white. The shelfbreak is shown by the dark line along the 200 m contour.

Temperatures were even on the shelf in January 1993 at around 17.0° C, with evidence of cooling by April of that year (Fig. 6.6). Shelf water in January 1994 was up to 2.0° C cooler than for the same period in 1993, although temperatures increased to around 16.5° C by April.
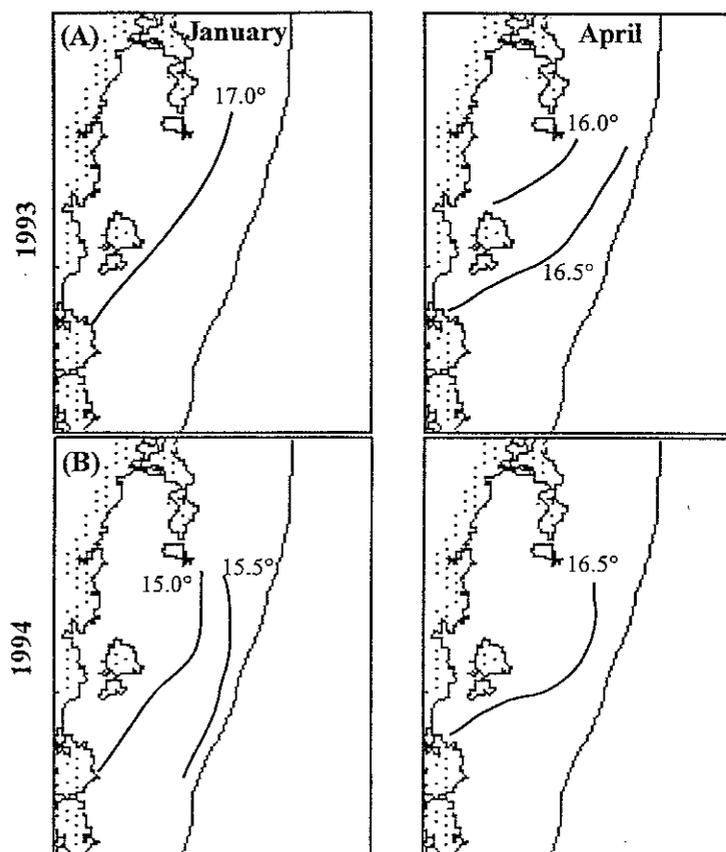
Fig.6.6 Sea-surface temperatures (° C) during January and April of (A) 1993 and (B) 1994 on the shelf of eastern Tasmania.

Vertical temperature structure of the shelf of eastern Tasmania during summer and autumn of 1989, 1990 and 1991 reveals clear interannual differences in the amount of thermal stratification (Fig. 6.7). A strong thermocline is evident in January 1989 between warm water of northerly origin and cooler bottom water, forming a shallow (~30 m) mixed layer. This persisted in February, and although it weakened during April, there was still a difference of ~3.0° C between surface and bottom waters at that time. In January 1990, waters were only poorly stratified with evidence of a weak thermocline at around 60 m. The thermal structure remained the same during February and March with a weak thermocline persisting. The water column was well mixed during the summer and autumn of 1991 with little sign of warming or thermal stratification except for a period in April when an influx warm surface waters onto the outer-shelf resulted in some stratification.
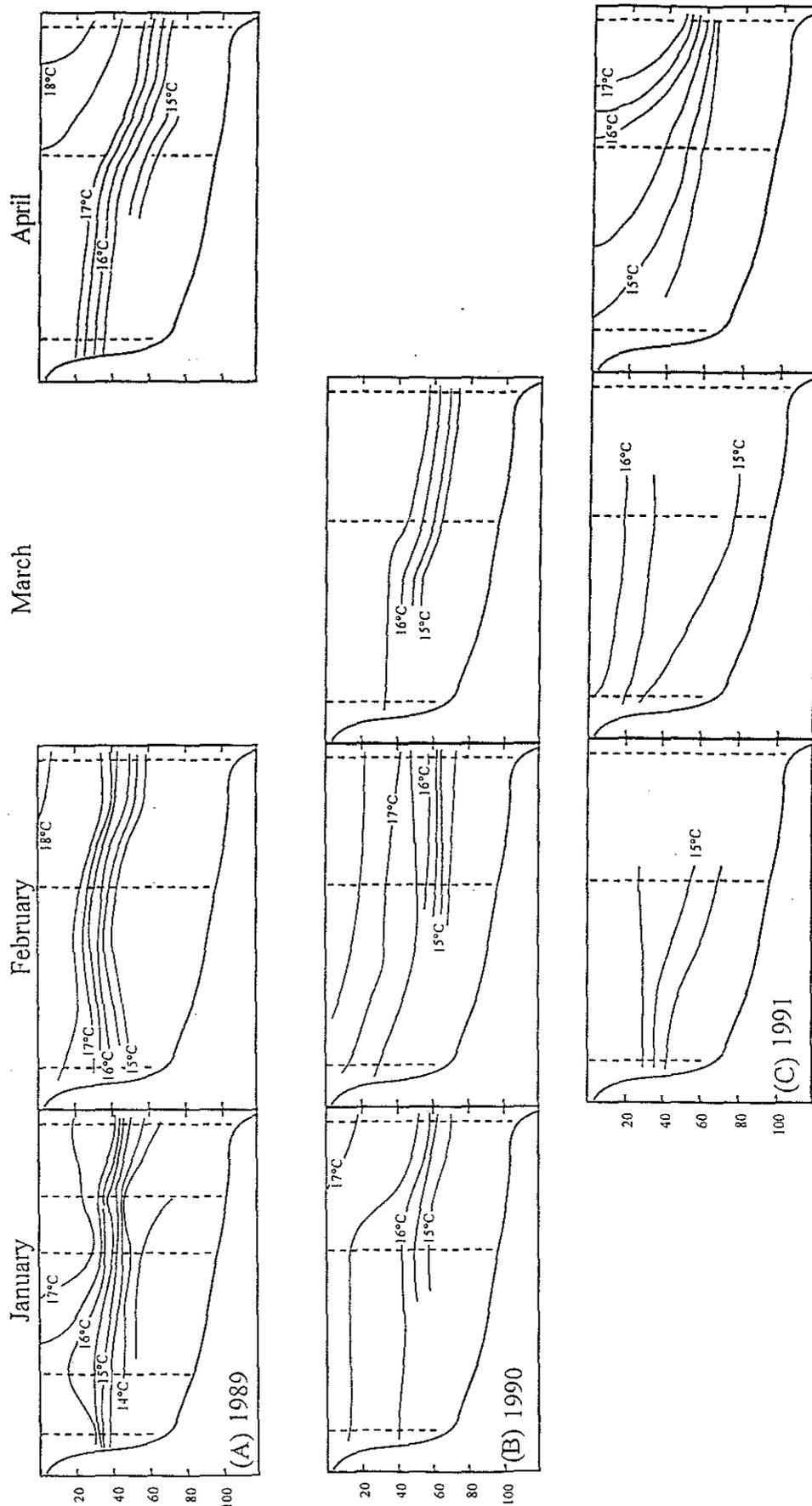
Fig.6.7 Monthly vertical sections of temperature(^{o} C) across Transect 5 between January and April of (A) 1989, (B) 1990 and (C) 1991.

6.3.4 Larval distribution

Identification of larvae to the family Cheilodactylidae was based on a combination of characters including an elongate body, moderate pigment on dorsal, ventral and lateral midlines and the presence of 34-36 myomeres (Okiyama 1988, Bruce 1989). Large preflexion and flexion larvae were identified as those of *N. macropterus* based the presence of 8-10 melanophores on the ventral midline of the tail, lateral melanophores on the lower jaw and presence of 13-15 anal ray bases (Bruce 1998). Identification of small preflexion larvae < 5.0 mm is still uncertain and is based on known adult distributions and spawning times of other cheilodactylid species. *Nemadactylus douglasii, N. valenciennesi, Cheilodactylus nigripes* and *C. fuscus* are only found as far south as Bass Strait with *C. spectabilis* the only species common to southern and eastern Tasmania waters (Gomon *et al.* 1994). *Cheilodactylus spectabilis* have never been recorded in spawning condition in Tasmania before mid-February, with the peak in spawning occurring mid-March (Murphy and Lyle 1998).

Nemadactylus macropterus larvae were found from the surface to 20 m, with highest densities at the surface before decreasing rapidly with increasing depth (Fig. 6.8). The small number of larvae at depth is likely to be due to contamination as the net sampled the non-targeted depths. Larvae were only caught in January of 1989 on the shelf of eastern Tasmania with no larvae caught in both 1990 and 1991 (Fig. 6.9A-C). Larvae were caught at all cross-shelf stations with densities highest on transect 5 in late January 1989 at 12 larvae.200 m^{-3}.
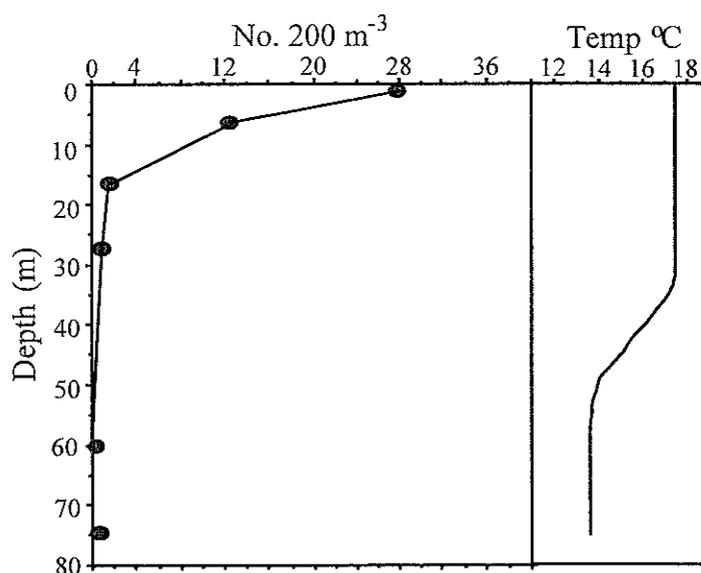
Fig. 6.8 Vertical distribution of *Nemadactylus macropterus* larvae at the mid-shelf station on Transect 5 in late January 1989.
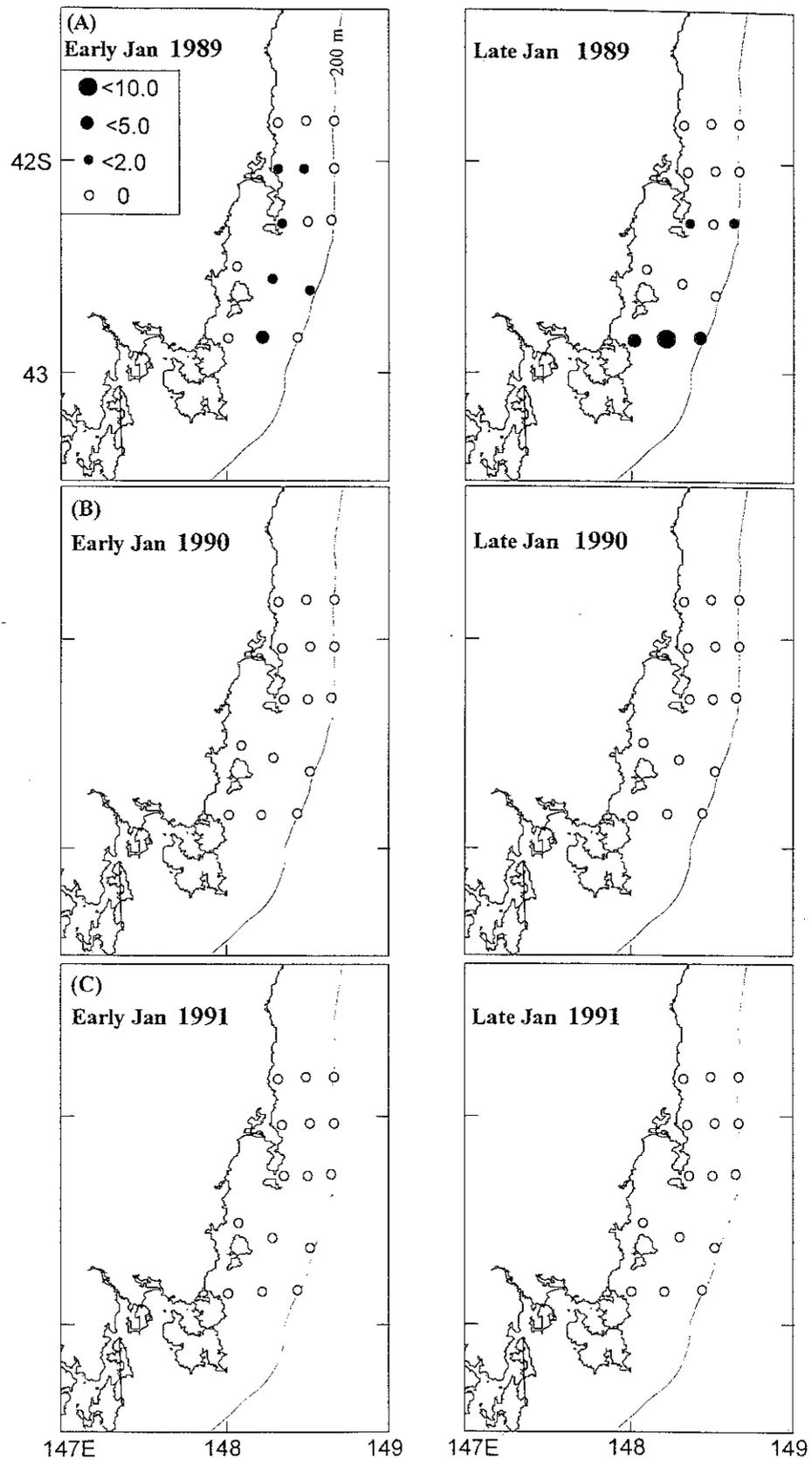
Fig. 6.9 *Nemadactylus macropterus* larval concentrations (N.200m^{-3}) during early and late January of (A) 1989, (B) 1990 and (C) 1991 on the shelf of eastern Tasmania.

6.4 Discussion

6.4.1 Size at maturity

In the present study, the size at 50% maturity for male and female *Nemadactylus macropterus* in eastern Tasmania was 27.0 and 25.0 cm, respectively which is consistent for male fish in waters of south-eastern Australia and New Zealand but smaller than that defined for females (Tong and Vooren 1972, Lyle and Ford 1993). The difference between the smallest and largest *N. macropterus* to reach maturity (males 25-29 cm and females 23-27 cm), indicates a broad range of sizes at which sexual maturity occurs. Such variations in body size at first sexual maturity are common to fishes (Nikolskii 1969), and may be related to variations in size at age resulting from differences in juvenile growth rate or extended spawning seasons. The size-at-age data indicates that this results in sexual maturity occurring at about 3 years of age (see Chapter 8), which is consistent with *N. macropterus* in southern New South Wales (Smith 1989a).

6.4.2 Gonadal development

In the present study, *N. macropterus* were found to be in spawning condition for an extended period between early January and May. The presence of pre-flexion and flexion larvae in early January also indicates that some spawning occurs in late December in some years. While both male and female GSI's peaked in January in 1993 and 1994, suggesting that egg production may have been higher early in the spawning season, this is influenced by a higher proportion of stage 5 gonads in January of both years. The presence of fish at stage 4 and 5 in April also indicates that spawning continued for some time, at least into late autumn (May). This is consistent with an analysis of monthly GSI values for *N. macropterus* off southern New South Wales and Victoria where fish were in spawning condition between January and June, although the peak in spawning activity was estimated to be from April to June (Hobday and Wankowski 1987b). The extended spawning period is related to the fact that *N. macropterus* are serial spawners (Tong and Vooren 1972, Hobday and Wankowski 1987b).

As a large proportion of mature fish in eastern Tasmania had gone back to resting stage 2 by April it is clear that a proportion of the population has finished spawning at that time suggesting spawning activity had peaked some time earlier. However,

the fact that the mean GSI's in stage 4 and 5 female gonads didn't decrease from January to April of both years also suggests that the timing and duration of peak spawning activity may vary slightly between years. While this trend will also be influenced by the size composition of the sample, as fecundity increases significantly in older, larger fish (Hobday and Wankowski 1987b), in the present study there was no significant difference in the size composition between January and April in either year.

As running ripe *N. macropterus* have been caught in eastern Tasmania in early January, there may be some variation in the timing of the peak spawning period with latitude. In New Zealand, *N. macropterus* spawn over a wide range of latitudes in waters of both the north and south islands with peak spawning activity commencing earlier at higher latitudes, which Tong and Vooren (1972) attributed to an earlier decrease in water temperatures. In Australia, peak spawning also occurs later in northerly waters (Hobday and Wankowski 1987b), however, earlier spawning in eastern Tasmania appears unrelated to a decrease water temperature as it either increases or varies little between January and April.

6.4.3 Spawning and larval distribution

In Australia, spawning occurs throughout their distributional range in New South Wales, Victorian and Tasmanian waters (Hobday and Wankowski 1987b, Lyle and Ford 1993), although there is no indication of distinct spawning areas. This is reflected in the even distribution of catch rates across the entire distribution of the commercial fishery in south-east Australia during summer and autumn (Smith 1994). In contrast, the distribution of ripe fish (Tong and Vooren 1972) and eggs of *N. macropterus* (Robertson 1978) suggests spawning occurs in a number of distinct areas in New Zealand waters. The disappearance of fish from fishing grounds between February and April has also been related to fish moving to distinct spawning grounds (Annala 1987).

While spawning appears to be widespread in Australian waters, very little work has been conducted on the fine-scale spatial distribution of spawning. In eastern Tasmania, spawning is restricted to mid- and outer-shelf waters as mature fish are confined to these depths (see Chapter 7), and running ripe fish were caught in both strata. This is consistent with *N. macropterus* in New Zealand where eggs were

concentrated in waters of the outer-shelf (Robertson 1978). In the present study, the spatial distribution of spawning was not examined by analysing egg distributions, as insufficient morphological characters have been published for the species to ensure accurate identification. However, Robertson (1978) reported *N. macropterus* eggs almost exclusively in surface tows, with oblique tows over known spawning areas providing no eggs. Spawning occurred in mid-water mainly at night, with fertilised eggs rising to the surface (Robertson 1978).

In the present study, *N. macropterus* larvae were caught at highest densities at the surface, although this was during a period of strong vertical stratification. The absence of larvae in subsurface tows in 1990 and 1991 when increased westerly wind stress resulted in shelf waters being well mixed also suggests that *N. macropterus* larvae are neustonic, regardless of the physical structure of the water column. This is consistent with Gray (1996) who found the vertical stratification of fish larvae to be independent of the extent of thermal stratification. In contrast, Robertson (1978) found larval *N. macropterus* to be absent from surface samples taken on the shelf of New Zealand, the lack of larvae being attributed to the lack of subsurface samples. While differences in the vertical distribution of *N. macropterus* larvae between Tasmania and New Zealand cannot be discounted, the lack of larvae in the study of Robertson (1978) more likely reflects a rapid advection of larvae off the shelf. This is supported by the offshore distribution of *N. macropterus* larvae off eastern Tasmania, with larvae caught up to 250 km offshore (the limit of sampling), and a significant relationship existing between length and age and distance off the shelf (Bruce *et al.* 1997). As the distribution of larvae was closely linked to the direction and rate of surface circulation patterns, and larvae were present offshore in all three years sampled, Bruce *et al.* (1997) suggested that the offshore distribution represents a regular strategy rather than anomalous transport.

