
**Ecology and Life History Characteristics of Black
Bream, *Acanthopagrus butcheri*, in Tasmanian Estuarine
Ecosystems**

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DECLARATION

I hereby declare that this thesis is my own work, except where due acknowledgement is given, and that the material presented here has not been submitted at another university for the award of any other degree or diploma.

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ABSTRACT

Estuaries are characterised by high biological productivity associated with relatively variable environmental conditions. Estuarine dependent fish fauna must cope with such variability and typically exhibit a range of life history adaptations in conjunction with migratory capabilities, to make use of a range of habitats throughout their life time. Their utilisation of these habitats is known to vary at a number of temporal scales, including tide, diurnal, seasonal and life history stage. Studies of the interrelationships between estuarine dependent fauna and environmental conditions have attracted much attention because of the physiological and/or behavioral adaptations to the unstable environment.

The black bream, *Acanthopagrus butcheri*, is an estuarine resident species that completes its whole life cycle within an estuary. It occurs extensively in temperate estuarine waters in southern Australia. This species is the subject of major recreational and commercial fisheries throughout its distributional range and has been the subject of several studies on mainland Australia, though very little work has been conducted in Tasmania. Black bream is known to exhibit significant variability between populations in some key biological and ecological characteristics (i.e. growth, size at maturity and spawning period), though relationships between life history stages, habitat utilisation and environmental conditions remain poorly understood. This information is required to guide conservation and management strategies. Using black bream as an example of estuarine resident species, this study describes key biological and ecological characteristics possessed by the species to successfully inhabit the unstable estuarine environment.

Biological and ecological characteristic of black bream, including distribution and movement patterns within an estuary, age and growth, aspects of reproductive biology such as age and length at maturity, spawning period, spawning locations, and feeding habits were studied in the Little Swanport Estuary and Swan River, east coast of Tasmania. The study involved extensive field sampling including collection of fish specimens and measurements of physical environmental parameters between April 2004 and April 2006, and fish tracking study using acoustic telemetry in the Little Swanport Estuary from August 2005 and January 2006.

The distribution patterns of adult black bream varied between the Little Swanport Estuary and Swan River. Adults occurred mainly within the middle estuary, moving into the upper estuary of the Little Swanport Estuary during the spawning season. By contrast, fish were largely distributed within the upper estuary of the Swan River throughout the year. This difference was probably due to more suitable habitats (i.e. submerged trees) and higher food availability in the upper estuary of the Swan River than in that part of the Little Swanport Estuary. Juveniles appeared largely restricted to the upper estuary, but as they grew they became widely distributed within the estuary.

Black bream in these Tasmanian estuaries had a long life span of up to 30 years, with slow growth rate. Females grew larger than males. Based on gonadosomatic index and back-calculated birth dates, spawning occurred from early October to early January with a peak in November-December. This study indicated that spawning was strongly influenced by the environmental conditions, especially salinity on the spawning ground. Successful spawning probably required salinities above approximately 10‰ and flood events during the spawning season negatively influenced spawning success. The ability to tolerate a wide range of

salinities, a prolonged spawning season and long life span are the key strategies that have enabled the species to adapt successfully to this highly variable environment.

Black bream fed on a variety of prey including molluscs, crustaceans, polychaetes, teleosts and insects; they also consumed considerable volumes of plant materials such as seagrass and algae. The diel feeding activity pattern of this species reached a peak prior to sunset with constant low values of gut contents from early morning to late afternoon. No substantial seasonal variation in the composition of the diets was observed, but plant material was consumed more during winter when food availability was lower. The diet of this species showed clear ontogenetic changes with increasing size, which would help to reduce the potential for intraspecific competition.

A study of the movements of individual fish using acoustic telemetry conducted in the Little Swanport Estuary demonstrated that adult black bream mainly utilised the upper and middle estuary regions, and showed that an upstream migration occurred from early August to middle January with a peak in November-December. There was no firm evidence that tagged fish moved out of the estuary, even during the periods of heavy freshwater discharge. However, during excessive freshwater inflows (flood events), fish moved or were washed away from the upper estuary region, and they remained the middle estuary region until water conditions in the upper estuary became favorable. Clearly, freshwater inflow was one of most important physical factors influencing movement and distribution of this species within the estuary.

This study has improved understanding of the key biological and ecological characteristics of black bream that enable them to successfully live in estuarine environments and knowledge of the interrelationship between the species and its environment by adding data on its

performance at the southern-most extent of its range. This study has also provided scientific information to support the recreational fishery management of black bream in Tasmania.

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CHAPTER 1

GENERAL INTRODUCTION

1.1. ESTUARINE ENVIRONMENT

Estuaries are semi-enclosed coastal bodies of water which lie at the interface of marine and freshwater (Cameron & Pritchard, 1963) associated with a gradient of conditions ranging from the saline to the fresh water (Elliott & McLusky, 2002). Generally, estuaries are relatively sheltered, with low wave energy compared with coastal waters, and they contain a variety of habitat types, such as sand and mud flats, and seagrass beds, which support productive biological communities (Faria et al., 2006). Estuaries provide important nursery grounds for many fish and crustacean species (Sheaves et al., 2007) and are among the most important coastal ecosystems with respect to human settlement, recreation, and commercial and recreational fisheries.

Estuaries are characterised by high biological productivity associated with rather variable environmental conditions. The relatively shallow waters of estuaries receive nutrients from both the land and sea, providing food and shelter for fish and other aquatic animals that can tolerate the variable conditions (Hodgkin, 1994). Physical and chemical conditions, such as salinity, temperature, turbidity and pH vary spatially and temporally within an estuary (Kimmerer, 2002), and may reach extreme levels at various times (Sheaves et al., 1999).

Estuaries are an ecosystem of particular interest in ecology because a number of factors including salinity, temperature, habitats and food availability strongly influence the types of organism found in each part of the estuary. Studies of the interrelationships between estuarine-dependent organisms and physical environmental factors have attracted much attention because of the particular physiological and/or behavioral adaptations to the unstable environment.

1.2. FRESHWATER INFLOWS

Freshwater inflows affect the circulation patterns and nutrient exchange processes in estuarine ecosystems (Drinkwater & Frank, 1994). Inflows often contain high levels of nitrates and phosphates arising from leaching of soils and/or agricultural and industrial run-off, and so provide additional nutrients into the ecosystem. Reduction of freshwater inflows can result in more marine conditions; alternatively increased inflows can dramatically change salinities over short time periods. Alteration of freshwater discharge into estuarine habitats may cause a reduction in the extent of wetlands and salt marshes, and degrade estuarine habitats by changing abiotic factors such as salinity, temperature and nutrient regimes (Gillanders & Kingsford, 2002).

Freshwater inflows are also important to maintain productive biological communities, and in controlling the distribution and abundance of organisms in estuaries by influencing physical factors such as salinity, temperature and turbidity. Furthermore, freshwater discharge is essential for egg and larval dispersal (Ganapati, 1973) and upstream migrations (Zhong & Power, 1996) in some species of fish. A reduction of freshwater run-off may cause significant changes in a variety of organisms such as phytoplankton, crustaceans and fish (Cloern et al., 1983; Knutson & Orsi, 1983; Jassby et al., 1995; Loneragan & Bunn, 1999; Pierson et al., 2002). The lack of freshwater discharge can lead to a decrease in the migratory population of fish such as salmonids (Northcote, 1982) or even to their complete elimination from the system (Larinier, 2000). On the other hand, excessive freshwater inflows may cause high mortality of invertebrate and fish populations in estuarine environments (Steffe et al., 2007) and also cause the advection of eggs, larvae and even adults of some fish species out of the system (Faria et al., 2006).

Freshwater discharge depends primarily on climatic factors such as precipitation and evaporation, but artificial structures, for example dams and levees may also alter freshwater flow regimes (Gillanders & Kingsford, 2002). Seasonal variation in rainfall is directly related to freshwater inflows while melting of snow or glaciers may also influence levels of freshwater inflows. El Niño and La Niña events can cause unusual precipitation patterns throughout the world (Gillanders & Kingsford, 2002). In south-eastern Australia, freshwater flows increase significantly during La Niña years, while significantly decreased freshwater flows occur during El Niño years. Generally, freshwater inflows in Australia tend to be less predictable, with high annual variability in discharge due to more extreme flood behaviour, than those on other continents (McMahon et al., 1992; Puckridge et al., 1998).

Rainfall in Tasmania is seasonal, with higher rainfall in the winter causing higher freshwater inflows into estuaries, but occasional unpredictable flood events may occur even in the warmer summer season (Edgar et al., 1999). Such unpredictable hydrological conditions can cause strong fluctuations of abiotic factors, such as salinity and temperature, and produce environmental instability that the estuarine fauna must cope with through a range of adaptations.

1.3. FISH IN THE ESTUARINE ENVIRONMENT

Since estuaries provide a rich food source and protection from large predatory fish, many species of fish use the estuarine environment for spawning and/or as nursery areas for juveniles to feed and grow (Miller et al., 1985). Some species only use estuaries as migratory routes to their spawning grounds (Potter et al., 1990; Hodgkin, 1994), whereas estuarine resident (Whitfield, 1994a; Elliott et al., 2007) complete their whole life cycle within estuaries

(Chaplin et al., 1998). Estuarine resident species are relatively uncommon, suggesting that few species have been able to adapt to the unstable and unpredictable environmental conditions that typify estuaries. Some estuarine resident species such as black bream show characterised limited migration between estuaries, implying that populations within different estuaries represent more or less discrete stocks. Thus over-exploitation or persistent recruitment failure in individual estuaries can cause marked localised reductions that are unlikely to be replenished by immigration from neighbouring populations. To understand the key biological and ecological characteristics of estuarine resident species, it is necessary to understand how species have adapted to the unstable estuarine environment.