A similar life-history strategy is evident in some species of rockfish, *Sebastes* spp., which spawn on the shelf and whose larvae are transported offshore in summer becoming an important component of the offshore ichthyoplankton assemblage (Richardson *et al.* 1980, Kendall and Clark 1982). The offshore transport of larvae appears to be maximised in fish species which have neustonic eggs and larvae (Richardson and Pearcy 1977, Shenker 1988). The consistent surface distribution of larval *N. macropterus* also appears to be a strategy to maximise offshore advection as

movement of surface waters on the shelf of south-eastern Tasmania are generally offshore (Cresswell *et al.* 1994). The offshore movement of larvae have been related to offshore Ekman transport (Bailey 1981) and mesoscale hydrographic events such as eddies and offshore jets (Mooers and Robinson 1984, Flierl and Wroblewski 1985).

If offshore advection of larvae is a consistent early-life history strategy of *N. macropterus* (Bruce *et al.* 1997), then intra- and interannual variability in the hydrography of surface waters on the shelf during the spawning period would result in considerable variability in the number of larvae reaching offshore. The oceanography of these waters is determined by a combination of the local westerly wind stress, and large scale oceanographic circulation dominated by the warm, stratified East Australian Current (EAC) water, and cool, well-mixed water of subantarctic origin (Harris *et al.* 1987). Generally, these two water masses meet on the east coast of Tasmania during the spawning period of *N. macropterus*, however, there are large variations in the position, timing and duration of EAC influence. While a consistent pattern of offshore transport of surface waters from the shelf of south-eastern Tasmania exists during years of increased westerly wind stress (Cresswell *et al.* 1994), such transport has not been documented during years of reduced westerlies and increased EAC influence.

The present data indicates strong variability at both temporal scales in the sea-surface temperature, thermal stratification and patterns of surface flow during summer and autumn on the shelf of eastern Tasmania. During the summer and autumn of 1989 the shelf of eastern Tasmania was dominated by subtropical EAC water, coincident with a reduction in the westerly wind stress, this event being linked to a major La Niña 'cold event' in the southern hemisphere (Harris *et al.* 1991). The continual influx of EAC water across the entire shelf indicates a persistent onshore component to the EAC flow. The vertical thermal structure confirms that in 1989 the upper mixed layer (~40 m) consisted entirely of EAC water that originated offshore and moved across the shelf. Warmer sea-surface temperatures were experienced again during the summer of 1990, although EAC water was mainly restricted to the outer shelf with cooler waters dominating inshore. The increased influence of cooler, well mixed water of subantarctic origin on the shelf during the summer and autumn of 1991 reflected an increase in westerly wind stress in that year and resulted in

increased offshore flow of surface waters. There is also clear evidence of considerable intra-annual variability, with the rapid advance of EAC water in March 1991 resulted in onshore flow, although it did not persist with the advance of subantarctic water by mid April.

This suggests that the reduction in the westerly wind stress and presence of EAC water in the upper water column through the entire period of peak spawning activity of *N. macropterus* in 1989 would have resulted in persistent onshore transport of eggs and larvae. In contrast, the increase in westerlies and dominance of water of southerly origin in 1990 and 1991 suggests there would be increased offshore advection in those years. While *N. macropterus* larvae are concentrated at the surface, and are therefore underrepresented in the oblique tows used in this study, the presence of larvae in oblique shelf samples in 1989 and their absence in 1990 and 1991 supports this conclusion. Such variations in the hydrography of eastern Tasmanian shelf waters are known to influence the distribution of eggs and larvae of jack mackerel (*Trachurus declivis*) (Jordan *et al.* 1995). While spawning of *T. declivis* was concentrated on the shelf break, high densities of eggs and larvae at inshore and mid-shelf stations in January of 1989 resulted from rapid onshore advection due to the strong EAC influence at that time (Jordan *et al.* 1995). Such rapid onshore advection was not observed in January of 1990 and 1991 when EAC influence was reduced.

For species whose larvae are distributed inshore and whose nursery areas are also inshore, variations in larval transport have been identified as a significant source of mortality with offshore transport of eggs and larvae playing a major role in determining recruitment success (Nelson *et al.* 1977, Bailey 1981). In a species such as *N. macropterus* whose larvae are distributed offshore, and a proportion of the population have nursery areas inshore in the same region as they were spawned, it is unclear whether retention of larvae on the shelf during years of strong onshore transport results in increased mortality. However, coincident with periods of onshore transport of EAC water is a significant decrease in zooplankton production on the shelf leading to lower prey abundance (Harris *et al.* 1991). This was reflected in the lower prey number in the diet of *Trachurus declivis* larvae on the shelf of eastern Tasmania in 1989 (Young and Davis 1992). While *N. macropterus* larvae also feed

primarily on small copepods (J. Young pers. comm.), the influence of variations in hydrography and plankton production on neustonic larvae has yet to be addressed.

In summary, *N. macropterus* spawn mainly in outer-shelf waters of eastern Tasmania between early January and May, although there are indications that egg production is higher early in the spawning season. The concentration of *N. macropterus* larvae at the surface, and their absence in subsurface shelf waters during years of increased westerlies suggests larvae are rapidly advected off the shelf. However, inter and intra-annual variations in hydrography during the spawning period influences patterns of larval advection. Such variability may explain the extended spawning period of *N. macropterus* which has developed in order to maximise the number of larvae encountering periods of offshore transport. The duration of the pre-settlement phase and distributional patterns of recruitment are examined in the following chapter.

Chapter 7 Spatial and temporal variations in abundance and distribution of *Nemadactylus macropterus*

7.1 Introduction

Jackass morwong, *Nemadactylus macropterus*, is an important commercial species with the bulk of landings taken off southern New South Wales, eastern Bass Strait and eastern Tasmania by both Danish seiners and otter trawlers as part of the South East Fishery (Smith 1994). Distinct seasonal and spatial variations in the abundance of *N. macropterus* occur on the shelf of eastern Bass Strait, the variations being attributed to migration of fish into the area and seasonal changes in vulnerability due to spawning activity (Wankowski and Moulton 1986). Seasonal and depth variations in catch rate were also apparent in commercial data across the entire South East Fishery with abundances highest in the 100-149 m stratum in summer (Smith 1994). Catch rates for *N. macropterus* around Tasmania peak in depths of 150-199 m (Lyle and Ford 1993).

The size distribution of commercial landings from New South Wales and north-eastern Victoria contain a single mode ranging from 20-50 cm, with a mean of 30-33 cm (Smith 1989). In contrast, size distributions from Tasmania show a broad mode between 33-40 cm and additional modes at 14 and 25 cm indicating the presence of juveniles in these waters (Lyle and Ford 1993). Several distinct nursery areas have been identified for *N. macropterus* in New Zealand waters with juveniles restricted to the inner-shelf (Vooren 1975). There is evidence that *N. macropterus* also utilise discrete nursery in south-eastern Australia as juveniles appear to be restricted to coastal waters of Bass Strait and Tasmania, and are rarely caught in eastern Victoria, New South Wales and the Great Australian Bight (Smith 1983, Lyle and Ford 1993). In Tasmania, juveniles dominate the inner-shelf with mature fish restricted to outer-shelf waters (Lyle and Ford 1993).

Settlement of *N. macropterus* into nursery areas in New Zealand occurs in spring and early summer (October-December) at between 7-9 cm long (Vooren 1972), with considerable interannual variability in the abundance of 0+ fish recruiting to individual nursery areas (Vooren 1975). Settlement of post-larval *N. macropterus* into south-east Tasmanian shelf waters occurs in summer at around 7-8 cm (Lyle and Ford 1993), after an extended larval period concentrated in offshore waters of south-

eastern Australia (Bruce *et al.* 1997). Post-larvae are morphologically very different from juveniles and are characterised by a deep, thin, laterally compressed body with a sharply keeled belly and silvery appearance below the lateral line (Vooren 1972, Bruce 1998).

While there is evidence of distinct spatial trends in catch rates and size compositions of *N. macropterus* in Tasmanian shelf waters (Lyle and Ford 1993), such patterns are likely to be biased as these surveys were unstratified and used Danish seine and otter board trawlers in different depths with differing fishing power, net designs and mesh size. By using a stratified random survey design with a standardised research vessel and demersal trawl gear, this chapter aims to confirm the depth related variations in catch rates and size compositions of Lyle and Ford (1993). In addition, in order to better understand the factors influencing the temporal and spatial structure of the *N. macropterus* population, I examine the seasonal, interannual and spatial patterns of abundance of juveniles and adults on the shelf of southern and eastern Tasmania.

7.2 Methods

7.2.1 Study locality and sampling regime

Nemadactylus macropterus were sampled seasonally on the shelf of eastern and south-eastern Tasmania in eight out of the nine seasons between summer 1993 and summer 1995. Full details of the shelf sampling areas, survey design and gear and biological sampling is presented in Chapter 2. In brief, demersal tows were made at random stations in three strata (10-50 m, 50-100 m, 100-200 m) on the east coast of Tasmania between the southern end of Marion Bay and the southern end of Schouten Island, and two strata (10-50 m, 50-100 m) in Storm Bay. Depth strata were allocated stations proportional to the area of the stratum with a maximum of 22 random stations on the east coast and 20 in Storm Bay. At each station the net was towed for 30 minutes (bottom time) at a speed of 3.0 knots. The total catch of *N. macropterus* at each station was weighed with either a 15 kg or 40 kg clock face scale ($\pm$0.1 kg) and all individuals sampled for length (FL), a minimum of 100 of these by sex. Catch rates were calculated as the number of fish per tow (N.tow^{-1}). Details of stratum area, numbers of stations sampled in each stratum in each season and station density for shelf surveys in Storm Bay and the east coast are presented in Table 2.1. Juvenile *N. macropterus* were also sampled from nearshore regions

(0-12 m) at several sites in south-eastern Tasmania between October and December 1995. Full details are presented in Chapter 2.

7.2.2 Statistical analysis

Spatial and temporal variations in the abundance of *N. macropterus* in Storm Bay and the east coast was assessed using analysis of variance (ANOVA). Variations in abundance (N.tow^{-1}) were analysed for Storm Bay and the east coast separately using a two-way ANOVA with season and depth considered fixed factors. Analysis of variations in the abundance of *N. macropterus* from Storm Bay was restricted to juveniles size-classes, which made up around 94% of the population. Fish were classified as juveniles based on their fork length and macroscopic gonad staging. Due to heterogeneity of data from winter 1994 on the east coast, analysis of variations in the seasonal abundance of *N. macropterus* from that area was restricted to four seasons (summer to spring 1993). Interannual variations in abundance of mature *N. macropterus* on the east coast between the summers of 1993, 1994 and 1995 was assessed using two-way ANOVA with year and depth considered fixed factors.

Before analysis, data were tested for conformity to the assumptions of ANOVA using the F_{max} test for heteroscedascity (Sokal and Rohlf 1981) and by examining residual and normal probability plots. Transformation of abundance to $ln(x+1)$ greatly improved the homogeneity of variances and distribution of residuals. Interannual variations in abundance of 0+ *N. macropterus* all three summers was to be assessed using ANOVA, however, as patchy distribution resulted in data remaining heterogeneous after transformation, the means were examined for trends. Ryans Q test was used to identify significant differences among means when there was significant main effects or interactions in the ANOVA. Ryans Q test is considered to be the most powerful post-hoc test which allows the user to control experiment-wise error rate (Day and Quinn 1989). Calculations were performed with the Peritz FORTRAN program (Martin and Toothaker 1989).

7.2.3 Size Composition

Size compositions of *N. macropterus* vulnerable to the sampling gear were firstly obtained by pooling lengths from all random trawl stations in a stratum in each season in both Storm Bay and east coast survey areas. The size composition of the

total population in each area, season and stratum was then estimated by weighting each size class by the number of tows relative to the stratum area, using the formula of Davis and West (1992):

$$F_i = \sum_{j=1}^{j=3} f_{ij}A_j/n_j \qquad (7.1)$$

where F_i is the relative frequency of size class i in the population; f_{ij} is the frequency of size class i in stratum j; A_j is the area of stratum j and n_j is the number of trawls in stratum j (see Table 2.1).

7.3 Results

7.3.1 Catch rates

Abundance of *N. macropterus* on the shelf of the east coast in 1993 varied significantly amongst seasons and depths (Table 7.1, Fig. 7.1). Post-hoc tests revealed that abundances were significantly higher on the outer- and mid-shelf than the inner-shelf (Ryans Q-test; $p<0.05$). Abundances were also significantly higher in summer, autumn and spring than winter (Ryans Q-test; $p<0.05$). The significance of trends in abundance in 1994 could not be tested as large but highly variable catches on the outer-shelf in winter 1994 resulted in high heterogeneity of variances. Mean catch rates were $48.6.tow^{-1}$ in winter 1994 compared to $1.9.tow^{-1}$ in winter 1993, indicating considerable year to year variations in abundance in winter. While such differences may also result from patchy distribution, station density was higher in winter 1993 which would result in an increased chance of sampling a patch of *N. macropterus* in that year.

Table 7.1   Analysis of variance of $\ln(x+1)$ transformed abundance $(N.tow^{-1})$ of *Nemadactylus macropterus* in three depth strata in four seasons on the east coast shelf.

Factor	Hypothesis	DF	MS	F	P
Season	a/r	3	14.905	7.370	<0.001
Depth	b/r	2	9.490	4.690	0.013
Season*Depth	ab/r	6	1.006	0.500	0.808
Residual	r	57	2.024		
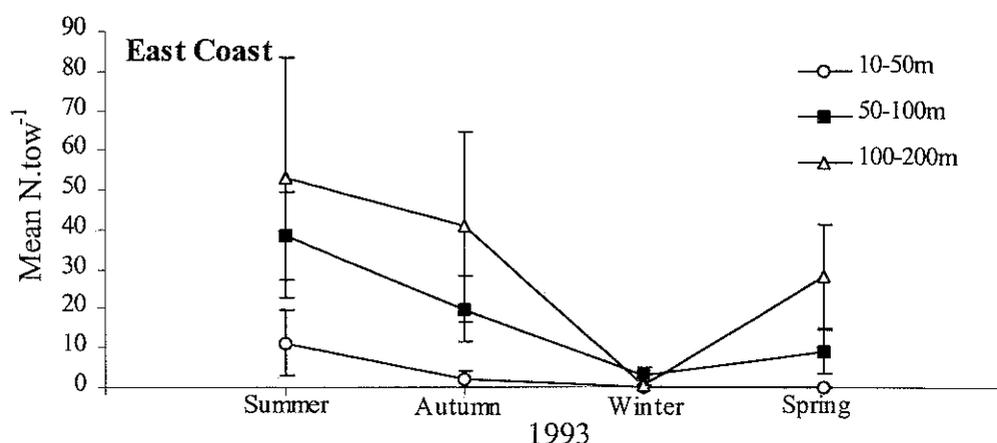
Fig. 7.1 Mean seasonal abundance (N.tow^{-1}) of *Nemadactylus macropterus* collected from inner-shelf (10-50 m), mid-shelf (50-100 m) and outer-shelf (100-200 m) strata on the east coast during 1993. Error bars are standard error.

Abundances of *N. macropterus* on the shelf region of the east coast in the summers of 1993, 1994 and 1995 varied significantly only amongst depths (Table 7.2, Fig. 7.2). Post-hoc tests showed that abundances were significantly higher on the outer-shelf than the mid-shelf, which in turn was significantly higher than the inner-shelf (Ryans Q-test; $p < 0.05$).

Table 7.2 Analysis of variance of ln(x+1) transformed abundance (N.tow^{-1}) of mature *Nemadactylus macropterus* in three depth strata in summer 1993, 1994 and 1995 on the shelf region of the east coast.

Factor	Hypothesis	DF	MS	F	P
Year	a/r	2	0.078	0.040	0.964
Depth	b/r	2	19.375	9.170	<0.001
Year*Depth	ab/r	4	2.746	1.300	0.287
Residual	r	39	2.112		
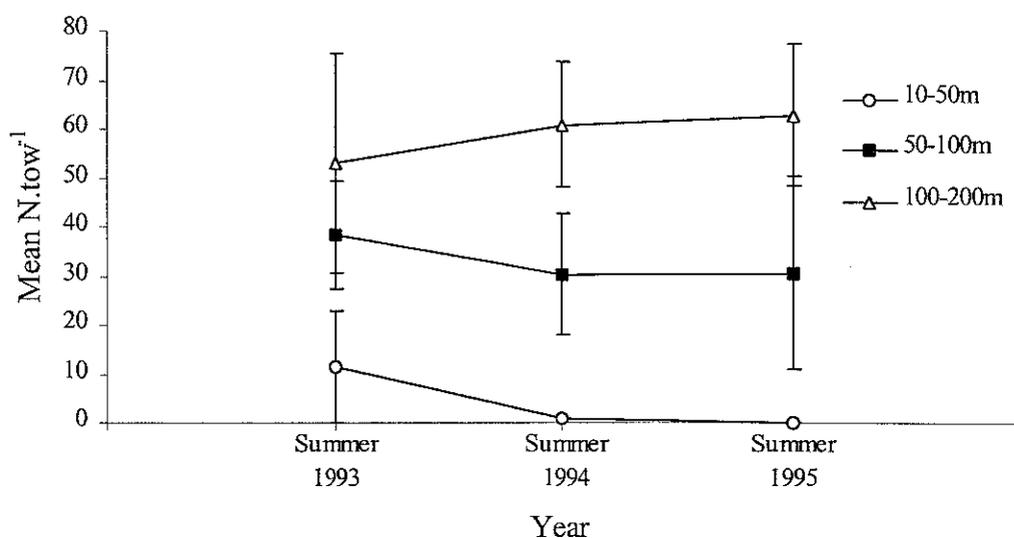
Fig. 7.2 Mean abundance (N.tow^{-1}) of mature *Nemadactylus macropterus* collected from inner-shelf (10-50 m), mid-shelf (50-100 m) and outer-shelf (100-200 m) strata on the east coast in summer 1993, 1994 and 1995. Error bars are standard error.

Abundances of juvenile *Nemadactylus macropterus* on the shelf of Storm Bay varied significantly amongst seasons, and there was also a significant season and depth interaction (Table 7.3, Fig. 7.3). Post-hoc tests indicated that, in terms of season, the major pattern was that on the inner-shelf, winter 1993 and summer 1994 were significantly higher than all other seasons (Ryans Q-test; $p<0.05$), while on the mid-shelf, autumn 1994 was significantly higher than all three summers, but not significantly different as all other seasons (Ryans Q-test; $p<0.01$). In terms of depths, abundances were significantly higher in winter 1993 than all other seasons (Ryans Q-test; $p<0.05$).

Table 7.3 Analysis of variance of ln(x+1) transformed abundance (N.tow^{-1}) of juvenile *Nemadactylus macropterus* in two depth strata over eight seasons on the shelf region of Storm Bay.