1.4. BLACK BREAM, *ACANTHOPAGRUS BUTCHERI*

The black bream, *Acanthopagrus butcheri*, is a member of the family Sparidae. The family consists of 37 genera with 125 species, including snappers, *Pagrus* spp., and various species of bream, *Acanthopagrus* spp., which include some important species for both commercial and recreational fisheries (Nelson, 1994). The family is widely distributed throughout the Atlantic, Pacific and Indian oceans and the Mediterranean Sea, and is found in both temperate and tropical waters (Nelson, 1994). Seven closely related species from this family occur in Australia, including five species belonging to the genus *Acanthopagrus*, one in *Rhabdosargus* (Munro, 1949), and another in *Pagrus* (Edgar, 1997). A further five species of *Acanthopagrus* are also found beyond the Australian region (Bauchot & Smith, 1984; Masuda et al., 1984).

The black bream is an endemic species to Australia occurring on the south coast of New South Wales, along the coasts of Victoria and South Australia, Tasmania, and in Western Australia as far north as Shark Bay (Cashmore et al., 1998) (Fig. 1.1). It occurs extensively in estuarine waters where it spends its entire lifecycle (Chaplin et al., 1998; Potter & Hyndes, 1999;

Walker & Neira, 2001). The species is the subject of major recreational and commercial fisheries throughout its distributional range. Its biological characteristics include a long life with slow growth rate, reaching a maximum size of 600 mm total length and 4 kg in weight (Stewart & Grieve, 1993).

Table 1. 1 Taxonomic classification of black bream, *Acanthopagrus butcheri*.

Class	Teleostomi
Subclass	Actinopterygii
Order	Perciformes
Suborder	Percoidei
Family	Sparidae
Genus	<i>Acanthopagrus</i>
Species	<i>butcheri</i>

Other sparids found in Australia.

- *Acanthopagrus australis*. This species is probably most closely related to *A. butcheri* (Farrington et al., 2000). It is a subtropical species found in creeks, rivers, estuaries and coastal waters of eastern Australia from Townsville in Queensland to the Gippsland Lakes in Victoria (Grant, 1982). It is an important fish in the markets of New South Wales and Queensland. The distribution of *A. butcheri* and *A. australis* can overlap in estuaries between Narooma in southern New South Wales and the Gippsland Lakes, Victoria (Starling, 1988). Although the reproductive cycles of *A. butcheri* and *A. australis* are distinct due to different spawning seasons and areas, hybridization between these *Acanthopagrus* species does occur (Rowland, 1984).
- *Acanthopagrus berda*. A close relative of *A. australis* inhabiting mangrove estuaries, with a range extending from Darwin in northern Australia to Gladstone on the east coast of Queensland (Thomson, 1974). It is also distributed in Japan, Taiwan,

Southeast Asia, and across the Indian Ocean to the east coast of South Africa (Masuda et al., 1984).

- *Acanthopagrus latus*. This species occurs in rocky coastal shores and reefs of the Shark Bay area in Western Australia and in the Indo-West Pacific along the coast of India eastward to the Philippines and northward to Japan excluding the Ryukyu Islands (Bauchot & Smith, 1984; Masuda et al., 1984).
- *Acanthopagrus palmaris*. Found in coastal reefs in the eastern Indian Ocean and northwestern Australia from Shark Bay northwards and sometimes enters estuaries (Allen & Swainston, 1988).
- *Rhabdosargus sarba*. Commonly found in coastal waters of eastern and western Australia including Queensland, New South Wales, Victoria and Western Australia (Albany to Coral Bay) (Hutchins & Swainston, 1986).
- *Pagrus auratus*. This species occurs in marine waters of Australia and New Zealand. In Australia it is found along the south coast and as far north as Coral Bay in the west, and Cape Manifold in Queensland in the east (Edgar, 1997).

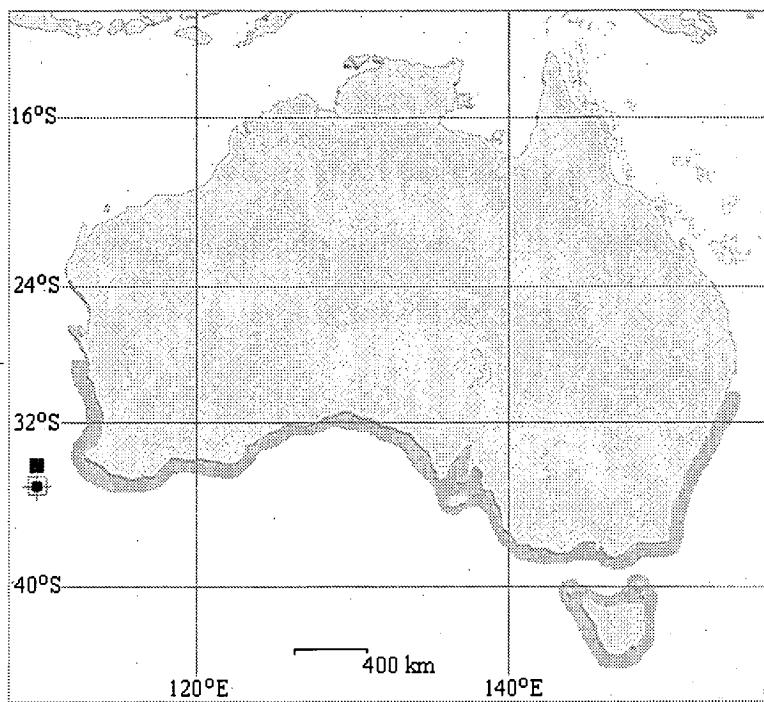


Figure 1.1 Distribution of black bream, *Acanthopagrus butcheri* (gray shading).

1.5. PREVIOUS STUDIES ON BLACK BREAM

Black bream have been the subject of several studies in recent years, mainly focused on their reproductive biology (Sarre & Potter, 1999; Haddy, 2000; Walker & Neira, 2001), age and growth (Sarre & Potter, 2000), otolith microchemistry (Elsdon & Gillanders, 2003; 2006), diet (Newton, 1996; Sarre et al., 2000) and movements (Hindell, 2007; Hindell et al., 2008). These studies have indicated that this species has considerable variation in its biology across its geographic range, particularly size at maturity and growth rate. Black bream in Western Australia attain about 100 mm fork length at the end of their first year of growth and reach maturity at the end of their second year, at which time they have reached over 200 mm (Sarre & Potter, 1999). In Victoria, this species grows more slowly, reaching a fork length of 60 mm at the end of their first year and maturity at the end of their second year (Butcher, 1945a). With respect to spawning periods, in the Gippsland Lakes, Victoria, most spawning occurs

between July and November (Hindell et al., 2008) while South Australia black bream usually spawn between August and November (Harbison, 1973; Elsdon & Gillanders, 2006). In Western Australia, spawning mainly occurs between September and December (Sarre & Potter, 1999). Relationships between life history stages, habitat utilisation and environmental conditions, however, remain poorly understood, especially in Tasmania. An understanding of how the life history characteristics of this species relate to its environment is, therefore, important for the understanding of population variability.

Studies on the genetics of this species have indicated that populations in different estuaries are distinct, but the genetic makeup of populations in neighbouring estuaries are more similar to each other than to those separated by greater distances (Chaplin et al., 1998). This suggests that dispersal between adjacent estuaries is more likely to occur than between estuaries located further apart, although the selective effects of similar environmental conditions in nearby estuaries could also result in the genetic similarities between neighbouring populations (Chaplin et al., 1998). However, contemporary gene flows between adjacent estuaries are very low (Burridge & Versace, 2007). Furthermore, very little information on movement patterns is available, though there is a little evidence of migration between estuaries (Norriiss et al., 2002). Butcher and Ling (1962) indicated that migratory movement of black bream was localised with no indication of fish moving out of the Gippsland Lakes. The result is consistent with the findings of Weng (1971) who also showed that black bream movements were localised with little evidence of dispersal out of the river and/or estuary in which individuals were tagged. It is unlikely therefore that local estuarine populations are replenished by immigrants from adjacent populations. While migration between populations is very limited, this species moves actively within an estuary. Hindell et al. (2008) found that some black bream in the Gippsland

Lakes traveled over 6 km per day (over 2000 km per year), while a migratory study using otolith elements, such as strontium/calcium, also has revealed that black bream have flexible movements, inhabiting from fresh to salt waters, especially during summer (Elsdon & Gillanders, 2006). By characterizing local movement patterns greater insights into the species ecology are possible and such information will be valuable in guiding conservation strategies.

1.6. TASMANIAN POPULATIONS OF BLACK BREAM

In Tasmania, black bream are a prescribed recreational-only species and as a result there is no commercial fishery for this species. Black bream are among the top five most frequently caught finfish by recreational fishers in Tasmania (Lyle 2005). A 2000/01 survey of the recreational fishery determined that approximately 80% of the catch was taken from estuarine waters, with the fishery peaking from November to February, which includes the spawning season of this species. Fifty two percent of black bream fishing activities occurred on the northern half of the east coast of Tasmania (Fig. 1.2). Over the past decade the value of black bream as a sport fish has been increasingly recognized amongst anglers, as evidenced by the increased profile of the species in recreational fishing magazines and the advent of targeted fishing competitions. It is likely therefore that fishing pressure on this species has increased markedly since the 2000/01 survey.