Factor	Hypothesis	DF	MS	F	P
Season	a/r	7	2.095	2.180	0.041
Depth	b/r	1	0.384	0.400	0.529
Season*Depth	ab/r	7	2.280	2.370	0.026
Residual	r	124	0.963		
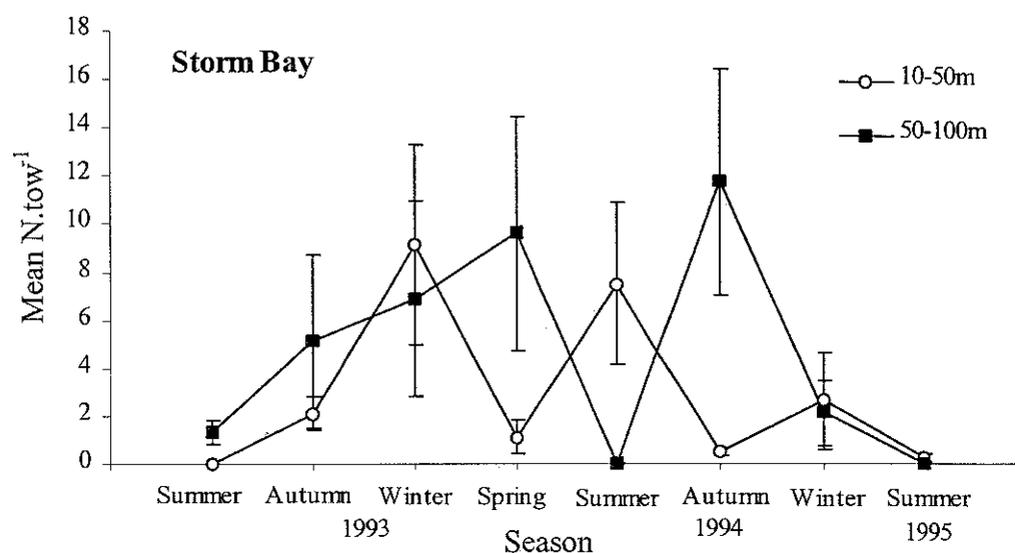
Fig. 7.3   Mean seasonal abundance (N.tow^{-1}) of juvenile *Nemadactylus macropterus* collected from inner-shelf (10-50 m) and mid-shelf (50-100 m) strata in Storm Bay between summer 1993 and summer 1995. Error bars are standard error.

The significance of the interannual variations in abundance of 0+ *N. macropterus* could not be tested as patchy distribution of this age-class resulted in high heterogeneity of variances. However, variation in the means indicate that settlement of 0+ *N. macropterus* was highest on the east coast in 1993, highest in Storm Bay in 1994, and was extremely low in both shelf regions in 1995 (Fig. 7.4).
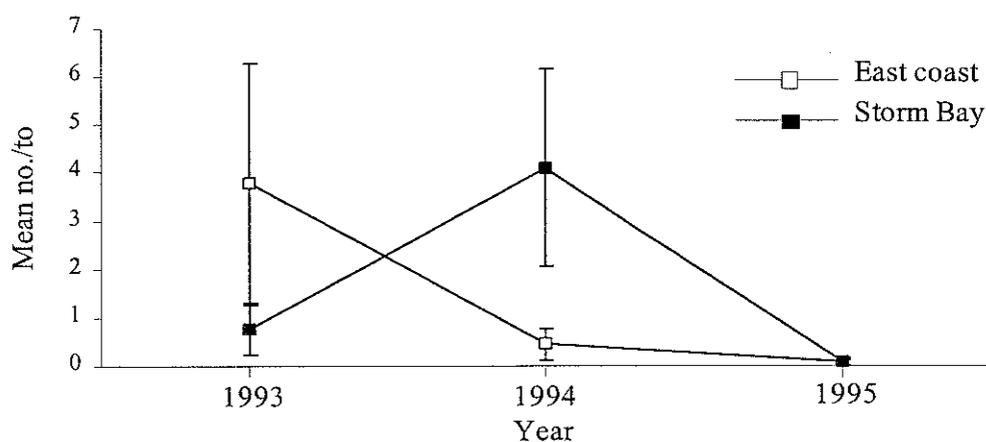

Fig. 7.4 Mean abundance (N.tow^{-1}) of 0+ *Nemadactylus macropterus* collected from inner-shelf (10-50 m) and mid-shelf (50-100 m) strata during summer 1993, 1994 and 1995 on the east coast and Storm Bay. Error bars are standard error.

7.3.2 Size composition

Nemadactylus macropterus on the shelf of the east coast ranged from 8.5 to 45.5 cm, with the distribution consisting primarily of a single mode at 34 cm, with two much

smaller modes at 9 and 15 cm (Fig. 7.5). The population was dominated by fish above the size at 50% maturity (25-27 cm) making up around 90% of the population.
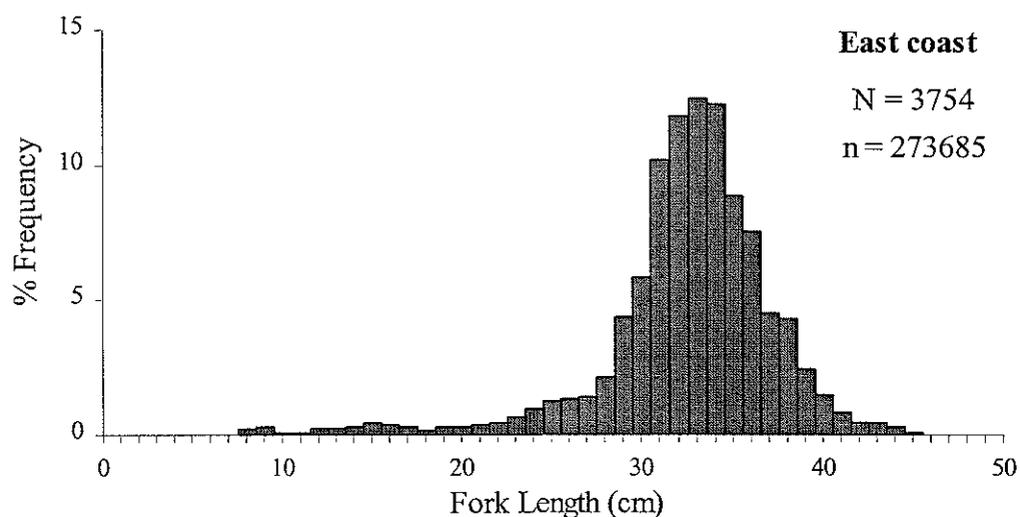
Fig. 7.5 Scaled length-frequency distribution of *Nemadactylus macropterus* collected on the shelf of the east coast between summer 1993 and summer 1995. N is measured sample size; n is scaled sample size.

The length-frequency distributions of *N. macropterus* on the inner- and mid-shelf regions of Storm Bay ranged from 6.6 to 45.1 cm, with the distribution dominated by a distinct mode at around 13-14 cm, with several smaller modes evident at 8, 20 and 37 cm (Fig. 7.6). In contrast to the east coast, mature fish made up only around 6% of the population in Storm Bay, which to some extent may reflect the lack of sampling in the outer-shelf stratum in that area.
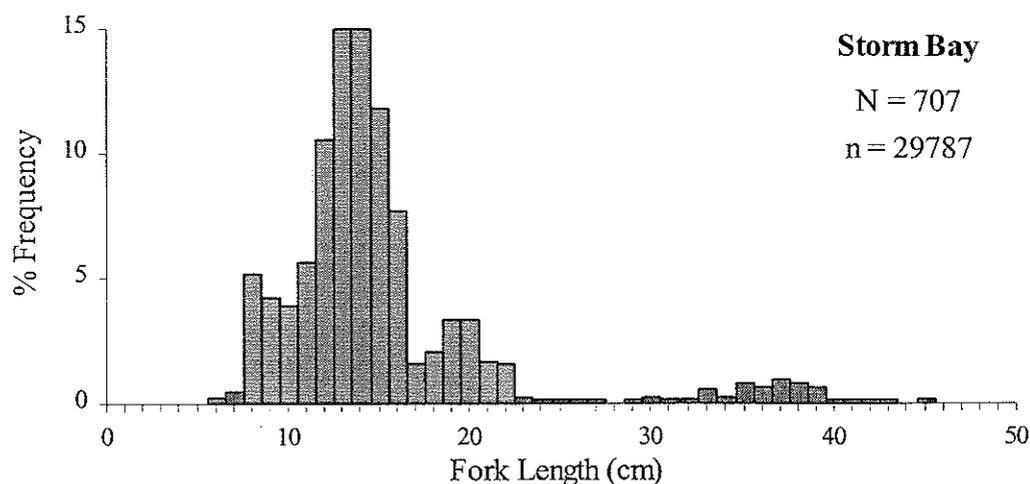
Fig. 7.6 Scaled length-frequency distribution of *Nemadactylus macropterus* collected on the shelf of Storm Bay between summer 1993 and summer 1995. N is measured sample size; n is scaled sample size.

Seasonal length-frequency distributions of *N. macropterus* on the east coast reveal distinct differences in the size compositions throughout the year, and between years (Fig. 7.7). In 1993, mature fish dominated the population in all seasons except winter, although the proportion of fish >35 cm decreased from 47% in summer to 20% in spring, with evidence of an increased abundance of fish around 25 cm. The cohort with a mean length of 9.6 cm in summer 1993 represents 0+ fish from spawning the previous summer and autumn. This size-class progressed to 17.4 cm by summer 1994. In contrast, mature fish were present on the east coast in all seasons in 1994, and although there was no distinct seasonal change in the proportion of large fish, a higher proportion of fish between 20 and 30 cm was present in autumn. Size compositions in summer 1995 were consistent with those in previous summers.

Comparison of length-frequency distributions by depth indicates little difference in the size composition of *N. macropterus* on the mid- and outer-shelf of the east coast (Fig. 7.7). All size-classes were present in both strata, with no evidence of seasonal movement between strata, except for winter 1994 when fish were caught exclusively on the outer-shelf. *N. macropterus* were present on the inner-shelf only in summer and consisted exclusively of fish <12 cm.

Seasonal length-frequency distributions of *N. macropterus* in Storm Bay reveal the presence of significant numbers of mature fish only in summer and spring 1993 (Fig. 7.8). Most seasons were dominated by a cohort that first appeared in summer 1993 with a mean length of 8.4 cm, representing the 0+ age-class. This size-class was present again in summer 1994, although its presence in spring 1993 at 7.0 cm suggests that settlement occurs over an extended period. This is supported by the broad range of lengths of the 0+ age-class in summer ranging from 6.6 to 11.1 cm. Given an arbitrary birthdate of 1 March, which corresponds to the mid-point of the spawning season (see Chapter 6), the 0+ age-class in summer 1993 progressed into the 1+ age-class by autumn 1993 with a mean length of 11.8 cm. This size-class progressed to a mean length of 15.0 cm by spring 1993, and can be followed through into the 2+ age-class in autumn 1994 with a mean length of 20.8 cm.
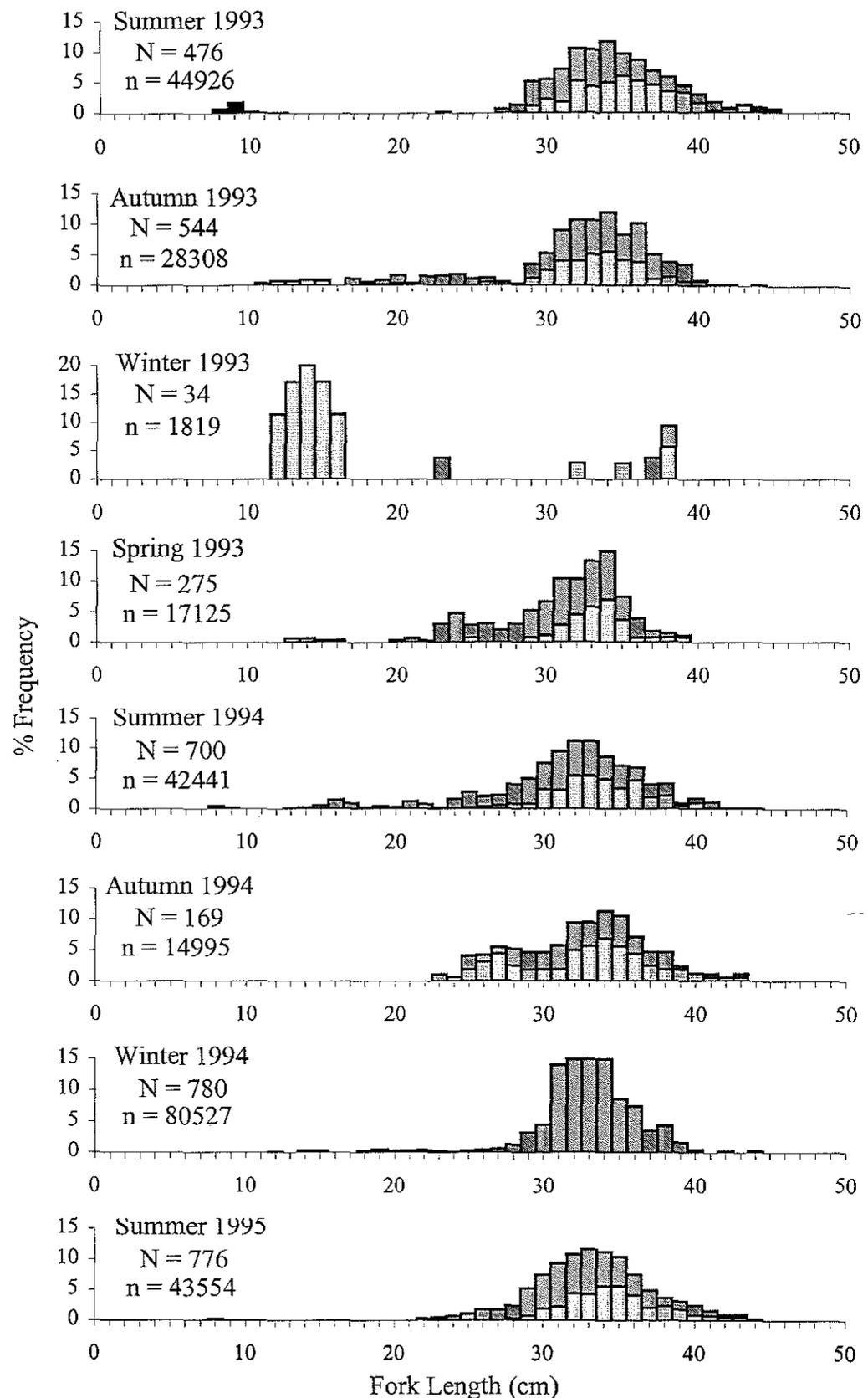
Fig. 7.7   Seasonal scaled length-frequency distribution of *Nemadactylus macropterus* collected on inner-shelf (dark bars), mid-shelf (light bars) and outer-shelf (striped bars) strata of the east coast between summer 1993 and summer 1995. N is measured sample size, n is scaled sample size.

Comparison of length-frequency distributions by depth indicates some size structuring of *N. macropterus* on the inner- and mid-shelf of Storm Bay with mature fish restricted to the mid-shelf (Fig. 7.8). In contrast, juveniles were evenly distributed between the two strata, although in some seasons fish were caught almost exclusively in a single stratum, such as summer 1993 when fish were restricted to the mid-shelf, and summer 1994 when 96% of fish were caught on the inner-shelf. This lack of depth preference is consistent across the 0+, 1+ and 2+ age-classes, with no indication of size- or age-structuring by depth of juveniles across the shelf of Storm Bay. This also indicates little specific preference in the depth of initial settlement.

7.3.3 Nearshore region

Very few *N. macropterus* were caught in nearshore waters despite extensive sampling of vegetated and unvegetated habitats with several gear types in three areas along the south and east coast (see sampling regime for *Platycephalus bassensis* in Chapter 4). However, vulnerability of juvenile *N. macropterus* to beam trawls appears to be low during the day as all catches were made in targeted sampling at night conducted over the settlement period. Juvenile fish in shallow coastal waters have been observed schooling midwater during the day over subtidal reefs adjacent to unvegetated habitats (Last 1983). The length-frequency distributions of *N. macropterus* from nearshore regions of south-eastern Tasmania ranged from 7.4 to 17.5 cm, with the distribution dominated by two modes at around 7-8 cm and 15-16 cm, previously identified as the 0+ and 1+ age-classes respectively (Fig. 7.9). Both age classes were caught in unvegetated soft-mud habitats in depths of 3 to 12 m. Of significance is the lack of larger juvenile or adult *N. macropterus* in nearshore waters, despite the extensive use of small mesh gill-nets.
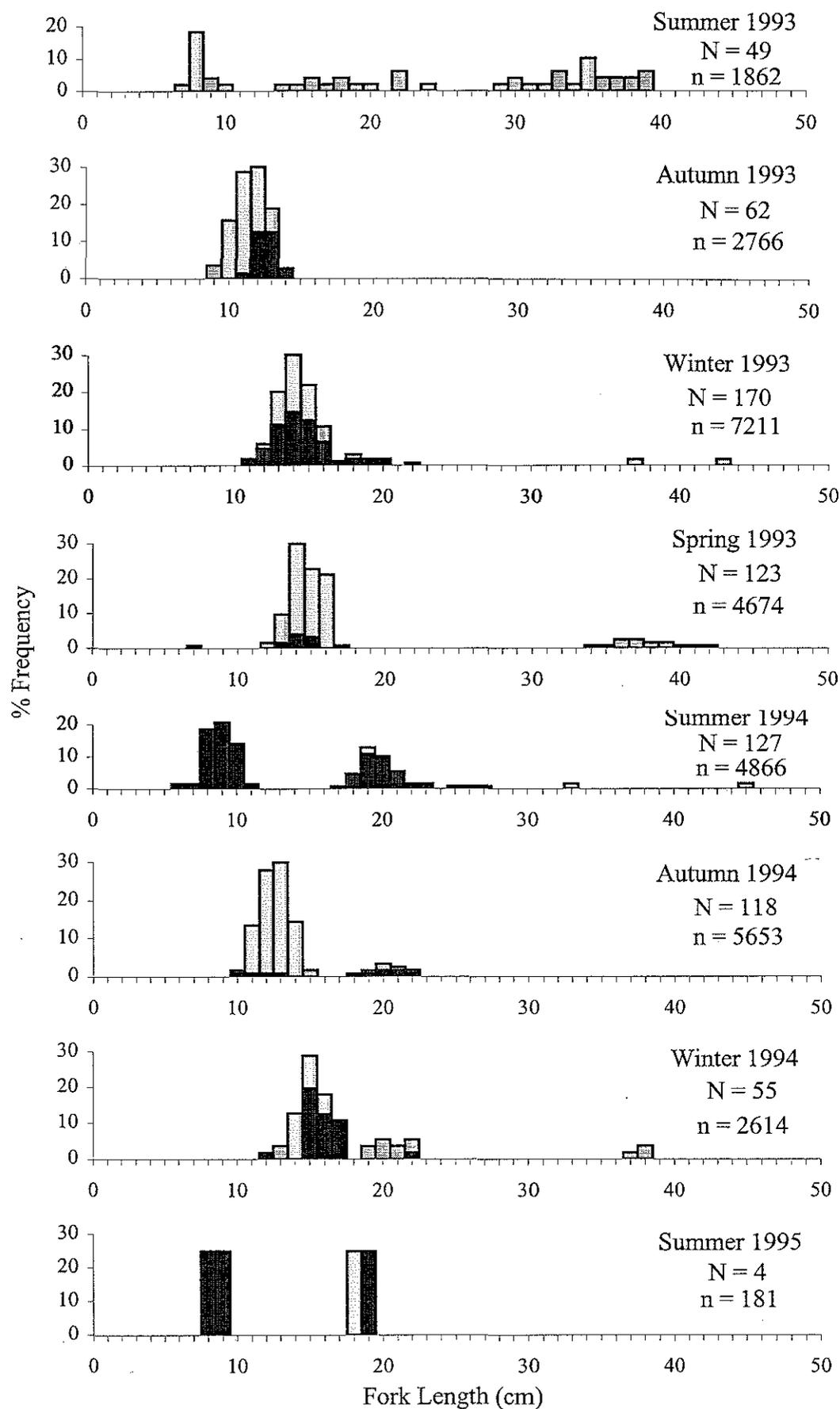
Fig. 7.8   Seasonal scaled length-frequency distribution of *Nemadactylus macropterus* collected on inner-shelf (dark bars) and mid-shelf strata (light bars) of Storm Bay between summer 1993 and 1995. N is measured sample size, n is scaled sample size.
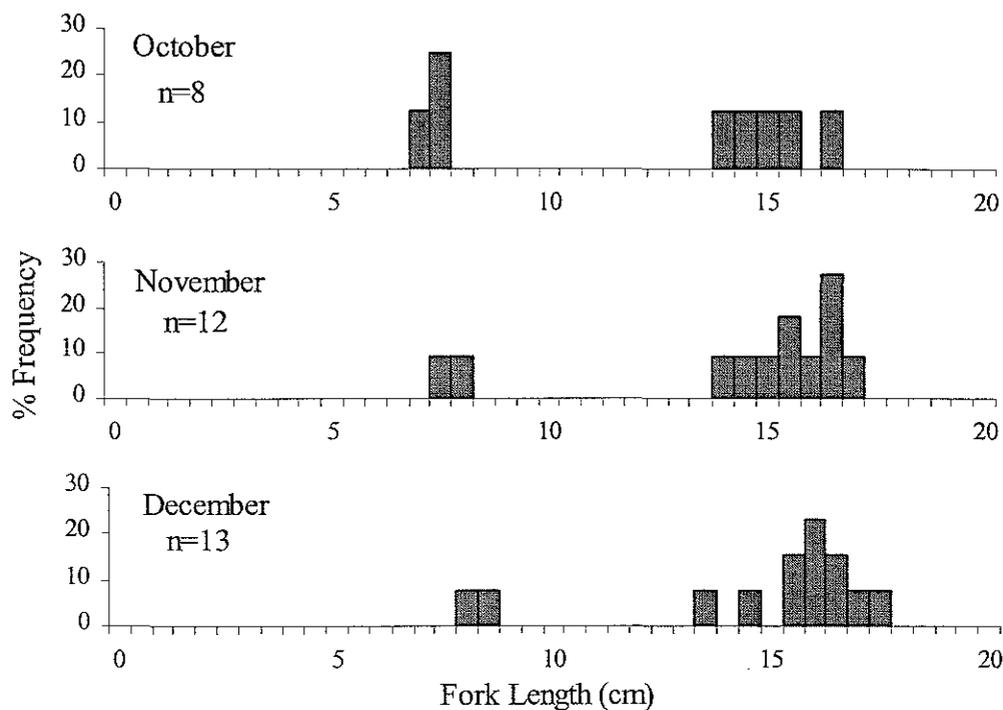
Fig. 7.9 Monthly length-frequency distribution of *Nemadactylus macropterus* collected on inshore region of the south-east Tasmania between October and December 1995. n is sample size.

7.4 Discussion

The present study revealed considerable seasonal variations in the abundance of *Nemadactylus macropterus* on the shelf of eastern Tasmania during 1993. While abundances were significantly different only in winter, a trend of decreasing abundance from summer during autumn to a low in winter was apparent. The variations were primarily driven by the decrease in abundance of mature fish on the mid- and outer-shelf. In contrast, abundance of *N. macropterus* on the shelf of eastern Bass Strait is highest in autumn before decreasing to a low in spring and summer, the autumn peak being attributed to an influx of fish and changes in vulnerability due to spawning at that time (Wankowski and Moulton 1986). The contrasting trends in abundance between the two shelf areas suggests there may be some movement of fish from eastern Tasmania into eastern Bass Strait during autumn. Given that spawning peaks in summer in eastern Tasmania (see Chapter 6) compared to autumn in eastern Bass Strait (Hobday and Wankowski 1987b), and the change in abundance consists primarily of mature fish, such movements may be related to spawning. Migration of mature fish into discrete spawning grounds are

reported in New Zealand (Annala 1987), however no large scale movement of mature *N. macropterus* has been reported in Australian waters (Smith 1989).

Abundance of *N. macropterus* on the east coast during 1993 was consistently highest on the mid-and outer-shelf with both strata dominated by mature fish. A comparison between all three summers also shows abundance was consistently highest on the outer-shelf in this season, which is consistent for *N. macropterus* around Tasmania (Lyle and Ford 1993), and from commercial catches throughout the entire South East Fishery (Smith 1994). There was also evidence of interannual variations in the abundance of *N. macropterus* during winter on the east coast, with catch rates in 1994 considerable higher than those in 1993. This contrasts that of *P. bassensis* on the east coast where catch rates were significantly lower in winter 1994 than 1993, which was possibly related to the lower micronekton biomass on the shelf in winter 1994 compared 1993 (see Chapter 4). The reasons for the peak in *N. macropterus* abundance in winter 1994 are still unclear but appear to be unrelated to variations in secondary productivity.

There were no consistent seasonal variations in the abundance of juvenile *N. macropterus* in Storm Bay with the trends in abundance on the inner-shelf reflecting the increased abundance of 1+ fish in winter 1993 and 0+ and 1+ fish in summer 1994. This, however. was not consistent between years as juvenile fish were mostly absent from the inner-shelf in summer 1993 and 1995, spring 1993 and autumn 1994. There was also no consistent seasonal trend in the mid-shelf strata, apart from the low abundance of juveniles in all three summers. The presence of significant interactions between seasons and depths indicates considerable seasonal movement of 1+ and 2+ fish between strata in Storm Bay. Despite this, initial settlement of 0+ fish in Storm Bay in summer occurred exclusively into a single strata in any year, with movement between strata apparent by autumn. This trend is also consistent on the east coast, although some movement of 1+ and 2+ fish also occurs onto the outer-shelf. While the low abundance of mature fish in Storm Bay can be partly attributed to the lack of sampling of the outer-shelf strata, size compositions reveal very few mature fish on the mid-shelf of Storm Bay compared to the east coast indicating clear differences in the significance of the two shelf areas for mature *N. macropterus*.

Given the significance of inner- and mid-shelf regions for juvenile *N. macropterus*, the large shelf area in these depths in south-eastern Tasmania (in the vicinity of Maria Island and Storm Bay) suggests that this region is an important nursery area for the species. Distinct nursery areas have also been identified for *N. macropterus* in inner-shelf waters of New Zealand (Vooren 1975). In addition, this is consistent with *N. macropterus* throughout south-eastern Australia as juveniles appear to be restricted to coastal waters of Bass Strait and Tasmania (Smith 1983, Lyle and Ford 1993). The present data also confirms the depth related variations in size composition reported by Lyle and Ford (1993).

Recruitment of pelagic post-larvae to shelf waters of Storm Bay and the east coast occurred over an extended period during spring and early summer (September-January). Recent settlement was indicated by the fact that all fish < 8 cm were either post-larvae, or intermediate between post-larvae and juveniles. Post-larval *N. macropterus* are morphologically very different from juveniles and are characterised by a deep, thin, laterally compressed body with a sharply keeled belly and silvery appearance below the lateral line, often referred to as 'paperfish' (Vooren 1972, Bruce 1989). Close to the size at settlement *N. macropterus* undergo metamorphosis from the pelagic post-larval phase into juveniles that are morphologically similar to adults. Settlement of *N. macropterus* in New Zealand waters also occurs prior to metamorphosis in spring and early summer at around 6.3-7.0 cm (Vooren 1972). The extended settlement period in Tasmania is likely to be related to the extended spawning period in southern and eastern Tasmania (January-May) (see Chapter 6). Gauldie (1994) estimated the age at settlement of *N. macropterus* from microincrements to be around 8-9 months old. This is consistent with the duration between spawning and settlement in Tasmania and indicates that *N. macropterus* has a long larval duration and large size at settlement compared with other species (Brothers *et al.* 1983, Victor 1986, Jenkins and May 1994).

While recruitment of *N. macropterus* from offshore waters into nearshore, inner-and mid-shelf waters of southern and eastern Tasmania occurs over several months, the mechanisms by which post-larvae move inshore are yet to be closely examined. During late autumn/early winter (May-June) *N. macropterus* larvae are found in surface waters up to 250 km offshore of eastern Tasmania (the limit of sampling),

with the offshore distribution closely linked to mesoscale surface circulation patterns indicated by satellite-tracked surface drifters (Bruce *et al.* 1997). The offshore movement of surface waters is related to the eastward flowing west coast water and water of subantarctic origin that are driven by the predominantly westerly winds over Tasmania (Cresswell *et al.* 1994). While satellite-tracked surface drifters moved quickly off the shelf, they were retained within offshore Tasmanian waters for periods of 8-12 months, which Bruce *et al.* (1997) suggested provided a mechanism to retain larvae within the Tasmanian region, and is consistent with the pre-settlement duration of *N. macropterus* determined in the present study.

The link between the offshore retention of larvae and subsequent onshore movement is poorly understood, reflecting the lack of research on the oceanography of waters offshore of eastern Tasmania, particularly during the spring/early summer (September-January) settlement period (see Young *et al.* 1996). Sea-surface temperatures in shelf and offshore waters are at a seasonal minimum in early spring (September), with the region dominated by water of west coast and subantarctic origin and a broad zone of convergence (Harris *et al.* 1987, also see Chapter 4, Fig. 4.1). This is clearly demonstrated in the satellite image of October 1989 presented in Chapter 2 (Fig. 2.2B). By late spring (November) there is often a rapid southerly advance of a shallow layer (0-50 m) of subtropical East Australian Current (EAC) water with considerable mesoscale activity dominated by EAC eddies. However, the timing and extent of southerly movement of EAC water varies considerably from year to year, as does the frequency, with rapid advances and retreats occurring (Harris *et al.* 1987) (also see Fig. 6.4). With *N. macropterus* larvae widely distributed offshore in water of subantarctic origin and EAC water, and within the broad convergence zone between the two, Bruce *et al.* (1997) suggested that recruitment to south-eastern Tasmania occurs from all three water masses. This is consistent with the stock structure throughout southern Australia indicated from analysis of otolith microchemistry (Thresher *et al.* 1994). This may also reflect the intra- and interannual variability in the relative influence of both mesoscale currents and wind driven surface flow during the recruitment period, which determines the source of post-larvae across both temporal scales.

The varying influence of each water mass on Storm Bay and the east coast may also influence the spatial patterns of settlement, with the present data indicating reversals

in the shelf regions with highest abundance of 0+ fish between 1993 and 1994, and a considerable decrease in the abundance in both regions in 1995. Similar interannual variability in the abundance of 0+ *N. macropterus* recruiting to individual nursery areas also occurs in New Zealand waters (Vooren 1975), with passive transport by mesoscale current systems hypothesized to influence the spatial patterns of settlement (Annala 1987). In the present study, there appears to be no clear relationship between the abundance of 0+ fish and the dominance of particular water masses, as recruitment peaked in Storm Bay in 1993, despite both shelf regions being dominated by subantarctic water during spring and summer in that year (see Fig. 4.1). The lack of 0+ *N. macropterus* in 1995 may reflect recruitment of fish to shelf regions adjacent to the study areas.

Spatial and temporal changes in abundance may also reflect differences in post-settlement mortality, although several factors found to be significant in post-settlement mortality, including shelter (Shulman and Ogden 1987), habitat complexity (Levin 1994) and physical disturbance (Stephens *et al.* 1994, Jenkins *et al.* 1997a) are unlikely to be of significance for *N. macropterus* which recruit to unvegetated, deeper subtidal habitats. The lack of data on benthic productivity in shelf habitats precludes an assessment of food limitation as a major source of mortality. In addition, analysis of gut contents of demersal shelf species in the study areas found no evidence of significant predation of newly recruited *N. macropterus* (A. Jordan unpubl. data). It is clear that further research is required to assess the entire spatial distribution of 0+ *N. macropterus* before the relative significance of nursery areas in southern and eastern Tasmania can be evaluated.

There was little evidence of large differences in the timing of settlement of *N. macropterus*, despite evidence of variability in the oceanography and westerly wind stress in the study area during the summers of 1993, 1994 and 1995 (Young *et al.* 1996, see Fig. 4.1). The seasonal sampling, however, is likely to miss finer-scale temporal patterns of recruitment resulting from variability in post-larval supply. If this supply is strongly influenced by physical transport processes then the short term variations in westerly wind stress and oceanography that are common in the area are likely to result in short-term variations in recruitment. Variations in westerly wind strength across Tasmania are most significant at periodicities of around 8-10 and 40 days (Harris *et al.* 1991). Such variations in westerly winds strongly influences the

hydrography in Bass Strait and results in pulses in recruitment of *Sillaginodes punctata* into Port Phillip Bay, Victoria (Jenkins *et al.* 1997a).

While the role of passive transport in determining patterns of recruitment of *N. macropterus* is still to be detailed, the large size at settlement (~7 cm) and lack of onshore surface flow during spring on the east coast suggests that active horizontal swimming plays a role in the movement of fish towards the shelf edge and then into the inner- and mid-shelf regions. The width of the shelf of southern and eastern Tasmania ranges from 20 Nm on the east coast to 40 Nm in Storm Bay. If larvae are retained within 100 Nm of the shelf edge, at an average swimming speed of 2 body lengths per second (Blaxter 1986), a 6 cm post-larvae would take between 21 and 25 days to move onto the inner-shelf. Horizontal swimming has also been implicated in the onshore movement of pelagic juveniles (Larson *et al.* 1994, Hare and Cowen 1996), although such onshore transport still appears to be associated with hydrological features, such as internal waves (Shanks 1983, Kingsford and Choat 1986), warm core ring streamers (Hare and Cowen 1996) and Ekman transport (Norcross and Shaw 1984, Shenker *et al.* 1993). While directed swimming may play a role in recruitment of *N. macropterus*, the 8-10 and 40 days periodicities in westerly wind strength may provide variations in conditions suitable for onshore movement. In addition, the cues with which post-larvae orientate the direction of movement are yet to be determined.

Despite strong recruitment variability being demonstrated for *N. macropterus* from estimates of population age-structure in New Zealand (Vooren 1977) and south-eastern Australia (Smith 1989), the influence of environmental and biotic factors on recruitment success has not been examined. It is clear that in order to determine the mechanisms of onshore transport of post-larval *N. macropterus* and assess the influence of oceanography on recruitment strength, more detailed studies are needed on the hydrography of offshore and shelf waters at a range of spatial scales, particularly during spring and early summer, in addition with finer scale monitoring of temporal patterns of recruitment. In particular, the relationship between temporal patterns of settlement of *N. macropterus* and periodicity of westerly wind stress warrants further examination.

Growth of the 0+ age-class was evident in both years, with progression into the 1+ age-class by autumn with a mean length of 13 cm and into the 2+ age-class the following autumn with a mean of 21 cm. There is evidence in the east coast population of the 3+ age-class in autumn 1994 at around 27 cm before it merges with the dominant size-class of mature fish. These lengths-at-age for juvenile *N. macropterus* are consistent with those reported for these age-classes through analysis of modal progressions (Vooren 1975, Lyle and Ford 1993), and otolith ageing (Vooren 1975). A detailed analysis of age and growth of juvenile *N. macropterus* from southern and eastern Tasmania using sagittal otolith increments is presented in Chapter 8.

The length-frequency distributions reveal some size-structuring of the population with depth, with the inner-shelf consisting exclusively of juveniles and the mid- and outer-shelf of juveniles and mature fish. There is, however, no distinct separation of juvenile size-classes as they were present on the outer-shelf on the east coast in most seasons. Regional differences were also apparent with very few mature fish present on the mid-shelf of Storm Bay compared to the east coast. This is clearly reflected in the distribution of commercial trawl catches in the region (Lyle 1994). Such regional differences are also apparent in New Zealand where the majority of nursery areas are spatially distinct from the mature population with fish returning to their parental spawning grounds with the onset of maturity (Vooren 1975). Such variations are also evident over a broad scale in Australia with juveniles absent from the shelf region of southern New South Wales, north-east Victoria and the Great Australian Bight, fish moving into these areas upon maturity at an age of around 3 years (Smith 1982, Smith 1983, Lyle and Ford 1993). However, an age-based migration from a distinct nursery area isn't evident in the east coast Tasmania population with both juvenile and mature fish present across the shelf.

The size composition of mature *N. macropterus* in the present study is consistent with those from the commercial inshore trawl catch in Tasmania which had a mean length of 34.6 cm (range 25-47 cm) (Lyle and Lennon 1996). This is larger than *N. macropterus* in commercial catches from New South Wales and north-east Victoria, although such commercial size compositions vary considerably between years (Smith 1995). Smith (1994) suggested that the greater proportion of larger fish in the eastern Tasmania than those from eastern Bass Strait reflected a lighter level of

exploitation in Tasmania. Alternatively, such differences could also result from differences in growth, age composition or sex structure of the population. This is examined in the following chapter on age and growth of *N. macropterus* in southern and eastern Tasmania.

Chapter 8 Age, growth and spatial trends in age composition of jackass morwong, *Nemadactylus macropterus*

8.1 Introduction

Jackass morwong, *Nemadactylus macropterus*, is a common demersal species found throughout continental shelf waters of southern Australia (Gomon *et al.* 1994). As it is an important component of the South East Fishery, estimates of age and growth have been published for *N. macropterus* based on whole sagittal otoliths from southern New South Wales and north-eastern Victoria (Smith 1982), and eastern Bass Strait (Wankowski *et al.* 1988). In both studies, growth was initially fast, with maximum reported ages for male and female *N. macropterus* of 11 and 16 years, respectively (Smith 1982), and 11 and 13 years, respectively (Wankowski *et al.* 1988). A recent reappraisal of ages using sectioned otoliths suggests maximum ages are considerably higher than previously estimated (Morison 1996). Using a combination of whole, and broken and burnt sagittae, Vooren (1977) reported a maximum age of 41 years for *N. macropterus* from New Zealand. These general findings are consistent with previous studies where ages were underestimated in whole otoliths compared to those sectioned or broken and burnt (Beamish 1979, Campana 1984, Collins *et al.* 1988).

Estimates of population age-structure of *N. macropterus* in New Zealand waters indicates considerable recruitment variability, although such variations are not evident in all stocks (Vooren 1977). In south-eastern Australia, estimates of age compositions show little evidence of such variations (Wankowski *et al.* 1988), however, variations between years in the relative abundance of 25-30 cm fish led Smith (1989) to conclude that recruitment was variable.

Given the lack of information on age and growth of *N. macropterus* from Tasmanian waters, particularly using sectioned sagittal otoliths, the aims of this chapter are to (1) determine the age and describe the growth of *N. macropterus* in southern and eastern Tasmania from sectioned otoliths, (2) describe the trends in sex-specific size compositions from shelf waters, and (3) examine spatial patterns in age composition and assess the extent of recruitment variability.