Currently, recreational fishers are restricted to a possession limit of 10 black bream and they are not permitted to take fish with total lengths of less than 250 mm. Since very little work on black bream has been conducted in Tasmania, with only one study on reproductive biology and endocrinology (Haddy, 2000), management strategies are based on empirical information obtained from the mainland of Australia. However, for a species that is known to exhibit

significant variability in biology characteristics, it is important that management strategies are based on detailed scientific assessment collected at a local or regional level.

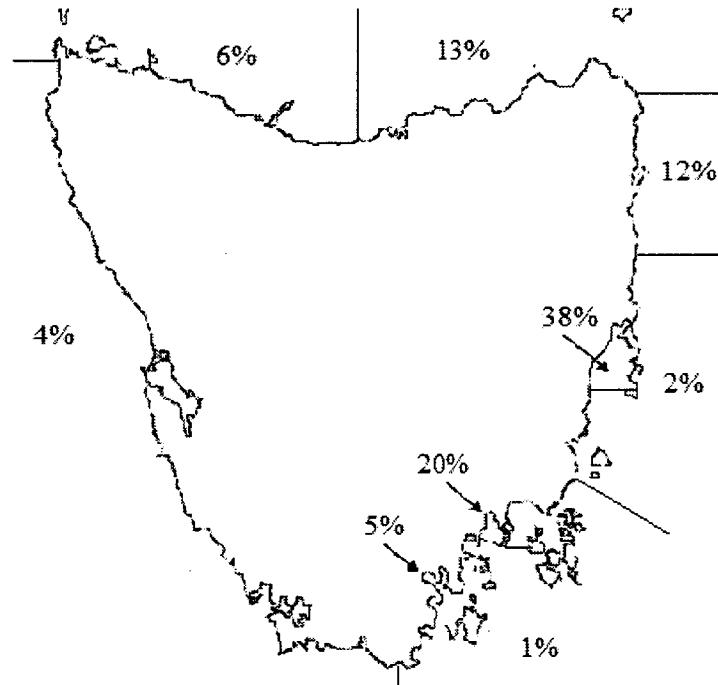


Figure 1.2 Proportion (%) of the total recreational catch of black bream among different regions between May 2000 and April 2001 (Lyle, 2005).

1.7. THESIS AIM

Since estuaries are highly variable environments, such environmental instability makes estuaries a challenging environment to inhabit. To complete their whole life cycle within an estuary, organisms must cope with the highly variable physical conditions through a range of biological and ecological adaptations. This gives rise to the interesting question of what particular biological and ecological characteristics enable organisms to be successful in estuaries. The main aim of this study was to examine the nature of the relationships between environment, habitats and life history of an estuarine resident species, using black bream as a case study. Such information will contribute significantly to understanding how the species

has adapted to estuarine life as well as providing information necessary to support the sustainable management of this important recreational species.

1.8. THESIS STRUCTURE

This thesis has been developed as a series of stand alone chapters. Each chapter represents a separate dataset, and thus can be read in isolation. However, for the purposes of this thesis they have been written and arranged in a manner to complement each other, with cross references between chapters. The thesis consists of five data chapters and a general discussion. Each data chapter addresses the central question; “What biological and ecological characteristics enable black bream to successfully inhabit estuarine environments?” A summary of the aims of each chapter is outlined below:

CHAPTER 2: Seasonal Distribution of Black Bream in Two Estuaries on the East Coast of Tasmania

Physical factors such as salinity and temperature in the estuarine environment vary considerably among regions and seasons. Estuarine resident species may show regional and seasonal variations in their distribution patterns in relation to environmental conditions, habitat types and life history stage. Understanding distribution patterns is important from conservation and ecological perspectives. The aim of this chapter is to describe the interrelationships between the distribution of black bream and environmental conditions by examining physical environmental factors, such as water temperature and salinity, and seasonal abundance exhibited by juvenile and adult fish within the different regions of the estuary. Emphasis has also been placed on establishing whether juveniles and adults fish show different distribution

patterns within an estuary and whether distribution patterns of the species differ among regions of an estuary and months.

CHAPTER 3: Comparison of Age and Growth of Black Bream between Two Adjacent Populations

Age and growth are essential parameters in understanding the population dynamics of species. This chapter describes age and growth of black bream collected from two estuaries on the east coast of Tasmania. The aim of this chapter is to examine whether the growth rates vary between neighbouring populations and to provide comparative data for populations from the Australian mainland subject to different environment regimes.

CHAPTER 4: Reproductive Biology of Black Bream in Tasmanian Estuarine System: Influence of freshwater inflows on Recruitment

Recruitment success is the most important factor for the replenishment of black bream populations, and an understanding of reproductive biology is thus essential for conservation (e.g. protection during spawning). No study has been conducted to examine the reproductive cycle and timing of spawning activity of black bream in Tasmanian estuaries, and relationship between environmental factors such as freshwater inflows and recruitment success is poorly understood. The aims of this chapter are to define basic reproductive biology (size and age at maturity and spawning period), and links between environmental conditions and recruitment success to understand how the species deals with unstable estuarine environment in terms of reproductive strategies.

CHAPTER 5: Feeding Ecology of Black Bream in Tasmanian Estuarine Waters

Knowledge of feeding habits and diet is a key to understanding many aspects of the biology, ecology and behaviour of fish. Benthic communities in the estuarine environment show temporal and spatial variations due to the highly variable physical conditions. Thus the capacity to consume diverse range of prey is important adaptation to the estuarine ecosystem. The aims of this chapter are to describe the diet of black bream in Tasmania estuaries to test hypotheses 1) diet compositions of black bream differ among regions of an estuary and seasons due to different availability of prey species and 2) there is ontogenetic shift in diets to reduce intraspecific competition.

CHAPTER 6: Movement Patterns in Black Bream, *Acanthopagrus butcheri* (Munro)

in a Tasmanian Estuary, Based on Acoustic Telemetry

Many species of estuarine fish make use of a wide range of habitats but their utilisation of these habitats can vary at a number of temporal scales including tidal, diurnal and seasonal, as well as being influenced by environmental and biological factors. The aim of this chapter is to examine small scale movements of black bream within an estuary in relation to biological (reproductive behaviour) and environmental factors (tidal cycles, freshwater inflows), and determine the influence of environmental conditions on distribution patterns of the species. Such information will contribute significantly to understanding how estuarine resident species cope with the environmental instability of estuaries.

CHAPTER 7: General Discussion

The general discussion synthesises the biological and ecological characteristics of black bream in the context of adapting to the estuarine ecosystem and implication for management. Black bream future research issues and impacts of climate change on estuarine environments are also discussed.

CHAPTER 2

Seasonal Distribution of Black Bream in Two Estuaries on the East Coast of Tasmania

2.1. INTRODUCTION

Estuaries are transitional environments between saline and fresh water (Claridge et al., 1986) and most of them are characterised by high biological productivity associated with relatively variable environmental conditions (Whitfield, 1999). Generally, estuaries can be divided into three regions; the lower, middle and upper estuary (Potter & Hyndes, 1999; Whitfield, 1999), though the extent of these will vary greatly, depending on local topography. The lower estuary, which is mostly a marine environment throughout the year, comprises a narrow and usually relatively short entrance channel, which connects with the open sea (Hoeksema & Potter, 2006). The middle estuary is a large and shallow basin, in which estuarine conditions can be found. The upper estuary is strongly influenced by the inflowing river and shows markedly variation in temperature and salinity, ranging from fresh to marine (Stephens & Imberger, 1996; Hodgkin & Hesp, 1998). The upper and middle estuary are naturally stressful environments due to strong interaction between freshwater and seawater (Elliott & Quintino, 2007) and are thus probably more difficult to inhabit.

Estuarine habitats play important roles in the life-cycle of many fish. Most fish found in estuarine environments are marine species which enter and remain within estuaries for only a period of time, particularly during early life stages (Claridge et al., 1986). Many marine species use these systems as nursery grounds (Valesini et al., 1997; Elliott & McLusky, 2002; Phil et al., 2002) because estuaries provide a rich food source and protection from large predatory fish (Miller et al., 1985; Elliott et al., 1990). There are also several marine species which occur irregularly and in small numbers in estuaries; they are opportunists which use estuaries mainly as adults (Potter et al., 1990; Hodgkin, 1994). Estuarine residents complete their life cycles within estuaries and must therefore cope with environmental variability by

typically exhibiting a range of life history adaptations in conjunction with migratory capabilities.

The black bream, *Acanthopagrus butcheri*, is one such example of an estuarine resident found in temperate Australian waters. Both juveniles and adults are well adapted to the estuarine environment, tolerating a wide range of salinities, ranging from 0-60 (Hoeksema et al., 2006). Research on various aspects of the distribution and abundance of black bream has been undertaken in the estuaries of southern mainland Australia (e.g. Weng, 1971; Harbison, 1973; Lenanton et al., 1999; Sarre, 1999), though no similar studies have been conducted in Tasmania. Anecdotal observations and genetic evidence suggest that black bream rarely leave an estuary (Burridge & Versace, 2007) and only enter the near coastal zone during periods of heavy freshwater discharge (Farrington et al., 2000). A study of black bream allozymes conducted by Chaplin et al. (1998) indicated that the local populations of this species in nine estuaries and one coastal lake, located along ca 2,000 km of coastline in Western Australia, were genetically distinct, indicating limited movement between estuaries. In south-western Australia, black bream are most abundant in the upper estuary and less abundant in the middle and lower estuary (Potter & Hyndes, 1999). However, there is evidence that black bream aggregate in the lower estuary during heavy freshwater inputs, probably to avoid unfavourable conditions in the upper regions (Potter et al., 1993). There is thus strong evidence that, under certain circumstances, freshwater discharge, tidal flow and/or the resultant salinity and temperature regimes can induce spatial and temporal changes in the distribution and abundance of this species within an estuary.