8.2 Methods

8.2.1 Study locality and sampling regime

Length-frequency data and otolith samples of *Nemadactylus macropterus* were obtained primarily from research demersal trawl surveys conducted seasonally on the shelf of southern and eastern Tasmania between January 1993 and January 1995. Full details of the shelf sampling areas, survey design, gear and biological sampling is presented in Chapter 2. In brief, *N. macropterus* were sampled from demersal tows made at random stations in three strata (10-50 m, 50-100 m, 100-200 m) on the east coast of Tasmania, and two strata (10-50 m, 50-100 m) in Storm Bay. All individuals were measured for fork length (FL) (length of the middle caudal ray), a minimum of 100 of these by sex, with on-board measurements rounded down to the nearest half centimetre. For each seasonal sample, up to 50 fish in each depth strata were retained and processed for biologicals in the laboratory.

Additional adult *N. macropterus* were sampled from commercial trawl catches made in eastern Tasmania in April, September, November and December in 1994. Further juvenile *N. macropterus* were also captured at several nearshore sites (0-12m) in south-eastern Tasmania using a beam trawl towed at two knots from an aluminium dinghy (see Chapter 2).

8.2.2 Laboratory procedures

All fish processed for biologicals were measured to the nearest millimetre fork length (FL) and weighed to the nearest gram. Sex was determined by macroscopic examination of the gonads. Sagittal otoliths of research shelf caught *N. macropterus* were removed from a random sample of 20 fish in each depth strata each season. Otoliths were removed from all fish caught from inshore surveys and commercial sampling. Otoliths were cleaned, dried, weighed to the nearest 0.001 gram and stored in envelopes prior to processing.

Preparation of sagittae follows that previously detailed for *Platycephalus bassensis* in Chapter 5. Age estimates were derived by counting the presumed annual increments (opaque or dark zones) from the primordium to the edge of the otolith section on the ventral sector of the proximal side. Along this same axis the distance from the primordium to the outer edge of the first four opaque zones, and the edge of the section was measured to the nearest 0.1 μm. The opaque bands considered true

annuli were distinguishable from false checks since they extended down both the ventral and dorsal sides of the medial groove and were continuous from the ventral edge to the sulcus. An increment was considered complete when a distinct opaque band was visible across the proximal face of the otolith section immediately inside a narrow discernible edge of translucent material. All counts and measurements of increments were made without knowledge of fish size, sex or date at capture. A total of 16% of otoliths were rejected to the poor quality of sections which were independent of both age and sampling region.

8.2.3 Precision of age estimates

To compare the precision of age estimates, a random subsample of 100 sagittae were read a second time by the main reader, and by a second reader experienced in the reading of transverse sagittal sections. The average percent error (APE) was calculated for both the within and between reader age estimates using the formulae of Beamish and Fournier (1981) (see Chapter 5). In addition, the percentage agreement of the within and between reader age estimates was calculated as another means of evaluating precision.

8.2.4 Growth

An absolute age was assigned to *N. macropterus* using a birth date of 1 March, which corresponds to the mid-point of the spawning season (see Chapter 6). Von Bertalanffy growth curves were fitted to the individual length at age data for males and females separately and combined by direct non-linear least-squares estimation using *Genstat* statistical package. To eliminate the bias of excluding slow growing juveniles that take longer to reach a size that can be sexed, juveniles were ranked by size, then each successive juvenile assigned an alternate sex and included in the calculation of the sex specific von Bertalanffy growth curve.

The growth curves derived for males and females were compared using an F test on the ratio of the mean square for the combined fit and the sum of the error mean square for males and females fitted separately (Ratkowsky 1983). Using the estimated ages, mean lengths at age were calculated for male and female *N. macropterus*, separately and combined.

8.2.5 Age composition

The size composition of male and female *N. macropterus* from Storm Bay and the east coast were firstly obtained separately by pooling lengths from all seasonal research samples. The sex specific size composition of the total population vulnerable to the sampling gear for both areas combined was then determined using the formula of Davis and West (1992), as given in Chapter 7. The age composition of the population was then estimated for the 1994 research samples, with the number of fish aged proportional to the number of fish in each 2 cm size-class from the scaled population size composition of the same year. Year-class distribution were also examined for 1994, with the year-class referring to the year in which the fish was spawned. Age composition of the research sampled shelf population was also examined by depth strata, with the number of fish aged proportional to the number in each 2 cm size-class from the scaled population size composition in each strata across years.

8.3 Results

8.3.1 Size and sex compositions

Length-frequency distributions for all shelf surveys combined were determined separately for males and females (Fig. 8.1). Lengths ranged from 13.5 to 42.3 cm (mean 30.8 cm) for males and 13.5 to 45.5 cm (mean 33.3 cm) for females. While the distribution of both sexes was dominated by a single mode at around 33-34 cm, there was a significant difference in the overall composition between sexes (KS test, P<0.001), with considerably more large females than males. This is reflected in the fact that around 44% of females were above 35 cm, compared to 18% of males.
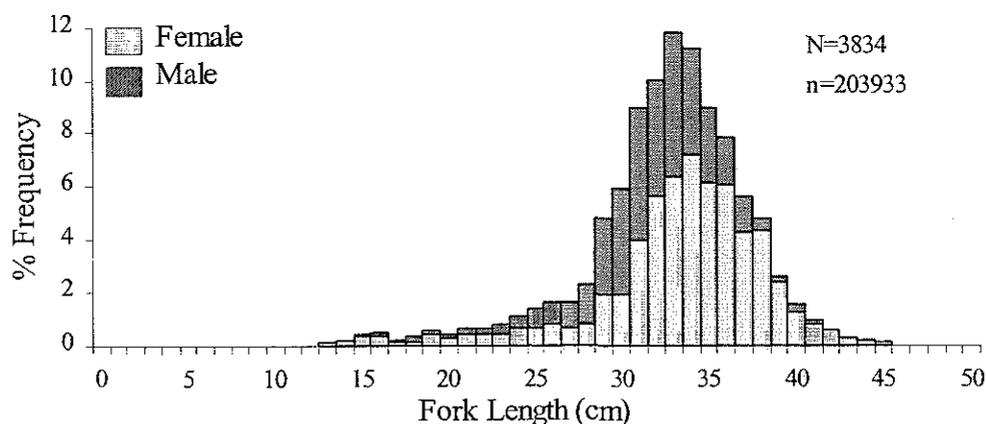
Fig. 8.1   Scaled length-frequency distributions of male and female *Nemadactylus macropterus* on the shelf region of southern and eastern Tasmania. N is measured sample size, n is scaled sample size.

Sex ratios were determined for *N. macropterus* >20 cm, with the proportion of females significantly higher than males in autumn and winter in both 1993 and 1994 (Table 8.1). In all other seasons, sex ratios did not differ from 1:1. Sex ratios varied considerably by size-class, with females dominant between 20 and 24 cm and above 34 cm, and males dominant between 27 and 31 cm (Fig. 8.2).

Table 8.1 Sex ratios of *Nemadactylus macropterus* based on proportion of female (prop. F) by season. P is probability of sex ratios varying from 1:1 based on Chi-square tests. n is female scaled sample size.

Year	1993				1994			1995
Season	Summ	Aut	Wint	Spring	Summ	Aut	Wint	Summ
prop. F	58.0	69.9	64.2	53.5	49.9	66.3	74.4	52.1
P	>0.05	<0.01	<0.01	>0.1	>0.5	<0.01	<0.01	>0.5
n	46763	24748	803	18511	39331	20354	55995	35118
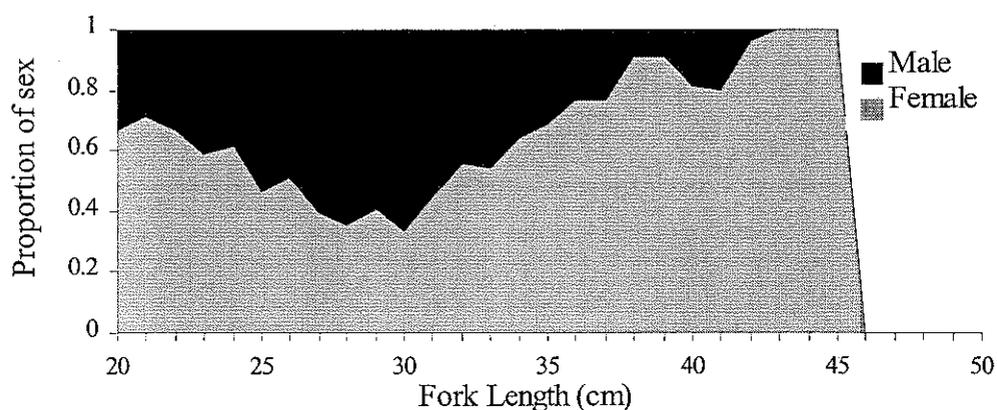
Fig. 8.2 Proportion of male and female *Nemadactylus macropterus* >20 cm by 1 cm length-class from the shelf region of southern and eastern Tasmania.

8.3.3 Otolith structure and interpretation

Transverse sagittal sections of *N. macropterus* showed clear and distinctive alternating opaque and translucent zones seen under transmitted light (Fig. 8.3). The increment banding pattern remained relatively easy to read in older fish despite the narrowing of translucent zones. The primordial area of all otoliths consisted of a broad opaque zone with no obvious increment structure with a mean radius (±s.d.) of 502.0 ±21.6 μm. It was visible in 58% of all sagittae examined, becoming less discernible with increasing age. A narrow band of poorly defined translucent

material occurred outside this zone, adjacent to a second broad opaque zone visible in 89% of all sagittae with a mean radius of 680.0 ± 29.7 μm (Fig. 8.3). The structure of the otolith differed outside this second zone with all sagittae of sufficient radius having a consistent narrower opaque zone with a mean radius of 922.3 ±18.8μm. Beyond this, there were clear and distinctive alternating opaque and translucent zones decreasing slightly in width towards the margin.

Given the variability in the structure of the opaque zones in the primordial region of sagittal otoliths, the first annual increment was defined by comparing the seasonal progression of mean lengths of the 0+ and 1+ cohorts, and the corresponding otolith radius. The radius from the primordium to the edge of the sagittal section on the ventral sector of the proximal side was measured from a representative subsample of these cohorts collected from inshore and shelf regions.

Progressions of size-compositions for *N. macropterus* < 25 cm show that 0+ fish first appear in October at a mean length of around 7.7 cm, progressing through to 9.1 cm by January (Fig. 8.4). Given the arbitrary birthdate of 1 March, the cohort with a mean length of 11.8 cm in April represents the 1+ age-class. This cohort had progressed to a mean length of 20.1 cm by the following January and 20.8 cm by April, therefore representing the 2+ age-class.

The progression of the otolith radius of these cohorts is presented in Fig. 8.5. The mean otolith radius of the 0+ cohort in October was 520 μm, which is only slightly greater than the mean radius of the first broad opaque zone (502 μm), suggesting this zone forms immediately prior to, or during, settlement. The otolith radius increased to 601 μm in January and 778 μm by April indicating that the second broad opaque zone (680 μm) is formed between these months and is consistent with being the first annual increment. By the following January, the cohort length of 20.1 cm had mean otolith radius of 996μm, a radius consistent with the third narrower opaque zone (922.3μm) visible in the primordial region of most otoliths, and hence defined as the second annual increment. This also indicates that new translucent material first appears in early summer (Dec-Jan).

A

500 microns

B

500 microns
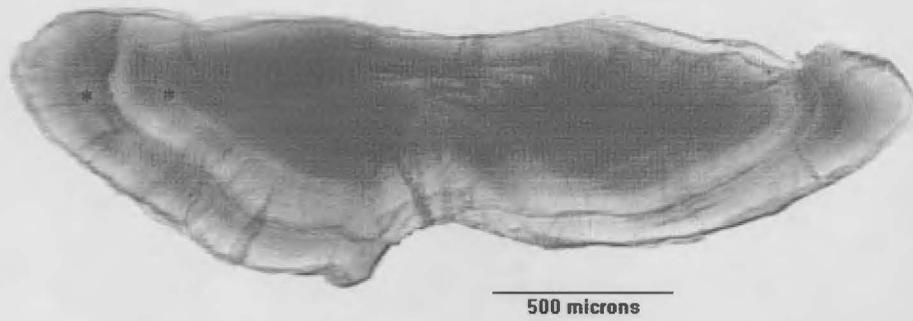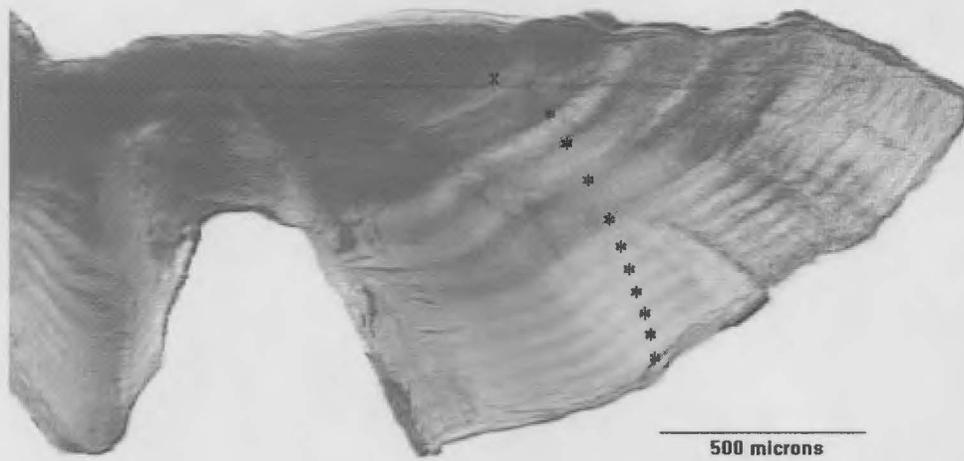
Fig. 8.3 Transverse sections of sagittal otoliths of *Nemadactylus macropterus* viewed with transmitted light; (A) 2 year old and (B) 10 year old. Annual increments marked as *; inner increment seen in 58% of otoliths marked as **x**.
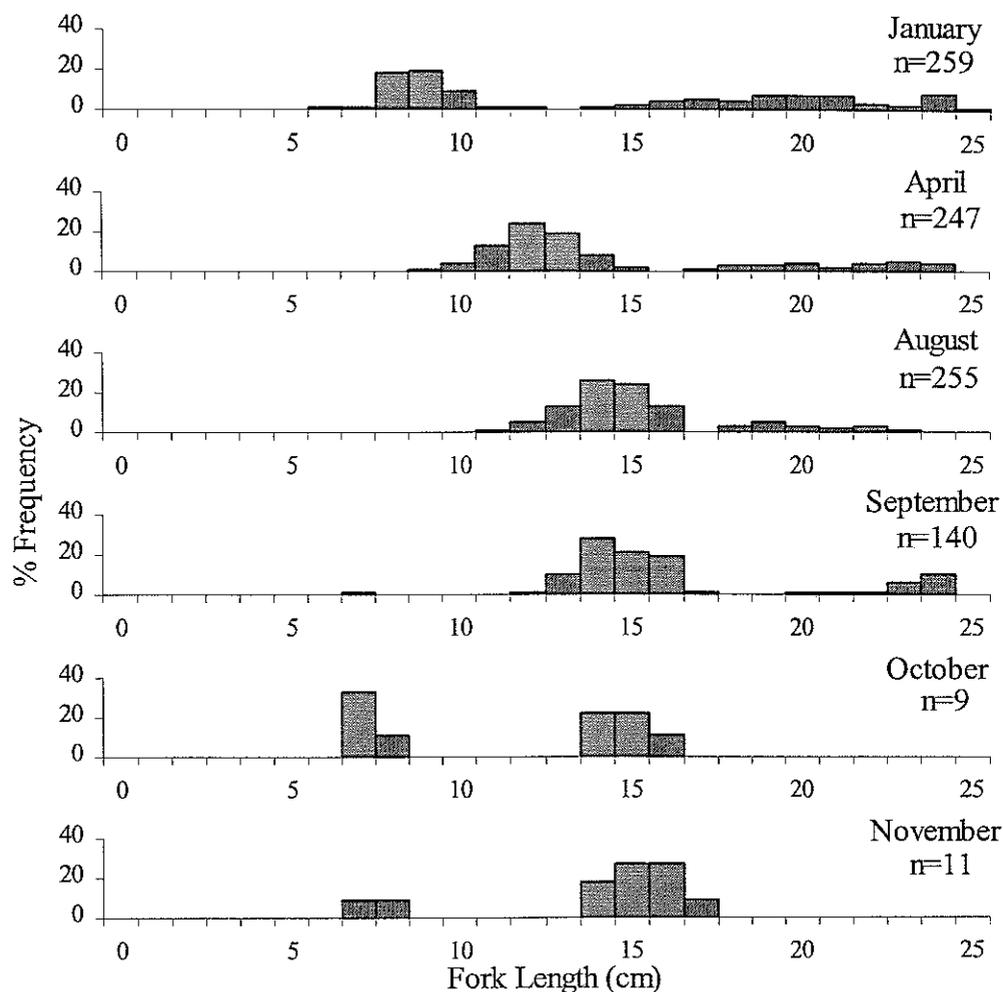
Fig. 8.4 Monthly length-frequency distributions of *Nemadactylus macropterus* <25 cm from southern and eastern Tasmania pooled across years. n is sample size.
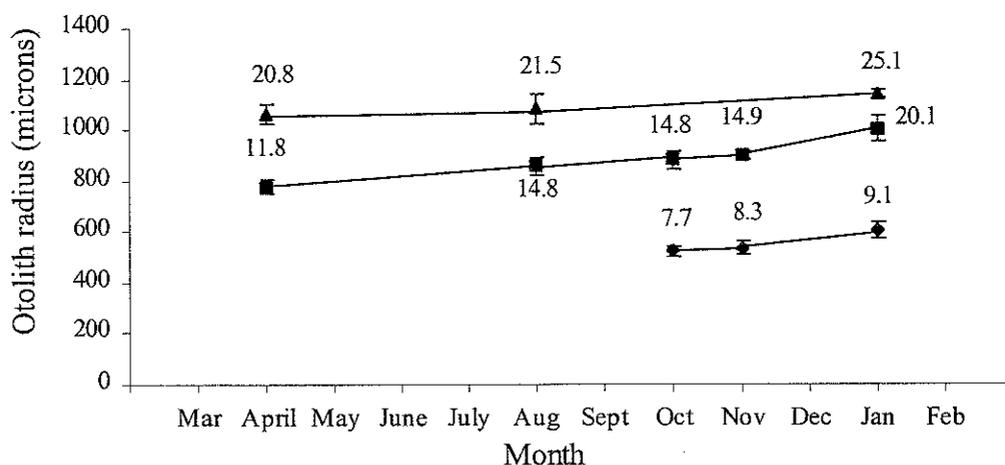
Fig. 8.5 Monthly progression of the mean otolith radius of cohorts of *Nemadactylus macropterus* < 25.0 cm from southern and eastern Tasmania pooled across years. Value labels are corresponding mean fish lengths (cm). Error bars are standard error.

8.3.4 Precision of age estimates

The index of average percent error (APE) calculated for repeat readings by the main reader was 0.25% indicating a high consistency of similarity between readings. This is reflected in the distributions of differences revealing that around 90% of first and second readings were the same (Fig. 8.6). The differences are evenly distributed indicating that there was no pattern of assigning consistently higher or lower estimates on the second reading. The index of APE for estimates between the main and second reader was higher at 2.23% reflecting less consistency between readers. Age estimates were the same 64% of the time, with evidence of the second reader assigning overestimates age by one year in 19% of all fish, compared to underestimates of one year of around 10%.
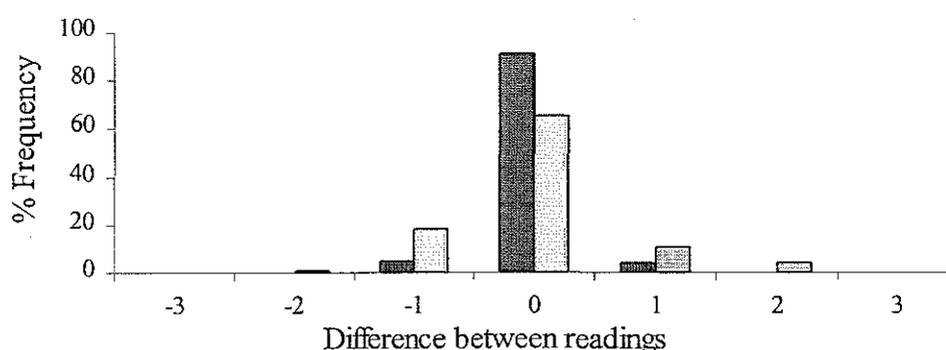
Fig. 8.6 Distribution of differences in estimated ages of *Nemadactylus macropterus* for repeat readings by the same reader (dark bars) and a second reader (light bars).

8.3.5 Growth

Mean lengths-at-age for male and female *N. macropterus*, separately and combined, are presented in Table 8.2. The mean length of females is consistently higher than that of males for all age classes up to 19 years, this last estimate consisting of only one fish. Von Bertalanffy growth curves were fitted to male and female individual length-at-age data separately, and combined (Fig. 8.7). While there was no significant difference in the growth curves between males and females (F=2.33, df 3,303, P>0.05), the distribution of lengths-at-age, particularly between 7 to 12 years, suggests some difference in growth between sexes. The lack of significance may result from the large number of juveniles and relatively few large, older fish in the samples. Hence, the sex specific von Bertalanffy growth parameters are presented in Table 8.3. The respective asymptotic lengths (L_∞) for males and females were 36.2 cm and 38.4 cm, respectively.

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There was a broad range of lengths within individual age-classes, with a maximum of 12 age-classes present in a 1 cm length-class. Growth in both sexes is rapid until around 5 years old (32-35 cm), and then slows appreciably. The maximum age for females was 30 years, while the oldest male examined was 41 years, although the next oldest male was 26 years old.

Table 8.2 Mean lengths at age ($\pm$ standard deviation) for the first 26 age-classes of male and female *Nemadactylus macropterus*, separately, and combined from southern and eastern Tasmania. n is sample size.

Age	Females - Males - Juveniles			Females - Juveniles			Males - Juveniles		
	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.
1	9	14.47	1.88	9	14.47	1.88	7	14.61	2.15
2	8	22.06	3.04	6	21.73	3.16	3	21.73	3.35
3	10	28.03	1.82	2	28.10	1.27	5	27.58	1.83
4	16	31.16	1.64	11	30.81	1.44	5	31.92	1.96
5	27	32.34	2.09	19	32.48	2.36	8	32.01	1.35
6	42	33.60	1.67	23	33.76	1.83	19	33.42	1.48
7	23	33.04	2.55	13	33.79	2.00	7	32.51	3.24
8	6	33.60	2.39	4	34.30	1.64	2	32.20	3.82
9	9	34.83	2.94	5	35.68	2.33	4	33.78	3.63
10	4	35.48	1.19	3	36.03	0.50	1	33.80	
11	13	35.86	2.26	8	37.15	1.91	5	33.80	1.76
12	6	35.67	2.31	4	35.53	2.94	2	35.95	0.78
13	2	36.20	1.41	2	36.20	1.41	0		
14	3	34.20	3.41	1	35.70		2	33.45	4.46
15	6	38.38	2.90	4	39.93	2.07	2	35.30	0.85
16	5	37.06	3.34	5	37.06	3.34	0		
17	5	35.68	3.81	3	37.67	3.72	2	32.70	0.85
18	3	37.60	0.40	2	37.75	3.54	1	37.30	
19	3	35.47	0.76	1	36.00		2	35.20	0.86
20	1	38.20		0			1	38.20	
21	1	39.10		1	39.10		0		
22	1	40.30		1	40.30		0		
23	4	37.45	2.38	0			4	37.45	2.38
25	2	36.80	2.69	0			0		
26	1	42.60		1	42.60		2	36.80	2.69

Table 8.3   Von Bertalanffy growth parameters derived from length at age data for *Nemadactylus macropterus* from southern and eastern Tasmania. n is sample size and s.e. is standard error.

		Von Bertalanffy growth parameters					
	n	L_∞	s.e.	K	s.e.	to	s.e.
All	316	37.41	0.28	0.37	0.02	0.40	0.07
Females/Juveniles	184	38.44	0.36	0.33	0.02	-0.07	0.09
Males/Juveniles	127	36.16	0.43	0.42	0.03	0.15	0.10
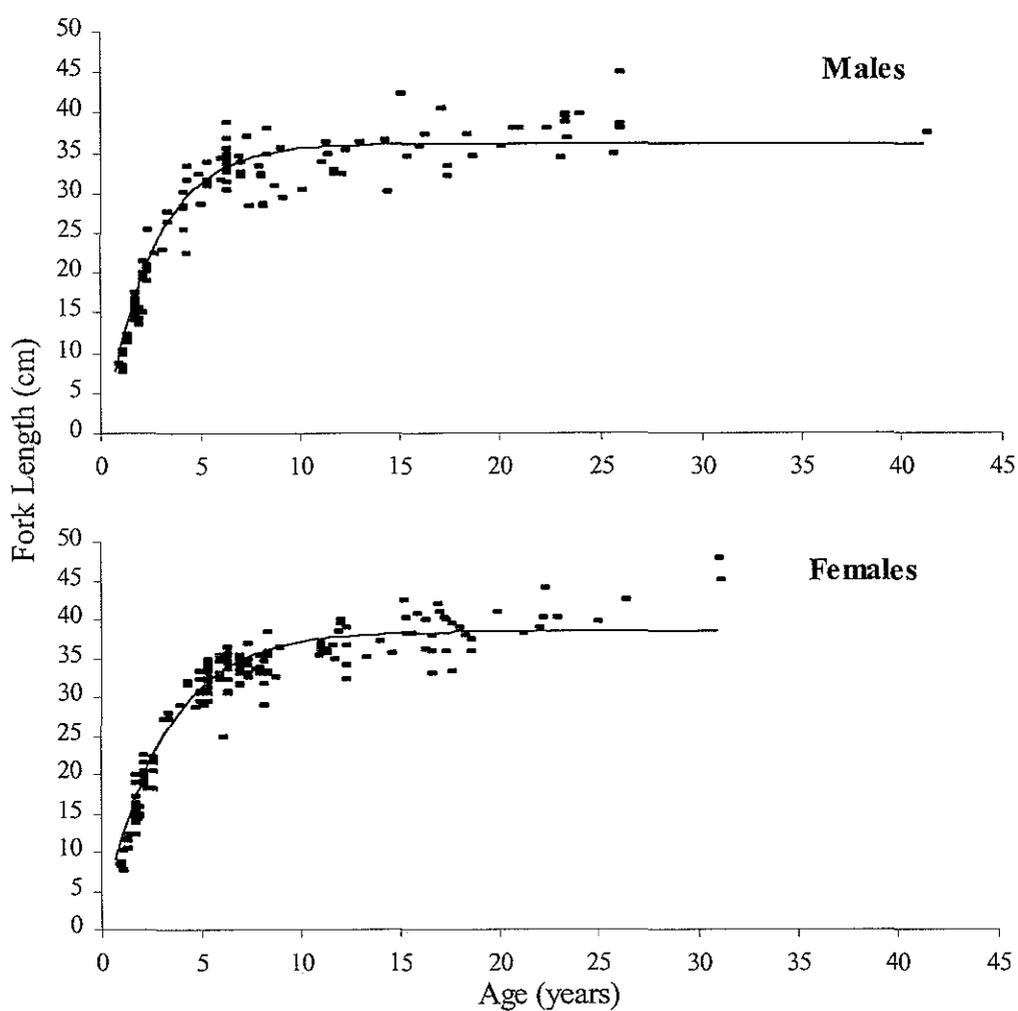
Fig. 8.7   Fitted von Bertalanffy growth curves for male and female *Nemadactylus macropterus* from southern and eastern Tasmania.

The relationship between fork length (cm) and weight (g) for *N. macropterus* is shown in Fig. 8.8. Slopes of the regression of log weight against log length for males and females were not significantly different (ANCOVA, F=1.95, df 1,602, P>0.1) and there was no significant difference in the intercepts for the two sexes (ANCOVA, F=0.66, df 1,603, P>0.1). Hence, both sexes and juveniles were combined with the relationship between length (cm) and weight (g) (Table 8.4).
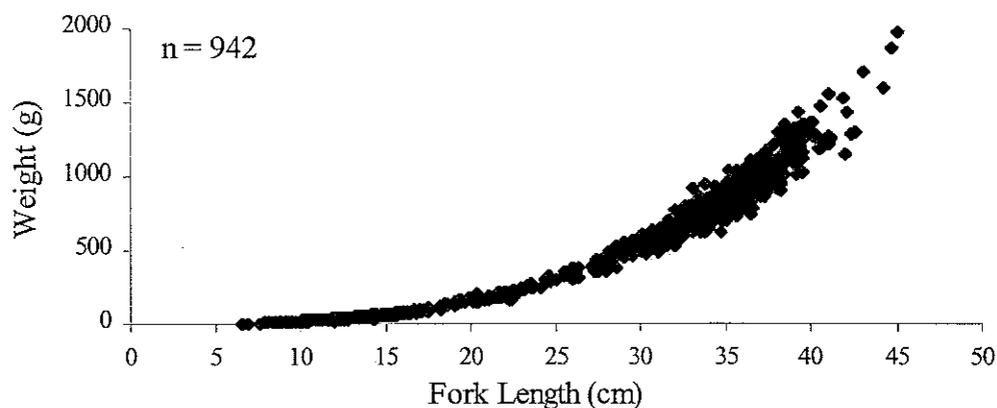
Fig. 8.8 Relationship of fork length against weight for *Nemadactylus macropterus* from southern and eastern Tasmania.

The relationship between otolith weight and age was examined separately for male and female *N. macropterus* (Fig. 8.9A). An examination of the distribution of residuals from the linear regressions shows little increase in variance in otolith weight with increasing age indicating a linear relationship for both sexes. There was, however, some evidence of the relationship being curvlinear in fish <5 years old. The regression of otolith weight against age was not significantly different for males and females (ANCOVA, F=1.82, df 1,255, P>0.1). Given similar slopes, there was also no significant difference in the intercepts for the two sexes (ANCOVA, F=1.96, df 1,255, P>0.1). Hence, the relationship between otolith weight and age was calculated for males and females combined (Table 8.4).

The relationship between otolith radius and age was also examined separately for male and female *N. macropterus* (Fig. 8.9B). Residuals from the linear regressions shows considerable increase in variance in otolith radius with increasing age with a distinct curvlinear relationship apparent for both sexes. The regression of log otolith radius against log age was not significantly different for males and females (ANCOVA, F=1.94, df 1,190, P>0.1), so the relationship was calculated for both sexes combined (Table 8.4).
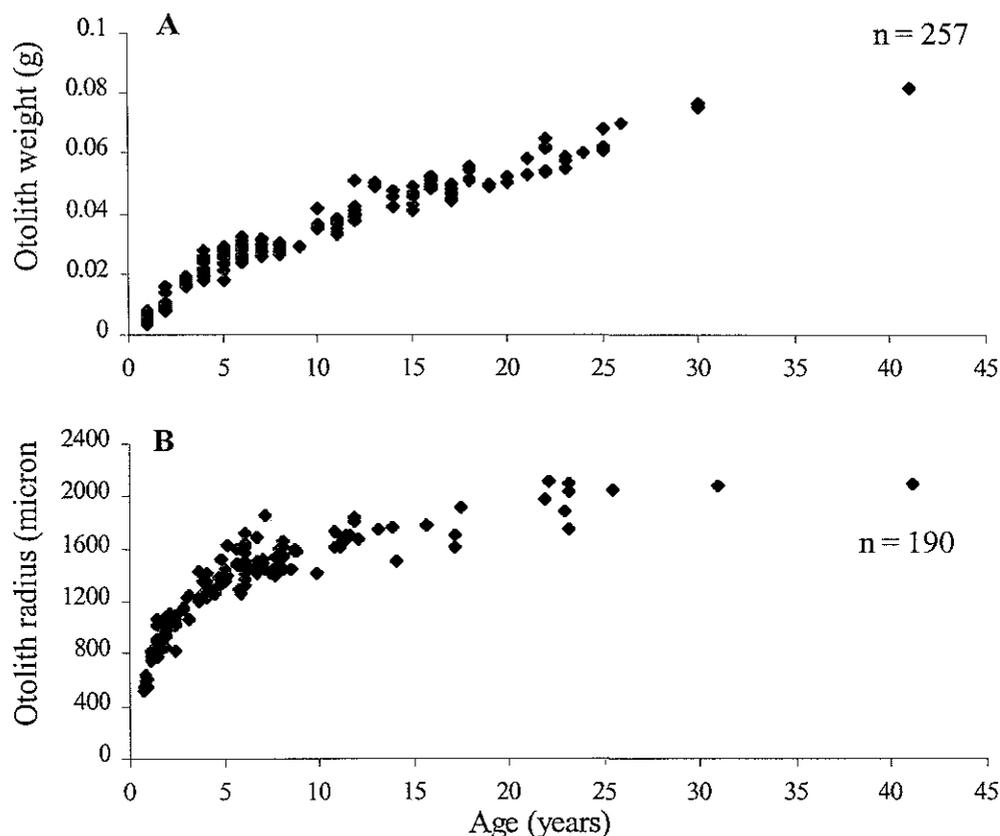
Fig. 8.9 Relationship of (A) otolith weight against age and (B) otolith radius against age for female and male *Nemadactylus macropterus* from southern and eastern Tasmania.

Table 8.4 Length (FL)-weight (WT), otolith weight (OT)-age and otolith radius (OR)-age regressions for *Nemadactylus macropterus* from southern and eastern Tasmania. n is sample size.

Y	X	n	$Y = a+bX$		
			a	b	r^2
$\log_{10}WT$	$\log_{10}FL$	941	-1.841	3.086	0.99
Female/Male OT	AGE	255	0.009	0.002	0.92
Female/Male $\log_{10}OT$	$\log_{10}AGE$	190	2.879	.338	0.91

8.3.6 Age composition

The age composition of male and female *N. macropterus* from shelf regions of southern and eastern Tasmania in 1994 is presented in Fig. 8.10. The samples contained a maximum of 19 and 22 age-classes of males and females, respectively and was dominated by 5 to 7 year old fish, which made up 44% of the population. There was no significant difference in the age composition of males and females (KS

test, P>0.8). The high proportion of 6 year olds in the population in 1994, representing the 1988 year-class, indicates that strong recruitment occurred in that year (Fig. 8.10). There is also some evidence of strong recruitment in 1983 and between 1977 and 1979, suggesting that variations in year-class strength may be a regular feature of the population of *N. macropterus* in southern and eastern Tasmanian shelf waters.
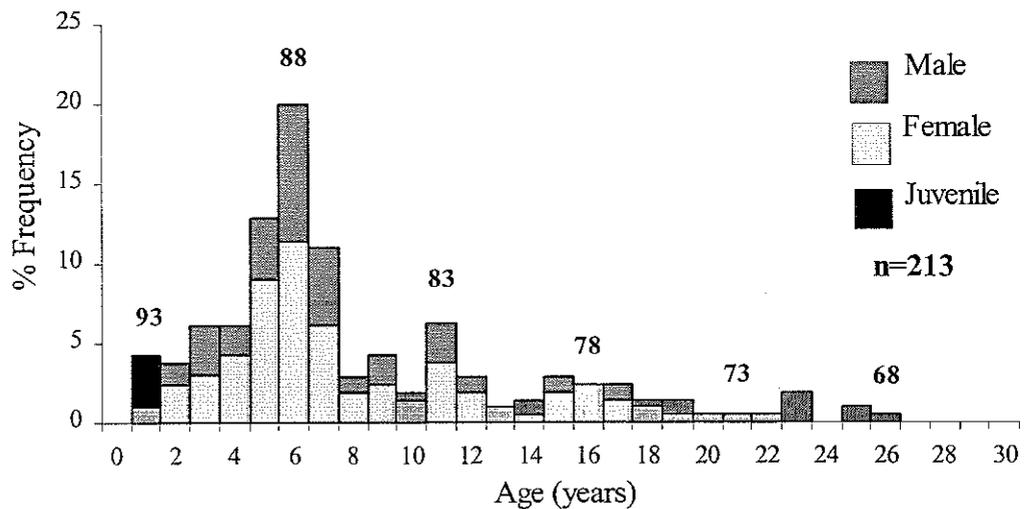
Fig. 8.10 Estimated age composition of *Nemadactylus macropterus* from the shelf regions of southern and eastern Tasmania in 1994. Year-class is provided above the age frequency for every fifth year. n is sample size.

Comparison of age compositions across depth strata in Storm Bay reveal the area was dominated by one year old *N. macropterus*, with little evidence of depth preference of juveniles (Fig. 8.11). While few mature fish were present in Storm Bay, all were caught in the mid-shelf stratum. The age structure of fish on the east coast differed substantially from those in Storm Bay, with the inner shelf consisting exclusively of 0+ fish (Fig. 8.11). In contrast, mid- and outer-shelf strata were dominated by older age-classes with no evidence of age-structuring between strata as fish were evenly distributed across these depths.
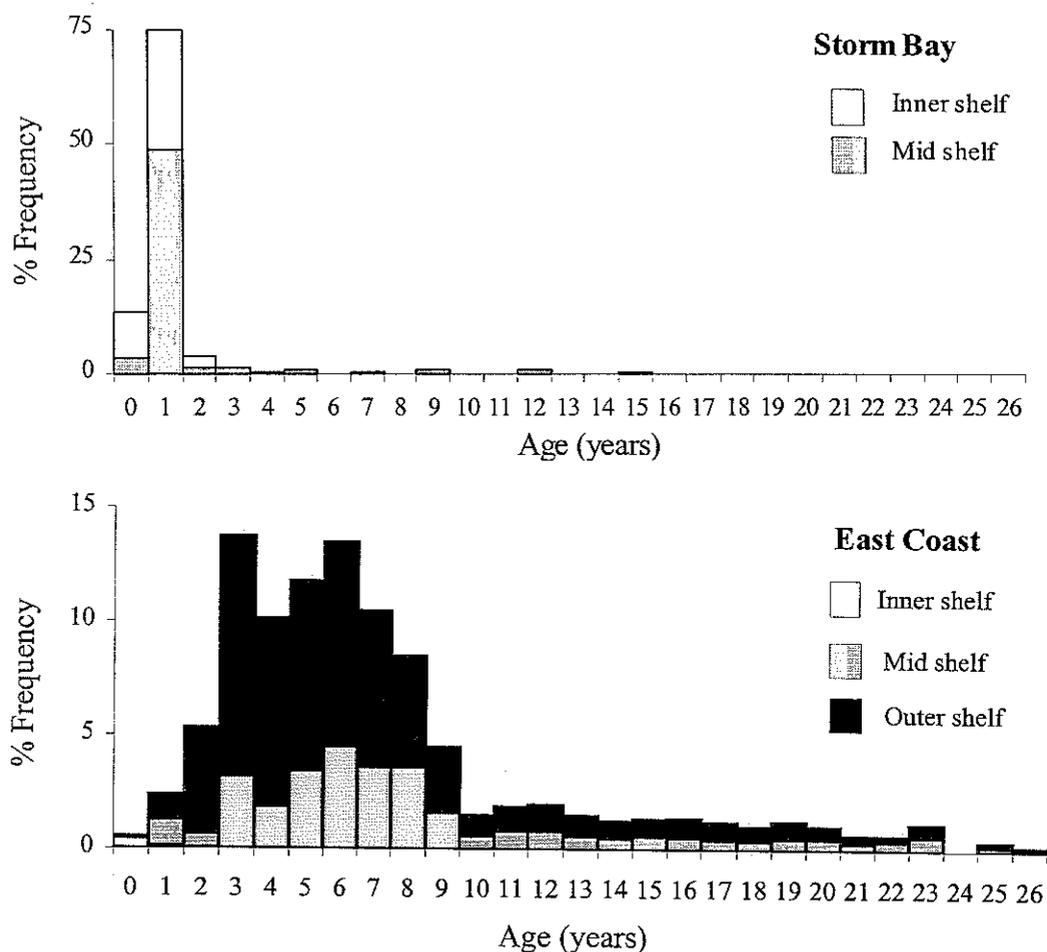
Fig. 8.11 Age composition of *Nemadactylus macropterus* from inner and mid-shelf regions of Storm Bay and inner, mid- and outer-shelf regions between 1993 and 1995.