In this study, habitat partitioning of black bream was investigated in the Little Swanport Estuary and Swan River on the east coast of Tasmania by comparing abundance of black

bream among three different regions within each estuary. To achieve this goal, a field survey was conducted over two consecutive years to investigate whether black bream underwent changes in distribution and abundance among different regions of an estuary in relation to seasonal and environmental factors.

2.2. MATERIALS AND METHODS

2.2.1. Study locations

2.2.1.1. Little Swanport Estuary

The Little Swanport Estuary (Fig. 2.1) is a relatively well-mixed estuary. It occupies an area of approximately 6.5 km², and is located on the western side of Great Oyster Bay. The Little Swanport River, which is the largest river that discharges into the Little Swanport Estuary, originates from Inglewood Hill, at an elevation of approximately 600 m above sea level and has a catchment area of approximately 610 km² and a total length of approximately 61 km (Little Swanport Catchment: Water Resources Information Package, 2003). The estuary is relatively shallow, ranging from approximately 1 to 9 m at high tide, with the deepest channel located in the middle estuary, between sampling sites LSP2 and LSP3 (Fig. 2.1). The estuary has a narrow entrance approximately 30 m wide and 5 m deep, and a long channel, with numerous shoals and irregular shape. Water circulation in the Little Swanport Estuary is complex, being largely wind and tide driven, and the complexity is accentuated during flood events (Great Oyster Bay and Mercury Passage Marine Farming Development Plan, 1998).

Field studies in the Little Swanport Estuary were carried out at four sites (Fig. 2.1). The upper estuary site (LSP1), which was located in the Little Swanport River and ca 8 km upstream from the estuary entrance, consisted of a rocky bottom and sparse *Ruppia megacarpa* beds. The site was very narrow, approximately 10 m in width, and with shallow water of 1 to 3 m in

depth. The middle estuary site (LSP2) was located approximately 5 km upstream from the estuary mouth and consisted of muddy substrate and dense areas of *Zostera muelleri* beds with shallow water of approximately 3 m deep. In the lower estuary, one site (LSP3) was located near Ram Island and another site (LSP4) was situated approximately 50 m inside the estuary mouth. The substrate at the Ram Island site (LSP3) ranged from silty sand to soft mud with dense *Zostera muelleri* and *Heterozostera tasmanica* meadows in water approximately 3 m deep. The site near the estuary mouth (LSP4), was very shallow (<2 m) and had a sandy bottom, dominated by *Heterozostera tasmanica*. Extensive sandflats were exposed during low tide with clearly defined channels. Tidal influence was low at LSP1 and strong at LSP2-LSP4, with a tidal range of up to 1.5 m. Fish species found in the Little Swanport Estuary include Australian salmon, *Arripis trutta*, flounder, *Ammotretis rostratus* and *Rhombosolea tapirina*, hardyhead, *Atherinosoma microstoma*, mullets, *Aldrichetta forsteri* and *Mugil cephalus*; sea garfish, *Hyporhamphus melanochir*, and silver trevally, *Pseudocaranx dentex* (Crawford et al., 2005).

2.2.1.2. Swan River

The Great Swanport Estuary (Fig. 2.1) is a partially mixed estuary located at 42° 04'S and 148° 07'E. The Swan River is the major river that flows into the Great Swanport Estuary, an area that is important for marine shellfish farming. The estuary entrance is very narrow and shallow being ca 20 m in width and 5 m deep. The estuary and river make up one of the most popular black bream fishing spots in Tasmania and support a variety of other fish species such as eels, *Anguilla australis* and *A. reinhardtii*, gobies, *Nesogobius* sp, hardyhead, *Atherinosoma microstoma*; luderick, *Girella tricuspidata*, mullets, *Aldrichetta forsteri* and *Mugil cephalus*, and silver trevally, *Pseudocaranx dentex* (personal observation).

Sampling was conducted at four sites in the Swan River (Fig. 2.1). The two uppermost river sites, SR1 ca 18 km upstream from estuary mouth, and SR2 ca 16 km upstream were characterised by dense seagrass beds of *Ruppia megacarpa*. At these sites the river was narrow, approximately 15 m in width, very shallow (1 to 3 m) and with a little tidal influence. Large amounts of submerged woody debris were present in these sites. The other two sites (SR3 and SR4) were located along a continuous wide and deep channel, ca 70 m in width and >10 m in depth. The habitats at SR3 and SR4 were relatively similar, with dense beds of *Heterozostera tasmanica* on silty substrates. Due to the strong current, high density of seagrass and difficulty of access (shallow mud flat) in the basin of the estuary, fish sampling was only conducted in the Swan River.

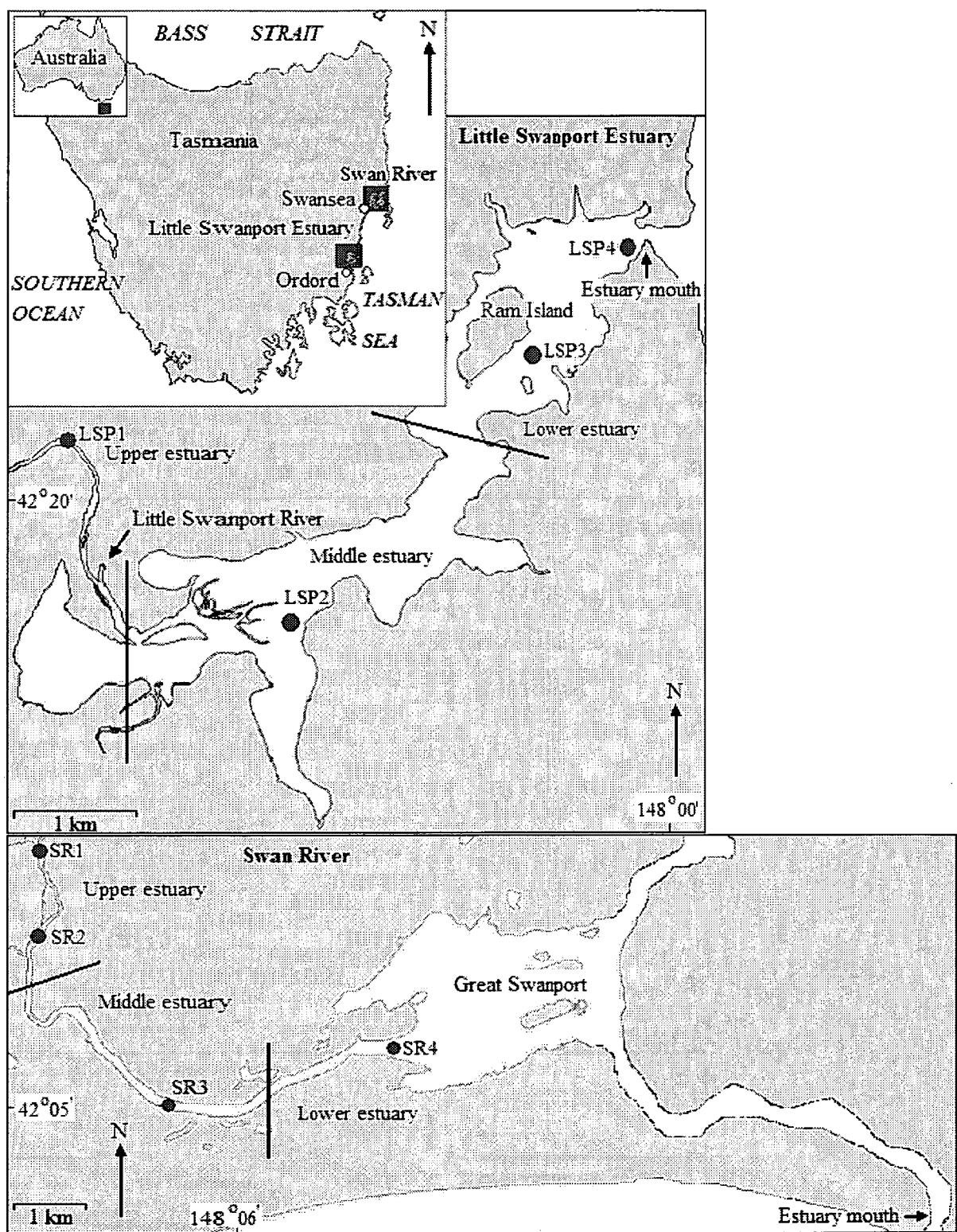


Figure 2.1 Map of the Little Swanport Estuary and Swan River showing the sampling sites. Lines indicate different regions of the estuary.

2.2.2. Sample collection

Hydrographic parameters, temperature ($^{\circ}\text{C}$) and salinity (‰) were recorded during each sampling session using a conductivity meter (WTW LF 197), in surface and bottom waters at all sites. Rainfall recorded at the nearby towns of Orford and Swansea was obtained from the Bureau of Meteorology of Australia. Daily freshwater discharge into the Little Swanport Estuary at the DPIW (Department of Primary Industries and Water) lower gauge (station No. 2235; 2 km upstream of B01) was estimated by Dr Jeff Ross, TAFI (Tasmanian Aquaculture & Fisheries Institute). Daily flow was estimated using river height data collected at the lower and upper (station N0. 2207) gauging stations in the catchment. In some instances when the rating curve for the lower gauge was exceeded, flow data from the Sinclair Knight Merz water balance model was used (SKM 2004).