8.4 Discussion

8.4.1 Otolith structure

Increment structure of sagittal sections of *N. macropterus* otoliths consisted primarily of clear and distinctive alternating opaque and translucent zones, with a narrowing of translucent zones with increasing age. However, the structure of the two inner-most opaque zones differed from those outside this region, being broader and poorly defined, particularly in older fish. By comparing the progression of mean lengths of the 0+ and 1+ cohorts and otolith radius, the first of these two zones was found to be formed immediately prior to, or during, settlement. The mark is consistent with the opaque zone that forms during post-larval metamorphosis of *N. macropterus* in New Zealand (Vooren 1972). The second broad opaque zone became discernible by February and is consistent with being the first annual increment. The third opaque zone was narrower than the inner two, being visible inside a narrow edge of

translucent material by January and is consistent with being the second annual increment. The close correspondence between increment radius and modal lengths of juveniles confirms that one increment is formed each year, at least for the first 2 years. While increments in older fish were clear and unambiguous, further validation is required of older age-classes which have only been validated through analysis of trends in marginal increments in whole otoliths (Smith 1982).

Despite the first annual increment being visible in most otoliths, it became more poorly defined with increasing age due to latter deposits of opaque material obscuring the region of the primordium. Vooren (1972) found the first two increments in whole sagittae of *N. macropterus* to be less clear with increasing age, suggesting that the diameter of the innermost rings should be measured to reduce underestimates of age. The present study indicates that such underestimates can also occur in transverse sagittal sections and therefore measurements of the inner increments should be routinely made, regardless of the method of otolith preparation.

8.4.2 Growth

Growth in *N. macropterus* is rapid for the first 3 years, reaching approximately 12, 20 and 26 cm after 1, 2 and 3 years, respectively. This size-at-age is consistent with that previously reported from south-eastern Tasmania based on modal progressions of juvenile cohorts (Smith 1989). The seasonal progression of these age-classes indicates that most growth occurs during summer and autumn when water temperatures on the shelf of southern and eastern Tasmania are at a maximum (see Chapter 3). The inclusion of considerable numbers of juveniles resulted in values for t_0 for males and females being 0.15 and -0.07 respectively, suggesting that the von Bertalanffy growth curve is a reasonably good representation of juvenile growth. After 3-4 years there was an increasing variation in size-at-age, with fish at a length of 30 cm ranging from 5 to 15 years old.

The maximum ages for female and male *N. macropterus* were 30 and 41 years, respectively. The difference of 15 years between the oldest and second oldest male indicates a larger number of fish may need to be aged in order to representatively sample the older fish in the population. The maximum ages in this study are considerably higher than those previously reported for male and female *N. macropterus* from New South Wales and north-eastern Victoria at 11 and 16

years, respectively (Smith 1982), and eastern Bass Strait at 11 and 13 years, respectively (Wankowski *et al.* 1988). The higher maximum ages of *N. macropterus* from eastern Tasmania may reflect spatial variations in size and age structure and/or underestimates of age in older fish by Smith (1982) and Wankowski *et al.* (1988) due to their use of whole sagittal otoliths.

With regard to the former hypothesis, the size composition of fish from southern New South Wales ranged from 22 to 47 cm, with most individuals between 27-37 cm (Smith 1983), which is consistent with the present study for fish from eastern Tasmania. Such size compositions are also evident in eastern Bass Strait in more recent years (Smith 1995). Seasonal variability in abundance also suggests some movement of fish between eastern Tasmania and eastern Bass Strait (see Chapter 7), indicating that age differences may not result from spatial differences in growth. The more likely explanation for the differences would appear to be that ages were underestimated, a conclusion which is consistent with previous studies where age estimates were lower from whole otoliths compared to those sectioned or broken and burnt (Beamish 1979, Campana 1984, Collins *et al.* 1988, Hyndes *et al.* 1992). It is also consistent with a recent reappraisal of ages of *N. macropterus* from south-eastern Australia using sectioned otoliths, where maximum ages of 31 and 38 years were estimated for males and females, respectively (Morison 1996). A similar maximum age of 41 years has been derived for *N. macropterus* from New Zealand based on examination of broken and burnt sagittae (Vooren 1977). While maximum age of *N. macropterus* in Australian waters are higher in the present study than previously derived, mean length-at-age for 3 to 5 year olds are similar to those of Smith (1982), indicating underestimates of age are restricted to older age-classes. This is consistent with the relationship between age and otolith weight where otoliths continued to thicken in older fish, whereas increases in otolith length slowed with increasing age.

While there was no significant difference in the growth curves between sexes, the larger lengths-at-age for females between 7 to 11 years suggests growth is faster for females in certain age-classes. The lack of significant difference may result from the small number of 3 to 5 year-olds, large number of juveniles and relatively few large, older fish in the samples. Smith (1982) found faster growth in females, although the lower K values of 0.13 and 0.17 for females and males, respectively can be attributed

to underestimates of age through the use of whole otoliths. Recent estimates of growth parameters of *N. macropterus* from ages derived from sectioned otoliths (Tilzey 1998), are consistent with those in the present study.

Despite some evidence of sex specific growth rates, the differences are unlikely to result in the predominance of females above 34 cm. This conclusion is consistent with Smith (1983) who considered growth differences to be insufficient to account for the dominance of females among the larger size-classes of *N. macropterus* off New South Wales and attributed the dominance to increased mortality of older males. Such differential mortality may explain the higher proportion of females in the older age-classes in the present study. Recent estimates of total mortality from sectioned otoliths by Tilzey (1998) are considerably lower (0.18) than previously derived (0.6 to 0.77) (Smith 1995), although the lack of sex specific mortality estimates precludes an assessment of the significance of such differences in structuring the sex composition of the population.

8.4.2 Age composition

The estimated age composition of *N. macropterus* in southern and eastern Tasmania in 1994 consisted of a maximum of 19 and 22 age-classes of males and females, respectively, and was dominated by 5 to 7 year old fish. The high proportion of 6 year olds in 1994, representing the 1988 year-class, suggests that strong recruitment occurred in that year. The relative abundance of this age-class will be, however, strongly influenced by the catchability of this age-class to the demersal trawl gear relative to others, particularly younger age-classes. In estimating the age composition of *N. macropterus* in eastern Bass Strait, Wankowski *et al.* (1988) considered 3 year-olds to be fully recruited to demersal trawl gear with similar mesh configurations to that used in the present study. This is supported by lengths at 50% selection for *N. macropterus* in 90 mm mesh ranging from 20 to 23 cm (Han 1964), and 100 mm mesh of around 24 cm (2+ fish) (Massey 1988). Hence, the use of 20 mm codend mesh in the present study resulted in 3 year-olds (~ 28 cm) being fully recruited to the trawl gear and therefore representatively sampled.

The relative abundance of age-classes will also be influenced by differences in age structure resulting from variations in the spatial pattern of recruitment and migration. However, while there was evidence of interannual variations in the distribution of

settlement between Storm Bay and the east coast (see Chapter 7), larger juveniles show movement at much larger spatial scales than examined in the present study, as 3 year old *N. macropterus* move into shelf regions of southern New South Wales from nursery areas in Tasmania (Smith 1989). Therefore, some movement of larger juveniles can be expected between areas sampled in the present study, which is consistent with the absence of 3 year olds in Storm Bay (see Chapter 7). While the migration of larger juveniles from Tasmanian nursery areas would result in a decrease in the abundance of such age-classes in these waters, there is considerable uncertainty regarding the extent of movement from the south-eastern Tasmania shelf region. This is reflected in the uncertainty in the stock structure of *N. macropterus* throughout southern Australia, with allozyme and mitochondrial DNA studies suggesting the presence of a single stock in these waters (Elliot and Ward 1994, Grewe *et al.* 1994). Otolith microchemistry analysis, however, indicates that distinct stocks occur in both Tasmania and New South Wales/Victoria, with mixing rates low, but sufficient to result in genetic convergence of samples (Thresher *et al.* 1994).

Despite the uncertainty regarding the extent of mixing throughout south-eastern Australia, there are few differences in the size composition of mature *N. macropterus* in south-eastern Tasmania and New South Wales (Smith 1983) that would result from a consistent, directional movement of fish. Therefore, the relative contribution of 6 year-old fish is unlikely to be biased indicating strong recruitment of the 1988 year-class. Evidence of strong recruitment is also present in 1983 and between 1977 and 1979, suggesting that variations in year-class strength is a consistent feature of the *N. macropterus* population in eastern Tasmania. The age composition of *N. macropterus* in New South Wales/Victoria waters also shows evidence of recruitment variability, with some indicating of strong year-classes in 1987 and 1988 (Tilzey 1998). An increased abundance of 3+ fish on the shelf of southern New South Wales in 1979/80 led Smith (1989) to suggest that there was strong recruitment of the 1977 and 1978 year-classes. The evidence of these strong year-classes in the present data clearly suggests that year-class variations are evident across the species distribution in south-eastern Australia.

Strong recruitment variability has also been demonstrated from estimates of population age-structure in New Zealand, although variability was not evident in all stocks (Vooren 1977). There is also considerable interannual variability in the

abundance of 0+ *N. macropterus* recruiting to individual nursery areas in New Zealand (Vooren 1975). In neither Australia or New Zealand have the relative influence of biotic or environmental factors causing such recruitment variability been examined. An examination of the likely causes of the strong recruitment evident in the 1988 year-class of *N. macropterus* in southern and eastern Tasmanian waters is presented in Chapter 9.

The present study revealed considerable differences in the age composition of *N. macropterus* between Storm Bay and the east coast, with very few fish older than 2+ present on the mid-shelf of Storm Bay compared to the east coast. The absence of sampling in the outer-shelf stratum in Storm Bay precludes a comparison of the age structure of these depths between areas. However, the results clearly indicate that the inner- and mid-shelf waters (10-100 m) of Storm Bay are primarily a nursery area for the species, fish moving out of this area at around 3 years-old with the onset of maturity. This is consistent with *N. macropterus* in New Zealand that also recruit to distinct nursery areas in depths of 20-100 m until age 3 (Vooren 1975). In contrast, while the inner-shelf on the east coast consisted exclusively of 0+ fish, the mid-and outer shelf contained both juveniles and mature fish. Therefore, not all juveniles are restricted to shallow distinct nursery areas, and as such, age-specific migrations are apparent for only a portion of the population. The effects of these spatial differences should be taken into consideration before a modal incorporating size-dependant depth distributions, as outlined by Chen *et al.* 1997, can be introduced into stock assessments for *N. macropterus*.

Chapter 9 Concluding Discussion

9.1 General

The central aim of this thesis was to describe the ecology of all life-history stages of two species of fish commonly found in coastal and continental shelf fish waters south-eastern Australia in order to elucidate some of the life-history strategies that have developed by demersal fish in these waters. This was done to gain a better understanding of the relative influence of the spatial and temporal distribution of spawning, larval transport and settlement in structuring the demersal population and influencing recruitment success. In addition, the seasonal, interannual and spatial patterns in abundance and size and age composition were examined in order to determine the influence of recruitment variability, habitat preferences and movement of post-settlement stages in structuring the population.

The causes of recruitment variability has been the focus of a significant amount of research, and has been particularly targeted at determining the causes of mortality in the early life-history stages. There is however, increasing evidence that all pre-recruit stages contribute to interannual variations in year-class strength (Sissenwine 1984, Peterman *et al.* 1988, Bradford 1992). While it is clear that a range of biotic and abiotic factors can play a role in determining survival, the lack available information on the early life-history and recruitment of most demersal species found throughout southern Australia has precluded an assessment of the influence of such factors on survivorship. This is particularly true for the species in the present study, despite their long period of exploitation and significant contribution to commercial and recreational landings in southern Australia.

While recruitment fluctuations are widely considered a central problem in the management of marine fish populations, it is important to note that recruitment variability has been clearly identified in only a few demersal species in southern Australian waters (Harris *et al.* 1988, Tilzey 1994). This suggests that in many temperate Australian species there are only small variations in larval and juvenile survival, or that density dependant mortality is important in regulating recruitment variations. However, as stock assessments for the majority of species relies on data from the commercial fishery, there is often uncertainty whether changes in annual

abundance are due to variations in recruitment or changes in catchability, or a combination of the two (Cheeson 1995).

9.2 Spawning and larval distributions

As the relative influence of transport processes will be strongly influenced by the temporal and spatial distribution of spawning and hydrography, this was examined for both species in the present study. While pelagic fish in regions of high oceanographic variability respond to fluctuating conditions by varying the both the location and timing of spawning to make best use of seasonal patterns of ocean stability and favourable transport (Parrish *et al.* 1983, Shelton and Hutchings 1989), such variability was not evident in the demersal species in this study. Both species had protracted spawning periods with little evidence of year to year variations in the timing of spawning, despite considerable variations in the hydrography of the spawning area. The timing of spawning in *P. bassensis* is likely to be related to the timing of the spring bloom in productivity in these waters which begins around mid-September (Harris *et al.* 1987). Tthe extended spawning period may also be a strategy to maximise the number of larvae encountering suitable feeding conditions, as the duration of the spring bloom in the shelf waters of southern and eastern Tasmania can vary by as much as three months from year to year (Harris *et al.* 1991). While the presence of several cohorts of 0+ *P. bassensis* in the present study may reflect periodicity in the temporal pattern of spawning and a fixed larval duration, it may also result from periodicity in larval survival through short-term variations in zooplankton production.

There is evidence of an average periodicity in peaks of westerly wind stress and coastal productivity in Tasmania at around 40 days, indicating a strong interaction between the time scale of wind events, resuspension of nutrients and zooplankton production (Clementson *et al.* 1989, Harris *et al.* 1991). Such periodicity in plankton blooms was strongly correlated with peaks in the recruitment of larvae in south-east Tasmania, with a match/mismatch hypothesis used to explain variations in larval survival (Thresher *et al.* 1989). Despite the strong relationship between westerly wind strength and plankton production, variations in survival may also reflect similar periodicities in anomalous transport. However, the consistent lag between productivity and settlement peaks, and the lack of evidence for water mass movement

at the same periodicity led Thresher *et al.* (1989) to discount advection as a significant source of larval mortality in Storm Bay.

In contrast, a strong correlation between the 10-14 day cycle of westerly wind stress, local hydrography and supply of larval *Sillaginodes punctata* into Port Phillip Bay was directly attributed to periodicity in the passive transport of larvae (Jenkins and Black 1994, Jenkins *et al.* 1997a). Such variations in larval transport have been identified as a significant source of mortality and can play a major role in determining recruitment success (Nelson *et al.* 1977, Bailey 1981). This is particularly significant in species whose larvae are distributed inshore and whose nursery areas are also inshore. By spawning throughout coastal, estuarine and inshore shelf waters close to settlement habitats, and by having larvae concentrated in mid-water, *P. bassensis* have developed a spawning and early life-history strategy that minimises the advective loss of larvae offshore that could occur during periods of increased westerlies and subsequent offshore flow of surface waters. Such offshore Ekman transport is often minimal directly adjacent to the coast (Parrish *et al.* 1981), which is supported in the present study by the concentration of larvae on the inner-shelf in 1990, despite increased westerly wind stress in that year. There was also no evidence of large scale replacement of coastal waters that would transport larvae away from suitable settlement areas.

Initial settlement of *P. bassensis* occurred exclusively into subtidal unvegetated habitats in coastal waters, which continue to be an important juvenile habitat for at least the first two years. The majority of the subtidal coastal zone throughout southern and eastern Tasmania consists of soft-sediment unvegetated habitats, with most areas containing only small beds of seagrass in the 2 to 7 m depth range. Therefore, given the extensive settlement habitat available within the area of spawning, the delivery of *P. bassensis* larvae to these habitats are unlikely to be strongly influenced by transport processes and habitat selection. Loss of larvae through transport away from inshore settlement areas is also minimised due to the relatively short larval duration and small size at settlement at around 2 cm. This is consistent with the small size at settlement of the flounders, *Rhombosolea tapirina* and *Ammotretis rostratus,* at around 1.5 cm which also spawns inshore and recruits to shallow unvegetated habitats in southern Tasmania (Crawford 1984). As suitable settlement sites are extensive, such species have little need for a long pre-competent

phase in order to maximise the chance of finding a suitable site. However, spatial variations in prey abundance and juvenile growth rates do occur in shallow unvegetated habitats, highlighting the potential influence of post-settlement processes in recruitment success (Poxton *et al.* 1983, Jenkins *et al.* 1993, Malloy *et al.* 1996).

While the factors influencing the spatial and temporal patterns of recruitment of fish into nearshore soft-sediment habitats has focussed on the importance of habitat structure (Orth *et al.* 1984, Bell *et al.* 1988) and larval supply (Bell and Westoby 1986, Jenkins *et al.* 1997a), very little research had been conducted on species that show little response to habitat structure, particularly in temperate Australian waters (May and Jenkins 1992). If at settlement, available habitat is widely distributed then spatial recruitment patterns are unlikely to be strongly influenced by hydrodynamics and larval supply, particularly in species that spawn close to settlement areas. While the fine-scale spatial variability in settlement of *P. bassensis* wasn't examined in the present study due to low and patchy distributions of new recruits, there is a need to examine in more detail the influence of coastal transport processes on patterns of larval supply. Such studies, in conjunction with a finer temporal examination of spawning, would help resolve the influence of egg production and pre-settlement processes in determining patterns of recruitment. Before such work can be advanced, there is a need to resolve the otolith microstructure of early life-history stages of *P. bassensis*.