Adult fish were collected in waters deeper than 2 m at both study locations between May 2004 and May 2006 using a multi panel gill net (three 10 m long by 2 m deep monofilament panels with stretched mesh sizes of 64, 89 and 105 mm) set for 30 minutes during day light hours, with four replicates at each site. The gill nets sites were situated in waters ranging from 2 to 6 m in depth and in close proximity to banks on which there was vegetation and submerged tree branches. The nets were set in a straight line parallel to these banks. In the Little Swanport Estuary, sampling was conducted at the upper estuary site (LSP1) and the most downstream site (LSP4) on a monthly basis while at the other two sites (LSP2 & LSP3), sampling occurred once every three months between May 2004 and April 2005. All sites were then sampled monthly from May 2005 to April 2006. Sampling was conducted monthly at all sites in the Swan River between June 2004 and May 2006. Due to mesh selectivity, gill nets caught very

few fish smaller than about 140 mm and as a consequence, the population survey was restricted to fish larger than this size.

Juvenile sampling was undertaken on a monthly basis using a beach seine net (20 m long with 10 mm mesh collecting fish within an area of 120 m²) at all sites in the Little Swanport Estuary between May 2004 and April 2006 with the exceptions of July to September, November and December 2004 when no sampling was conducted at LSP2 and LSP3. The seine net sites were situated in nearshore, shallow waters ranging from 0.5 to 1.5 m in depth. The net was laid in a semi-circle, starting from the shore, and was immediately pulled on to the shore. Three replicate hauls of the seine net were conducted at each site on each sampling occasion.

It should be noted that as a result of net-selectivity, fish in some size class would have been under-represented in the samples obtained using the above two methods. For example, in gill nets, fish >140 mm would not be caught, and the beach seine net was particularly effective in capturing fish ranging from 30 to 200 mm, but not effective in capturing fish <30 mm.

All fish were counted and fork length (FL) measured to the nearest 1 mm for fish collected by gill net, and to 0.1 mm for juveniles collected by beach seine. Catches obtained by the four gill net sets, and three beach seine hauls were expressed as abundance based on the mean catch per set or haul at each site. Numbers obtained by gill nets were used to compare the relative abundance of black bream among four sites within the same estuary. Fish ≥140 mm comprised 3.4% of the total beach seine catches (number) and were excluded prior to analyses to limit the beach seine data to an assessment of juvenile abundance.

2.2.3. Analysis of data

All data were assessed for homogeneity of variances and normality using box plots and residual plots. Data were transformed when it was necessary to produce acceptable homogeneity of variances and distribution of residuals. For each estuary, variability in the abundance of black bream was analysed using nested, repeated measures analysis of variance (ANOVA) to examine whether the abundance of black bream differed among months (fixed factor) and sites (fixed factor). Due to lack of abundance data in some months of the first year of study in the Little Swanport Estuary, only second year abundance data were used to compare the abundance among months and sites in that estuary. Pearson's correlation coefficient was calculated to characterize the relationship between abundance of black bream and water temperature and salinity. All statistical analyses were carried out using SPSS 15.0 statistical software.

2.3. RESULTS

2.3.1. Rainfall & freshwater discharges

The highest monthly rainfalls during the study period were 121 mm recorded in September 2005 at Orford and 142 mm in October 2005 at Swansea (Fig. 2.2). The total annual rainfall in 2004 of 678 mm at Orford and 590 mm at Swansea, respectively, were very close to the long term mean annual rainfall, which is based on rainfall data from the last 21 years, of 677 mm at Orford and 596 mm at Swansea. Annual rainfall totals in 2005 of 727 and 621 mm at Orford and Swansea, respectively, were both higher than the long-term means.

Average monthly freshwater discharge in the Little Swanport Estuary followed a similar trend to that of rainfall (Fig. 2.2). The highest total freshwater discharge during the study period was 212645 mega-litres recorded in September 2005, followed by 210945 mega-litres in October

2005. In general, freshwater discharge was higher during the second year of this study (May 2005-May 2006).

2.3.2. Environmental conditions

2.3.2.1. Little Swanport Estuary

The mean surface and bottom salinities in the Little Swanport Estuary decreased with increasing distance from the estuary mouth, with values ranging downwards from 33.5 at LSP4 to 13.9 at LSP1 for surface salinity and from 34.7 at LSP4 to 23.6 at LSP1 for bottom salinity (Table 2.1). Although differences between the mean surface and bottom salinities at LSP2, LSP3 and LSP4 varied by a narrow range (less than 2.5), there was much greater variability (approximately 10) between the mean surface and bottom salinities at LSP1 (Table 2.1).

Salinities at LSP1 remained relatively high during the warmer months (e.g. November 2004-May 2005) but they showed fluctuations during colder months (Fig. 2.3). In some months, the surface and bottom salinities at LSP1 differed by more than 15, showing the formation of salt wedge. Water conditions found at LSP2 were marine in most months, while marine conditions were found at LSP3 and LSP4 at all times except during major flood events (Fig. 2.3). In most months, the surface and bottom salinities differed by <2 at LSP2, LSP3 and LSP4. However, differences of ca 10 between the surface and bottom salinities were recorded at these sites in September and October 2005 due to heavy rainfall and freshwater discharge, and resultant significant flood events (Fig 2.2 & 2.3).

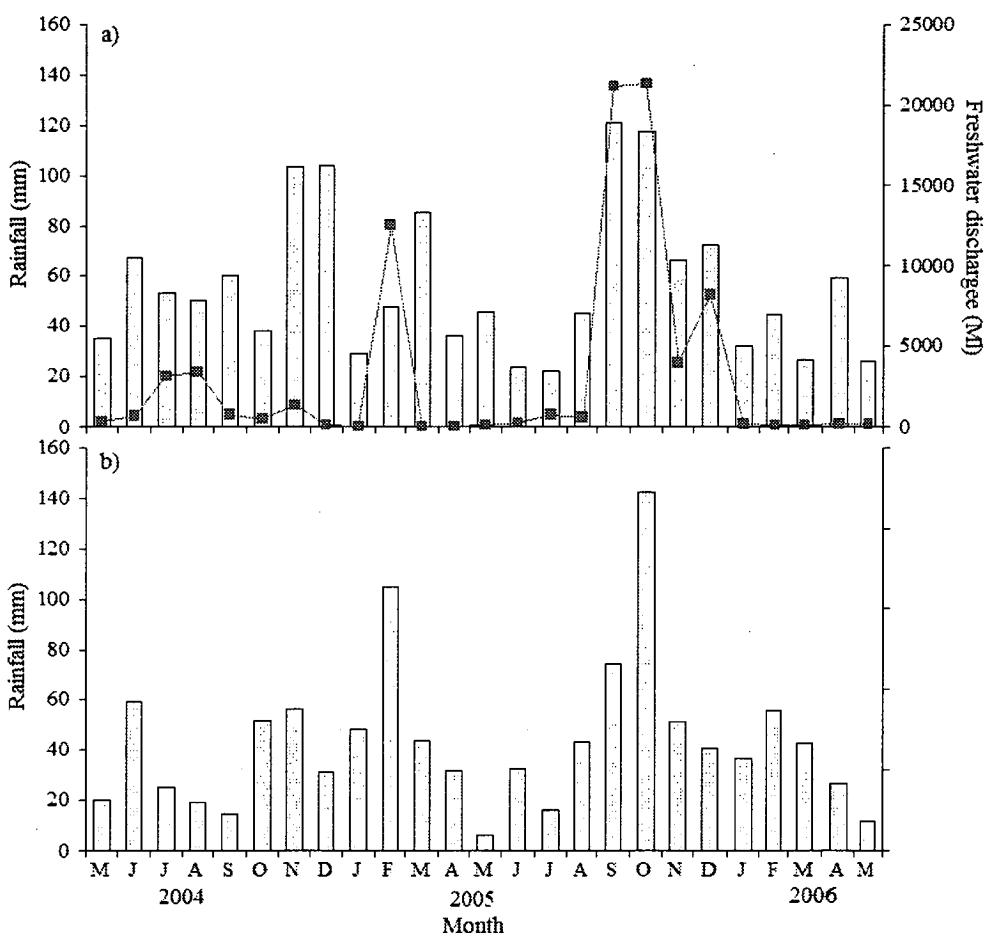


Figure 2.2 Monthly rainfall (bars) recorded at (a) Orford (near the Little Swanport Estuary) and (b) Swansea (near the Swan River) between May 2004 and May 2006, and total freshwater discharge into the Little Swanport Estuary between May 2004 and May 2006.

Generally, water temperature at LSP1 showed a similar trend to the salinity with more fluctuation than at other sites throughout the year (Fig. 2.4). The mean surface and bottom temperatures at the four sites in the Little Swanport Estuary all lay within the narrow range of 14.2-15.0 °C for surface and 14.1-16.6 °C for bottom (Table. 2.1; Fig. 2.4).

Table 2.1 Mean, minimum and maximum surface and bottom salinities and water temperatures at the four sampling sites in the Little Swanport Estuary (LSP1-LSP4) between May 2004 and April 2006.

Salinity						
	Surface			Bottom		
	Mean	Min	Max	Mean	Min	Max
LSP1	13.9	0.0	31.6	23.6	0.0	34.2
LSP2	30.6	3.7	36.0	33.1	18.3	35.9
LSP3	32.4	14.2	34.9	34.0	25.5	35.2
LSP4	33.5	19.3	35.2	34.7	31.5	36.3
Temperature (oC)						
	Surface			Bottom		
	Mean	Min	Max	Mean	Min	Max
LSP1	15.0	4.6	23.0	16.6	7.1	26.3
LSP2	14.3	9.4	19.5	14.1	7.8	19.2
LSP3	14.3	10.0	18.6	14.2	9.9	18.5
LSP4	14.2	10.2	18.6	14.3	9.7	18.5

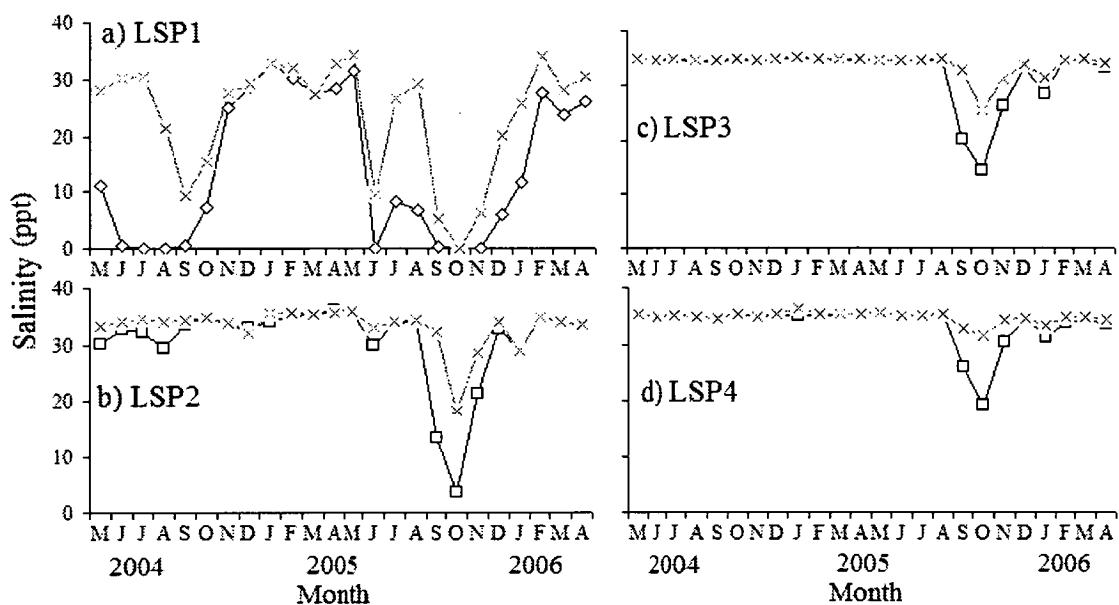


Figure 2.3 Surface (□) and bottom (×) salinities at the four gill net sampling sites (LSP1-LSP4) in the Little Swanport Estuary between May 2004 and April 2006.

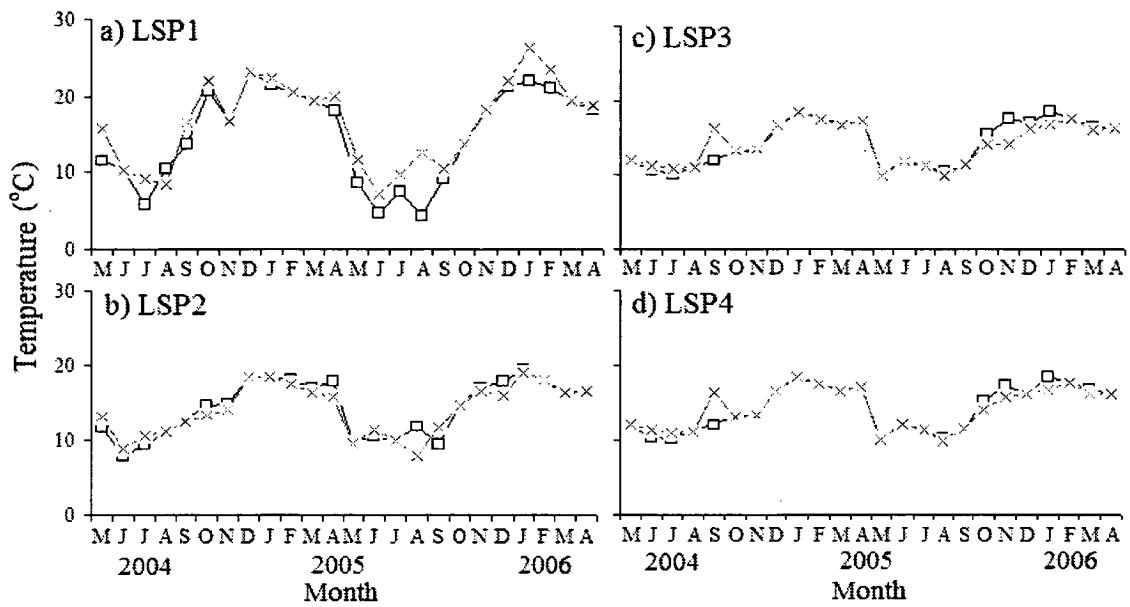


Figure 2.4 Surface (□) and bottom (×) temperatures at the four gill net sampling sites (LSP1-LSP4) in the Little Swanport Estuary between May 2004 and April 2006.

2.3.2.2. Swan River

Although the minimum surface salinity at the four sites lay within the narrow range of 0.0-0.2, the minimum bottom salinity at each site varied by >15, indicating that while freshwater discharge strongly influenced the surface waters throughout the estuary, it only influenced the bottom water strongly in the upper estuary (SR1 & SR2) (Table 2.2).

Surface salinities of less than 2 were recorded in the Swan River during three periods in 2004 and 2005 (Fig. 2.5). The surface waters in the upper estuary were fresh between June and October 2004, but were brackish in the middle and lower estuary regions. In October 2005, water at SR1 became fresh throughout the entire water column (Fig. 2.5). However, in most months, the bottom salinities at SR1 were >5 higher than at the surface. Surface and bottom salinities at SR2 showed a similar seasonal trend to those at SR1, although salinities at SR2 were generally higher. The monthly surface salinities at SR3 & SR4 showed a similar trend, although the mean bottom salinities remained above 20 throughout the study period (Fig. 2.5).

Mean surface and bottom water temperatures gradually increased from SR4 to SR1, ranging from only 14.4 °C to 15.7 °C for surface temperature and from 14.2 °C to 17.1 °C for bottom temperature (Table 2.2). The monthly surface and bottom temperatures at the four sites followed similar trends with minimum values of 7 to 11 °C recorded during winter and maximum values of 20 to 26 °C observed between late-spring and late-summer (Fig. 2.6).

Table 2.2 Mean, minimum and maximum surface and bottom salinities and water temperatures at the four sampling sites in the Swan River (SR1-SR4) between May 2004 and April 2006.

Salinity						
	Surface			Bottom		
	Mean	Min	Max	Mean	Min	Max
SR1	6.1	0.0	20.6	14.9	0.0	26.8
SR2	10.6	0.0	27.3	17.7	0.0	28.9
SR3	13.1	0.2	28.1	23.7	16.3	30.9
SR4	14.1	0.2	27.9	25.6	20.0	31.5

Temperature (oC)						
	Surface			Bottom		
	Mean	Min	Max	Mean	Min	Max
SR1	15.7	7.6	24.8	17.1	10.1	25.8
SR2	15.6	7.9	23.3	16.6	11.0	23.8
SR3	14.7	8.6	21.9	14.6	10.1	20.6
SR4	14.4	8.0	21.8	14.2	9.1	20.3

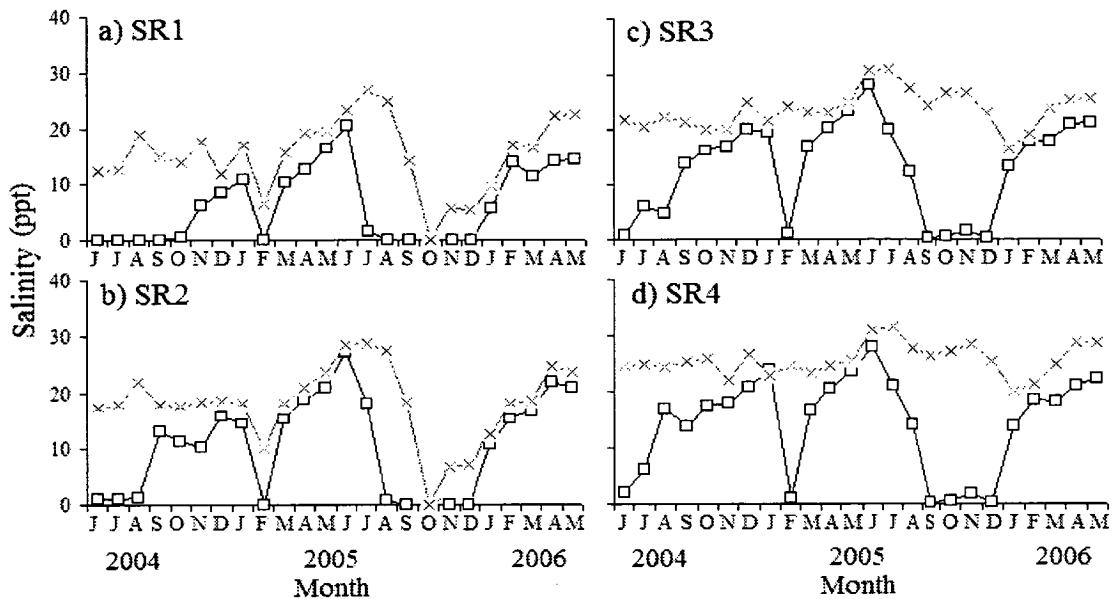


Figure 2.5 Surface (□) and bottom (×) salinity at the four gill net sampling sites (SR1-SR4) in the Swan River between June 2004 and May 2006.