In contrast to the reproductive and early life-history strategy developed by *P. bassensis*, the spawning of *N. macropterus* in mid- and outer-shelf waters, and concentration of larvae in surface waters, is an adaptive strategy to maximise offshore transport. The development of neustonic eggs and larvae appears to be common in fish species that are important components of offshore larvae assemblages (Richardson and Pearcy 1977, Shenker 1988). The offshore transport of larvae have been related to offshore Ekman transport (Bailey 1981) and mesoscale hydrographic events such as eddies and offshore jets (Mooers and Robinson 1984, Flierl and Wroblewski 1985). The reproductive strategy of *N. macropterus* appears to contrast that described by Parrish *et al.* (1981) who suggested that species that spawn in upwelling regions have adapted to spawn at a time of minimum offshore transport. However, in the Pacific north-west some species spawn at a time of

maximum offshore transport resulting in different coastal and offshore ichthyoplankton assemblages during different seasons (Richardson and Pearcy 1977, Richardson *et al.* 1980).

The offshore movement of surface waters from the shelf off southern and eastern Tasmania is due primarily to the predominance of westerly winds (Cresswell *et al.* 1994). The hydrography, however, shows considerable intra-annual variability during the spawning period of *N. macropterus*, which should strongly influence the number of larvae reaching offshore waters. This was evident during the cool windy year of 1991 when the rapid influx of East Australian Current (EAC) water from the north-east in March resulted in onshore flow of surface waters, clearly demonstrating the dynamic nature of the local hydrography. Such variability may explain the extended spawning period of *N. macropterus* which has developed in order to maximise the number of larvae encountering periods of offshore transport. The significance of the summer and autumn spawning in relation to the timing of plankton production and feeding conditions is difficult to assess given the lack of data on temporal trends in productivity in offshore waters. While phytoplankton blooms have been identified on the shelf during autumn (Harris *et al.* 1987), it is unknown whether these extend offshore.

As little research has been conducted on the offshore larval assemblages off southern Australia the advantages of offshore distribution during the larval phase is yet to be examined. The presence of larvae in waters off the shelf is often attributed to anomalous transport resulting in increased larval mortality (Bailey 1981), although it is unclear whether this is an important source of mortality in many species (Moser and Boehlert 1991). The offshore distribution of larval *Pomatomus saltatrix* in the South Atlantic Bight appears to be an adaptive response to transport larvae close to nursery areas (Hare and Cowen 1996). This strategy is consistent with the New South Wales and north-east Victorian populations of *N. macropterus*, whose larvae are transported south in EAC water (Bruce *et al.* 1997) into nursery areas in Bass Strait and Tasmania. For *N. macropterus* larvae spawned in eastern Tasmania and whose nursery areas are in the same shelf region, there is evidence of offshore surface circulation patterns that act to retain larvae within this region (Bruce *et al.* 1997). The period of recirculation of surface drifters is consistent with the pre-settlement duration of larvae of around 8-9 months. It is also unclear whether

retention of larvae on the shelf during years of strong onshore transport results in increased larval mortality as there is little difference in the abundance of microzooplankton between shelf and offshore waters off Tasmania during winter in years of reduced westerly winds stress (Young *et al.* 1996).

Coincident with an offshore distribution is a long pelagic post-larval phase of around 8-9 months and a large size at settlement of around 7 cm. While data are limited, the adoption of such an early life-history strategy appears to be common in several cheilodactylid and latrid (trumpeter) species that occur in south-east Australian waters. It also appears to be consistent with cheilodactylids in New Zealand (Vooren 1972) and South American waters (Nielsen 1963). While few small juvenile bastard trumpeter, *Latridopsis forsteri* have been collected in Tasmania, several fish at around 16 cm have recently been caught still undergoing post-settlement metamorphosis suggesting settlement has recently occurred (A. Jordan unpubl. data). Such post-larval *L. forsteri* are similar to *N. macropterus* as they are morphologically very different from juveniles, being characterised by a deep, thin, laterally compressed body with a sharply keeled belly and silvery appearance below the lateral line. While it appears that many reef associated fish and invertebrate species found in south-east Australian waters have developed a life-history strategy with an extended offshore distribution, it is of particular significance that all such species show evidence of considerable recruitment variability (Harris *et al.* 1988, Gardner *et al.* 1998, Murphy and Lyle 1998).

During the period of recruitment of *N. macropterus* (spring/early summer), the relative influence of the dominant water masses shows considerably intra- and interannual variability, and is coupled with variations in westerly winds (Harris *et al.* 1991). This is particularly evident in variations in the frequency, timing and duration of the southerly extension of EAC water onto the shelf of eastern Tasmania (Harris *et al.* 1987, see Chapter 6). If the supply of post-larvae is strongly influenced by physical transport processes, then the short and long term variations in westerly wind stress and oceanography that are common in the region are likely to result in variations in recruitment at both intra- and interannual scales. As larvae are present in both water of subantarctic origin and the EAC, and within the broad convergence zone between the two (Bruce *et al.* 1997), variations in recruitment are likely to result from the changing influence of particular waters masses.

While the role of passive transport in determining patterns of recruitment is still to be examined in detail, the large size-at-settlement of post-larval *N. macropterus*, and other offshore species such as *L. forsteri*, suggests that horizontal swimming plays a role in the movement of fish towards the shelf. Horizontal swimming has been implicated in the onshore movement of pelagic juveniles (Larson *et al.* 1994, Hare and Cowen 1996), although such onshore transport still appears to be associated with hydrological features, such as Ekman transport (Parrish *et al.* 1981, Norcross and Shaw 1984, Shenker *et al.* 1993), internal waves (Shanks 1983, Kingsford and Choat 1986) and warm core ring streamers (Hare and Cowen 1996). Movement of *N. macropterus* post-larvae onshore through active horizontal swimming is supported by the lack of consistent surface hydrological features that would transport larvae as far as the inner-shelf region of south-eastern Tasmania.

A better understanding of the mechanisms of cross-shelf transport of *N. macropterus* can only be advanced through a more detailed examination of the hydrography of offshore and shelf waters, in addition with a closer examination of the temporal pattern of recruitment and aspects of post-larval behaviour. The differences in the reproductive and early life-history strategies of *P. bassensis* and *N. macropterus* described in this study indicate that the relative influence of transport and feeding is strongly controlled by the timing of spawning, vertical distribution of larvae, location of spawning in relation to appropriate settlement habitats and the duration of the pelagic larval and juvenile phase. In addition, given that size at settlement varies markedly between species, the significance of behavioural mechanisms in influencing patterns of recruitment are likely to be species specific.

9.3 Juvenile Distribution

The present study also revealed that the distribution of nursery areas of demersal fish in Tasmania is also species specific. While *P. bassensis* showed a strong preference for unvegetated nearshore habitats, *N. macropterus* utilised both inner- and mid-shelf regions, although there was some evidence of juveniles nearshore. These results contrasts with the widely recognised belief that within soft-sediment habitats, seagrass beds are the dominant nursery area for many coastal species of commercial and recreational importance in southern Australia by providing protection and increased food resources compared to bare substrates (see Bell and Pollard 1989). It is likely that *P. bassensis* use unvegetated habitats as a nursery area, as camouflage

allows them some protection from predators. In addition, there is evidence of enhanced prey production in unvegetated areas due to organic enrichment from detached macrophytes (Robertson and Lenanton 1984, Shaw and Jenkins 1992). This is similar to juvenile Pleuronectidae (flounders) that are also associated with unvegetated habitats and are protected by camouflage (Crawford 1984, Connolly 1994, Jenkins *et al.* 1997b). In contrast, *N. macropterus* appear to use schooling behaviour as a means of protection from predation.

The dependence on nearshore unvegetated habitats by juvenile *P. bassensis*, and the lack of small juveniles of any economically important species in seagrass beds in Tasmania (Jordan *et al.* 1998b), indicates that such vegetated habitats are considerably less important as a nursery area than other soft-sediment habitats in this region. This supports several recent studies in southern Australia where shallow unvegetated habitats were found to be an important habitat for juvenile fishes (Potter *et al.* 1990, Ayvazian and Hyndes 1995, Edgar and Shaw 1995a, Jenkins *et al.* 1997b). In contrast, few studies have investigated the distribution of nursery areas of continental shelf species in southern Australia, although recent studies have focussed on several whiting (Sillaginidae) species (Hyndes *et al.* 1996). This is particularly significant for species caught in the South East Fishery where little is known of the recruitment mechanisms for the majority of species (Lyle and Ford 1993, Tilzey 1994).

The present study revealed that the distribution of juvenile *N. macropterus* in southern and eastern Tasmania is consistent with many demersal species that are common on the shelf in this region, including tiger flathead (*Neoplatycephalus richardsoni*), silver dory (*Cyttus australis*) and latchet (*Pterygotrigla polyommata*), which also utilise inner- and mid-shelf waters as a nursery area (Jordan 1997). These shallow shelf regions (<100 m) are extensive in southern and eastern Tasmania suggesting that this region is an important nursery area for these species. While juvenile *N. macropterus* appear to be restricted to waters of Bass Strait and Tasmania (Smith 1983, Lyle and Ford 1993), the relative abundance of juveniles have not been examined at the larger spatial scale across south-eastern Australia. Given that distinct nursery areas have been identified for *N. macropterus* in inner-shelf waters of New Zealand (Vooren 1975), such areas may also exist in southern Australia. This is supported by the differences in the size and age composition between areas in the

present study which suggest that Storm Bay may principally be a nursery area, while the east coast is important for both juveniles and adults. As some movement of 3 years olds occurs into waters of southern New South Wales and north-east Victoria (Smith 1989), there is however, considerable uncertainty regarding the extent of movement of juveniles from the south-eastern Tasmania shelf region (Thresher *et al.* 1994). It is clear that further research is required to assess the entire spatial distribution of juvenile *N. macropterus* before the relative significance of nursery areas in southern and eastern Tasmania can be evaluated. Such research is essential before the development of indices of pre-recruit abundance can be advanced for this species. There is also some need to examine spatial variations in prey abundance and growth rates in juveniles of demersal species in order to assess the characteristics of optimal nursery areas in unvegetated habitats.

These results have particular significance in relation to the management of both nearshore and shelf habitats. While the widespread loss of seagrass beds throughout Tasmania has resulted primarily from increased turbidity and nutrient levels (Rees 1993), anthropogenic impacts on the extensive areas of nearshore unvegetated habitats have not been studied in detail, but are likely to result from algal and dinoflagellate blooms, accumulation of wood pulp effluent and introduction of exotic species. There is often a high priority to minimise impacts on seagrass beds as they have a higher abundance and diversity of fishes than adjacent unvegetated areas (Orth and Heck 1980, Connolly 1994, Gray *et al.* 1996, Jordan *et al.* 1998b). However, in order to minimise impacts on juveniles of economic importance, management actions should also be directed at coastal unvegetated habitats, particularly areas of high macrophyte detritus which can enhance infaunal production (Edgar *et al.* 1994), and growth and survival of juveniles (Jenkins *et al.* 1993). In addition, given the potential significance of inner-shelf areas of southern and eastern Tasmania for juveniles of *N. macropterus,* and other commercially important species, the impact of by-catch mortality of juveniles from the inshore demersal fisheries also needs to be addressed. While levels of by-catch of *N. macropterus* are around 4% by weight and 8% by number on the shelf of New South Wales (Liggins 1996), such levels would be expected to be considerably higher in south-eastern Tasmania given the presence of juveniles in shelf waters of this region.

9.4 Adult distribution

The spatial patterns of recruitment of both *P. bassensis* and *N. macropterus* had a varying influence on the spatial structuring of the populations. Firstly, as both juvenile and adult *P. bassensis* are found in nearshore waters, there is no evidence for a distinct ontogenetic change in depth preference, although there is an increasing use of seagrass beds by *P. bassensis* close to onset of maturity. This contrasts that of many south-eastern Tasmanian shelf species, including tiger flathead, *Neoplatycephalus richardsoni*, which show a distinct trend of increasing size with depth (Jordan 1997). There is, however, evidence of a seasonal movement of *P. bassensis* from inshore bays onto the shelf close to the size at maturity.

In contrast, the considerable increase in size and age between inner-shelf and deeper shelf waters in *N. macropterus* resulted in a general increase in abundance of fish across the shelf, a pattern common to most commercially important demersal species in south-eastern Tasmanian (Lyle and Ford 1993, Jordan 1997). While similar spatial variability in abundance of demersal fish occurs in other shelf areas of southern Australia (Gray and Otway 1994), the influence of size structuring in determining such patterns has been described in few studies (Hyndes *et al.* 1996).

The present study also revealed considerable seasonal and interannual variations in the abundance of *P. bassensis* and *N. macropterus* on the shelf of southern and eastern Tasmania. For *P. bassensis*, the seasonal variations were primarily driven by the seasonal movement of the mature fish between shelf and nearshore waters. Overlying the seasonal trends in abundance were interannual variations that were at least an order of magnitude in difference. There was some evidence of variations between winters resulting from interannual variations in oceanography and shelf productivity. However, variations between summers differed between shelf regions and appeared to be related to a localised ecosystem wide response as a trend of declining abundance was evident for all demersal species in Storm Bay during the study period (Jordan 1997).

There were also considerable variations in the abundance of *N. macropterus* across both temporal scales, however, the trends were often inconsistent with those of *P. bassensis* indicating that the factors influencing temporal patterns often differ between species. While the processes driving productivity in the pelagic

environment of the shelf of eastern Tasmanian have been closely examined (Harris *et al.* 1987, Young *et al.* 1993, Young *et al.* 1996), the role of variations in demersal productivity in determining temporal patterns of demersal species have been poorly studied. Therefore, before the role of environmental factors on demersal fish abundance and distribution can be evaluated, there is clearly a need for further research into patterns of demersal ecosystem productivity in south-eastern Tasmania. This is particularly significant in this region as it represents a boundary between subtropical and subantarctic waters which show intra- and interannual variability in their relative influence, which strongly affects pelagic productivity at similar temporal scales (Harris *et al.* 1991).

The fishery independent estimates of spatial and temporal variations in abundance and size/age composition of *P. bassensis* and *N. macropterus* should provide a valuable input into the stock assessment for these species, which is currently based on analysis of fishery dependant CPUE trends and size/age structure (Chesson 1996). Of significance is the variations in abundance across depths and areas. This has implications for the interpretation of such data from the commercial fleet as variations in size compositions and catch rates from the commercial fishery may purely reflect shifts in effort across these spatial scales. In addition, the presence of considerable seasonal and interannual variations in catch rate in the present study suggests that changes in CPUE in the commercial fishery could result from changes in effort across these temporal scales rather than reflecting changes in the size composition or abundance of the stock. This highlights the usefulness of fishery independent surveys in providing information on the distribution, abundance and size and age composition of commercially important species.

9.5 Recruitment variability

While the relative importance of physical and biological processes in determining recruitment success has been the focus of considerable research in waters outside Australia (Cushing 1975, Sissenwine *et al.* 1984, Sinclair *et al.* 1985, Rothschild 1986, Francis 1993), few local studies have examined the relationship between environmental variations and year-class strength, particularly for species in the South East Fishery. Thresher (1994) provided evidence of a relationship between the number of days per year of strong westerly winds and recruitment of gemfish (*Rexea*

solandri) throughout south-eastern Australia, although exactly how the variations in winds affect recruitment was not described.

Off eastern Tasmania, interannual levels of coastal productivity are related to variations in westerly wind stress and regional oceanography (Clementson *et al.* 1989, Harris *et al.* 1991). There was clear evidence of variations in the strength of recruitment in the population of *P. bassensis* in both inshore and shelf waters, with the 1986 year-class dominant in all three years sampled. Of significance for *P. bassensis* is the fact that 1986 was characterised by increased westerly wind stress resulting in high levels of phytoplankton and zooplankton production that persisted through the spring and summer spawning period (Harris *et al.* 1991). As detailed previously, periods of increased westerlies are unlikely to result in a significant increase in advective loss of *P. bassensis* larvae from inshore settlement areas. Therefore, the strong year class of 1986 may be related to the increased productivity in coastal waters of south-east Tasmania of that year through a similar processes proposed by Thresher *et al.* (1989), where a match/mismatch hypothesis was used to explain variations in larval survival of temperate reef fish in these waters. The increased frequency of intensity of peaks in production may have extended the optimal environmental window in which larval feeding, growth and survival was maximised. The evidence of a poor year-class of *P. bassensis* in 1989 supports this hypothesis, given the significant reduction in westerly winds and productivity evident throughout southern and eastern Tasmania in that year, which has been related to a major El Niño/Southern Oscillation (ENSO) event (Harris *et al.* 1991). Detailed studies on the temporal patterns of zooplankton and larval production will be required before the influence of variations in food availability on larval survival and subsequent recruitment in *P. bassensis*, and other commercially important fish species, can be fully evaluated.

In contrasts to *P. bassensis,* there was clear evidence of strong recruitment of the 1988 year-class of *N. macropterus* sampled from eastern Tasmania. In support of this conclusion is the presence of a similar peak in recruitment of the 1988 year-class in *N. macropterus* in New South Wales/Victoria waters (Tilzey 1998). As detailed in Chapter 7, the period of recruitment of post-larval *N. macropterus* from offshore waters shows considerable interannual variations in westerly winds resulting in variations in the influence of the dominant water masses (Harris *et al.* 1991). These

variations suggest that the source of post-larvae will vary in response to both mesoscale currents and wind driven surface flow.

The recruitment period of 1988/89 was characterised by a reduction in the westerly wind stress resulting in a persistent onshore flow of subtropical EAC water onto the shelf of south-eastern Tasmania. If the supply of post-larvae is strongly influenced by transport processes, then the reduction in westerlies in 1988 may have provided optimum conditions for onshore movement of fish onto the inner-and mid-shelf through passive transport, active horizontal swimming, or a combination of the two. What is particularly noteworthy is the similarity in the timing of reductions in westerly winds and good recruitment in *N. macropterus*, with evidence of strong year-classes in the period around 1978, coincident with reduced westerlies in those years (Harris *et al.* 1988).

It is clear that in order to determine the mechanisms of onshore transport of post-larval *N. macropterus* and assess the influence of oceanography on recruitment variations, more detailed studies are needed on the hydrography of offshore and shelf waters at a range of spatial scales, in addition with finer scale monitoring of temporal patterns of recruitment and an examination of the development of swimming abilities in post-larvae. Such studies would also provide a better understanding of the recruitment dynamics of a number of commercially important species in Tasmania that have an extended offshore larval distribution and show strong variations in recruitment, including the southern rock lobster (*Jasus edwardsii*), bastard trumpeter (*Latridopsis forsteri*), striped trumpeter (*Latris lineata*) and banded morwong (*Cheilodactylus spectabilis*) (Harris *et al.* 1988, Gardner *et al.* 1998, Murphy and Lyle 1998).

In conclusion, this study has provided information on the life-history ecology of two species of demersal fish commonly found in coastal and continental shelf waters of southern and eastern Tasmania. Life-history strategies differed considerably, indicating that the influence of such factors as the distribution of spawning, larval transport and habitat selection at settlement on recruitment success are clearly species specific. In addition, the spatial and temporal patterns of abundance clearly differed between species indicating a need for further research into patterns of demersal productivity in south-eastern Tasmania, particularly as this region is strongly

influenced interannually by ENSO driven variations in oceanography and productivity (Harris *et al.* 1991). Such studies will need to be advanced before the role of environmental factors in influencing CPUE in the commercial fishery can be separated from changes in stock abundance, an issue that is becoming increasingly important in the management of species in the South East Fishery.

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