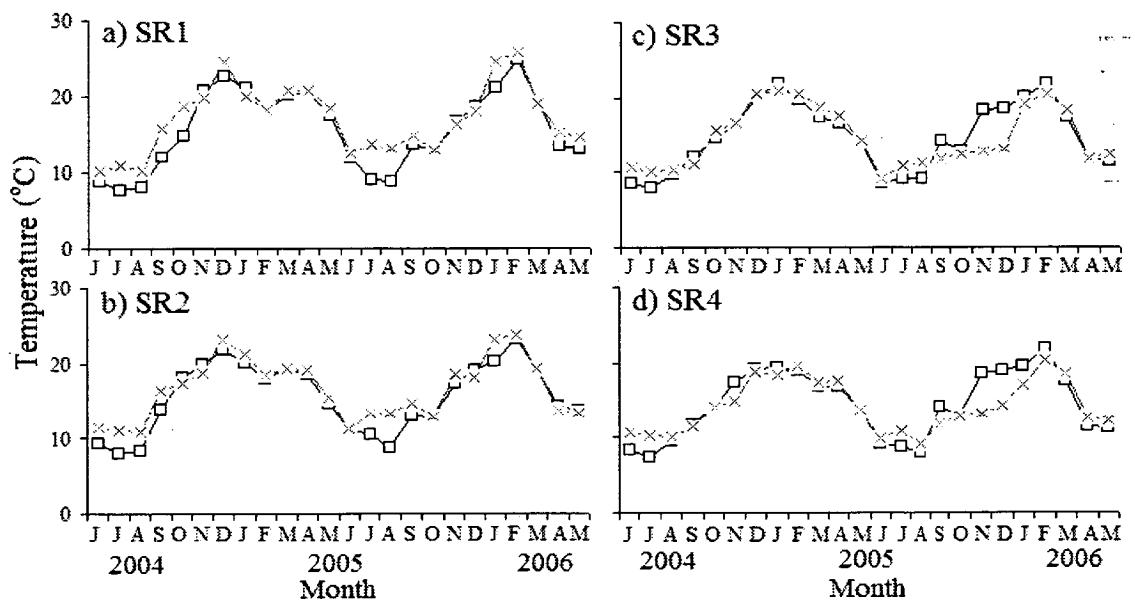


Figure 2.6 Surface (□) and bottom (×) temperatures at the four gill net sampling sites (SR1-SR4) in the Swan River between June 2004 and May 2006.

2.3.3. Seasonal distribution and abundance in the Little Swanport Estuary

2.3.3.1. Sub-adult and adult abundance

Mean monthly abundances at LSP1 and LSP2 showed strong seasonal fluctuations while those at LSP3 and LSP4 showed generally low numbers (Fig. 2.7). Overall black bream were more abundant in the upper estuary (LSP1) and middle estuary (LSP2) than in the lower estuary (LSP3 & LSP4). However, when bottom salinities at LSP1 dropped below approximately 10 (i.e. September and October 2005), no fish were recorded. Abundance at LSP1 showed a clear seasonal pattern with increasing numbers in spring-early summer. At LSP2, relatively large numbers of fish were also caught during the study period. Between January and March 2005, large numbers of fish were caught in this area, whereas only a few fish were recorded at LSP1 during the same period, suggesting that fish may have migrated downstream. Mean monthly abundances at LSP3 and LSP4 were very low throughout the study period, although there was a slight increase in numbers during the summer/autumn of 2004/05 at LSP4 (Fig. 2.7). Two-factor repeated measures ANOVA indicated that there was significant difference in the abundance of black bream among months and sites and also significant interaction between month and site (Table. 2.3). In addition, when bottom salinities at LSP1 dropped below approximately 10 (i.e. September and October 2005), fish became more abundant at LSP2, where relatively higher salinities remained than at LSP1.

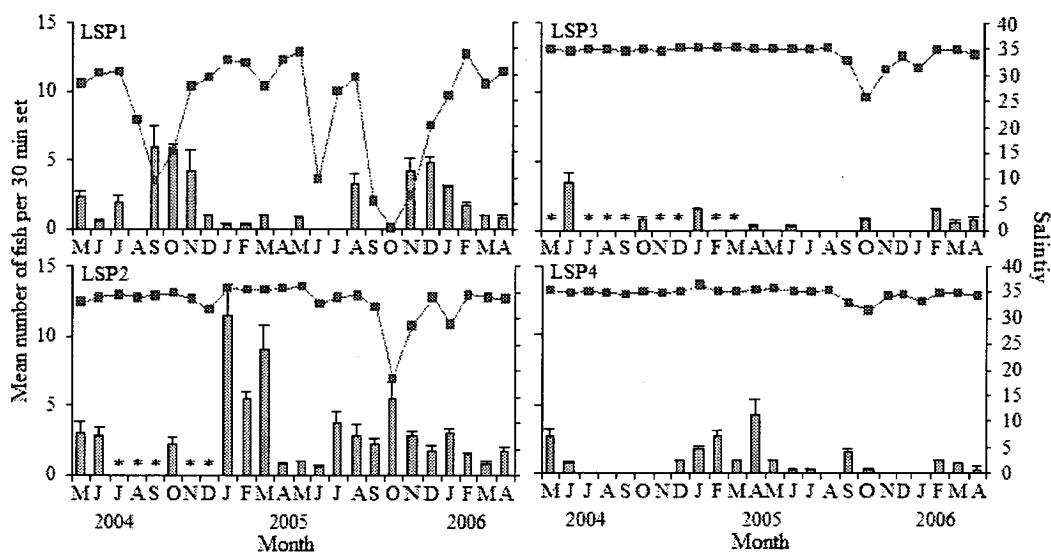


Figure 2.7 Mean number of black bream (+S.E.) caught in composite gill nets at the four sites (LSP1-LSP4) in the Little Swanport Estuary in each month between May 2004 and April 2006. Symbols (*) indicate months in which sampling was not conducted. Bottom salinities (■) at each sampling occasion are also shown.

Table 2.3 Two-factor repeated measures ANOVA comparing the numbers of black bream caught in the Little Swanport Estuary. Data were log(x+1) transformed prior to statistical analysis.

Source	df	F	P
Month (M)	11	5.101	< 0.001
Error	33		
Site (S)	3	125.059	< 0.001
Error	9		
M × S	33	7.933	< 0.001
Error	99		

2.3.3.2. Juvenile abundance

Abundances of juveniles varied greatly among months and sites (Table 2.4). A large number of juveniles were caught from LSP1, but numbers remained relatively low at LSP2, and no juveniles were caught at either of the lower estuary sites LSP3 and LSP4 during the study period. Seasonal abundances at LSP1 showed significant variation while those at LSP2 remained low throughout the sampling period (Fig. 2.8). Abundances at LSP1 increased rapidly in December 2004 and January 2005 then decreased sharply in February 2005 and remained at about this level until April 2005. Abundances remained low from May to July

2005, and no fish were captured between August and November. There was a sharp increase in juvenile abundance in December 2005 with moderate abundances recorded to the end of the study period in April 2006. Peak abundances at LSP1 in the first year of this study occurred in January 2005 and in December 2005 in the second year (Fig. 2.8).

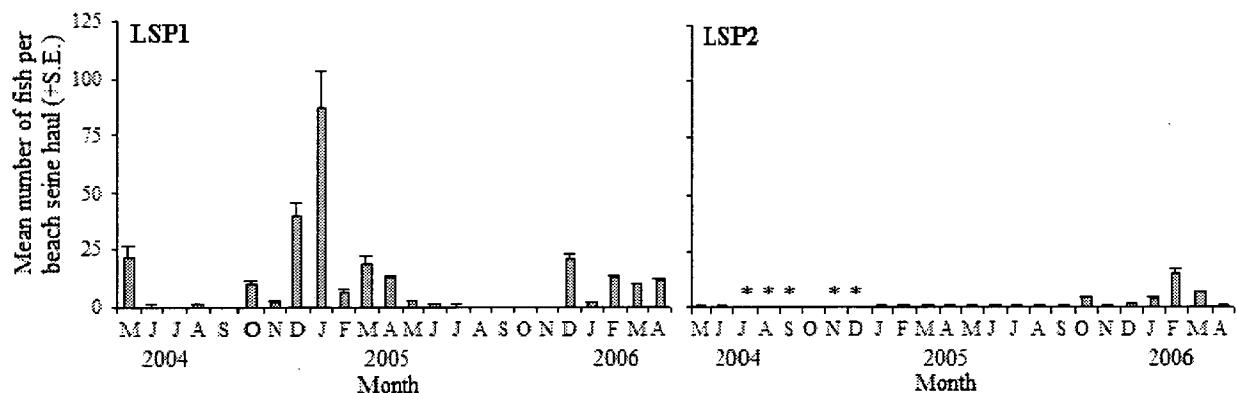


Figure 2.8 Mean monthly number of juveniles (<140 mm fork length) (+S.E.) caught by beach seines at LSP1 and LSP2 between June 2004 and May 2006. No juveniles were caught from LSP3 and LSP4 during the study period. Symbols (*) indicates months in which sampling was not conducted.

Table 2.4 Two-factor repeated measures ANOVA comparing the numbers of juveniles black bream caught in the Little Swanport Estuary. Data were log(x+1) transformed prior to statistical analysis.

Source	df	F	P
Month (M)	11	17.859	< 0.001
Error	33		
Site (S)	3	27.089	0.001
Error	9		
M × S	33	6.020	< 0.001
Error	99		

2.3.4. Seasonal distribution and abundance in the Swan River

There was no clear seasonal pattern in black bream abundance throughout the Swan River estuary and abundance varied significantly with months and sites, but was not significantly different between years (Table. 2.5). Black bream were recorded at SR1 in all months except October 2005, with a mean monthly abundance of 10.5 individuals. Abundances at SR1 decreased dramatically during the months in which low salinities were recorded. Relatively

large numbers of fish were also caught at SR2 in most months, but they were less abundant than at SR1 with a mean monthly abundance of 5.9 individuals. Fish in the middle and lower estuary sites (SR3 & SR4) were much less abundant than the upper estuary sites, with the mean average monthly abundances of 2.5 and 0.8 at SR3 and SR4, respectively (Fig. 2.9).

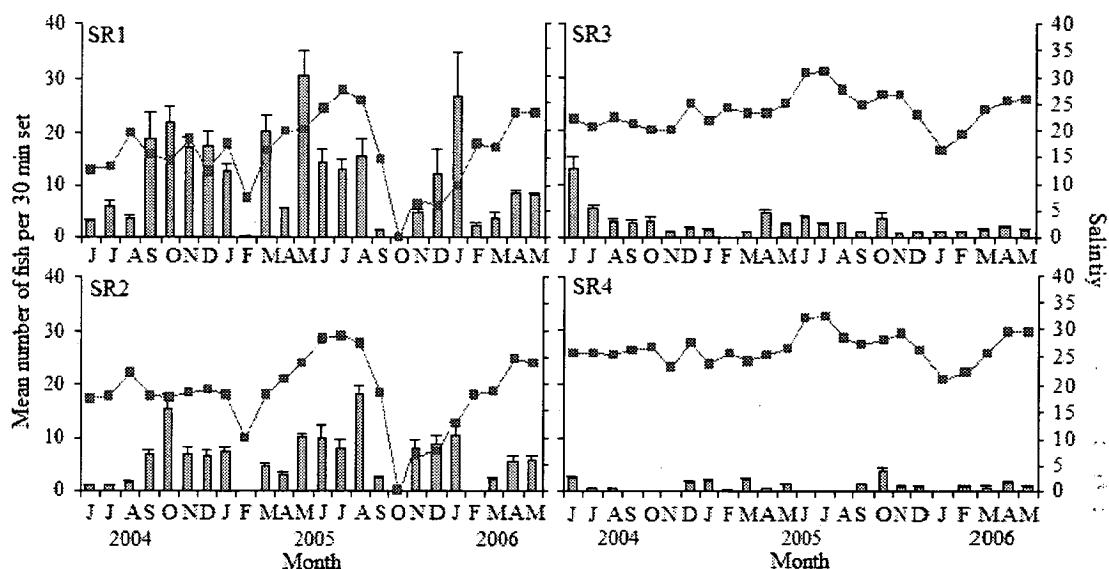


Figure 2.9 Mean number of black bream (+S.E.) caught in composite gill nets at the four sites (SR1-SR4) in the Swan River in each month between June 2004 and May 2006. Bottom salinities (■) at each sampling occasion are also shown.

Table 2.5 Three-factor repeated measures ANOVA comparing the abundance of black bream. Data were log(x+1) transformed prior to statistical analysis.

Source	df	F	P
Year (Y)	1	8.516	0.062
Error	3		
Month (M)	11	8.544	<0.001
Error	33		
Site (S)	3	157.808	<0.001
Error	9		
Y×M	11	8.783	<0.001
Error	33		
Y×S	3	5.832	0.017
Error	9		
M×S	33	5.319	<0.001
Error	99		
Y×M×S	33	12.214	<0.001
Error	99		

2.3.5. Size compositions

2.3.5.1. Little Swanport Estuary

A variety of size classes between 140 and 400 were caught at LSP1 and LSP2 (Fig. 2.10). In contrast, most of fish caught at LSP 3 and LSP4 were larger than 220 mm, although the numbers were low, suggesting that larger fish utilize a wider range of habitats within the estuary. There were clear indications of mature fish aggregated (>220 mm) at LSP1 during the spawning season (spring-summer) (see Chapter 4), although timing of aggregation differed between the two spawning season, caused by different environmental conditions.

2.3.5.2. Swan River

In general, a wide range of size classes were recorded in the upper estuary sites (SR1 & SR2) throughout the years while smaller individuals around 200 mm occupied the middle and lower estuary sites (SR3 & SR4) (Fig. 2.11). Between spring 2004 and autumn 2005 greater numbers of fish <200 mm were caught from SR1 & SR2 although a wide size range of fish was also evident at these sites during most months of the year. There were no clear indications of an increase in the abundance of mature fish during the spawning season.

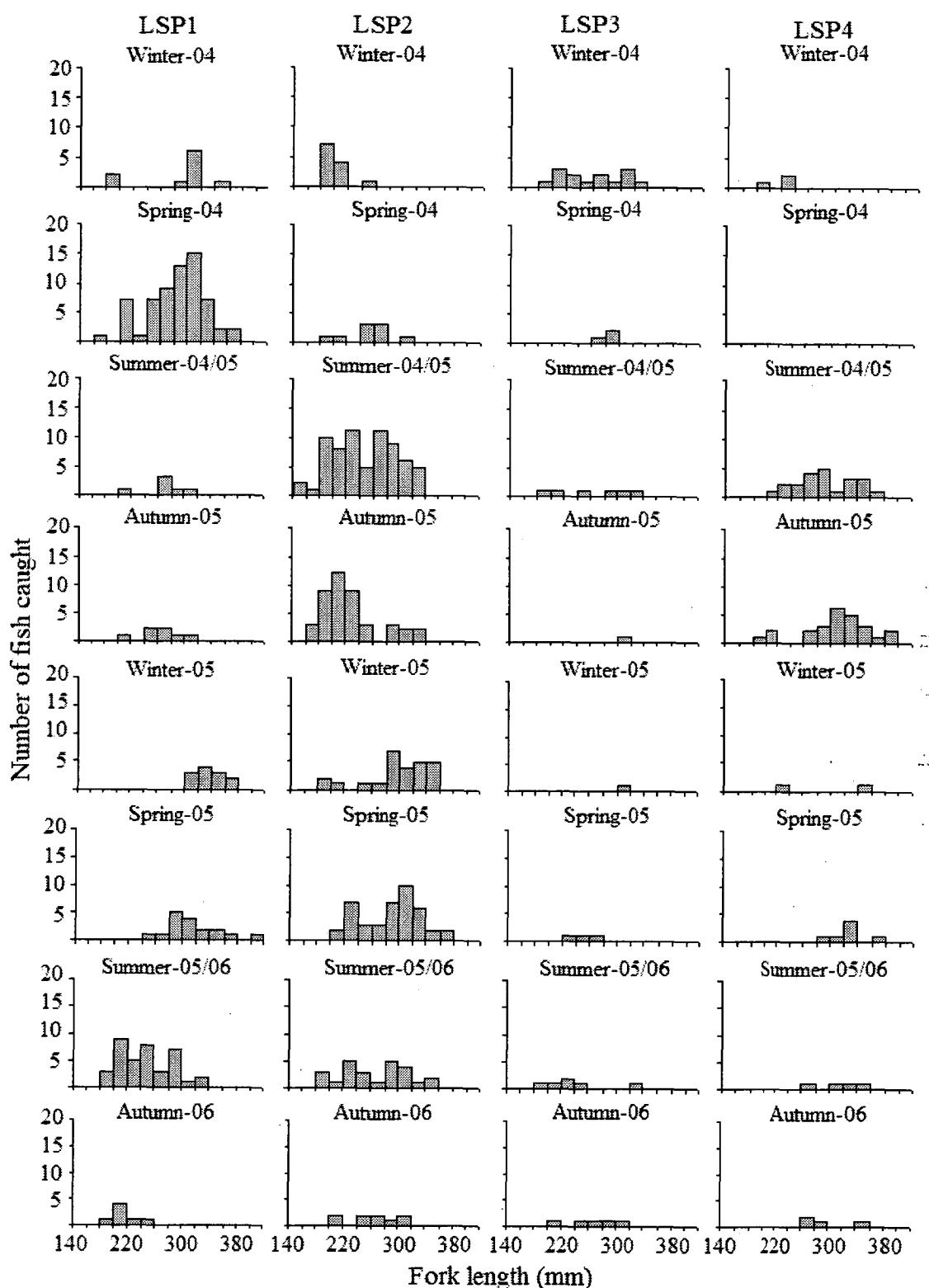


Figure 2.10 Length frequency histogram of black bream caught by gill nets at LSP1, LSP2, LSP3 & LSP4 from May 2004 to April 2006. Winter (June + July + August); Spring (September + October + November); Summer (December + January + February); Autumn (March + April + May).

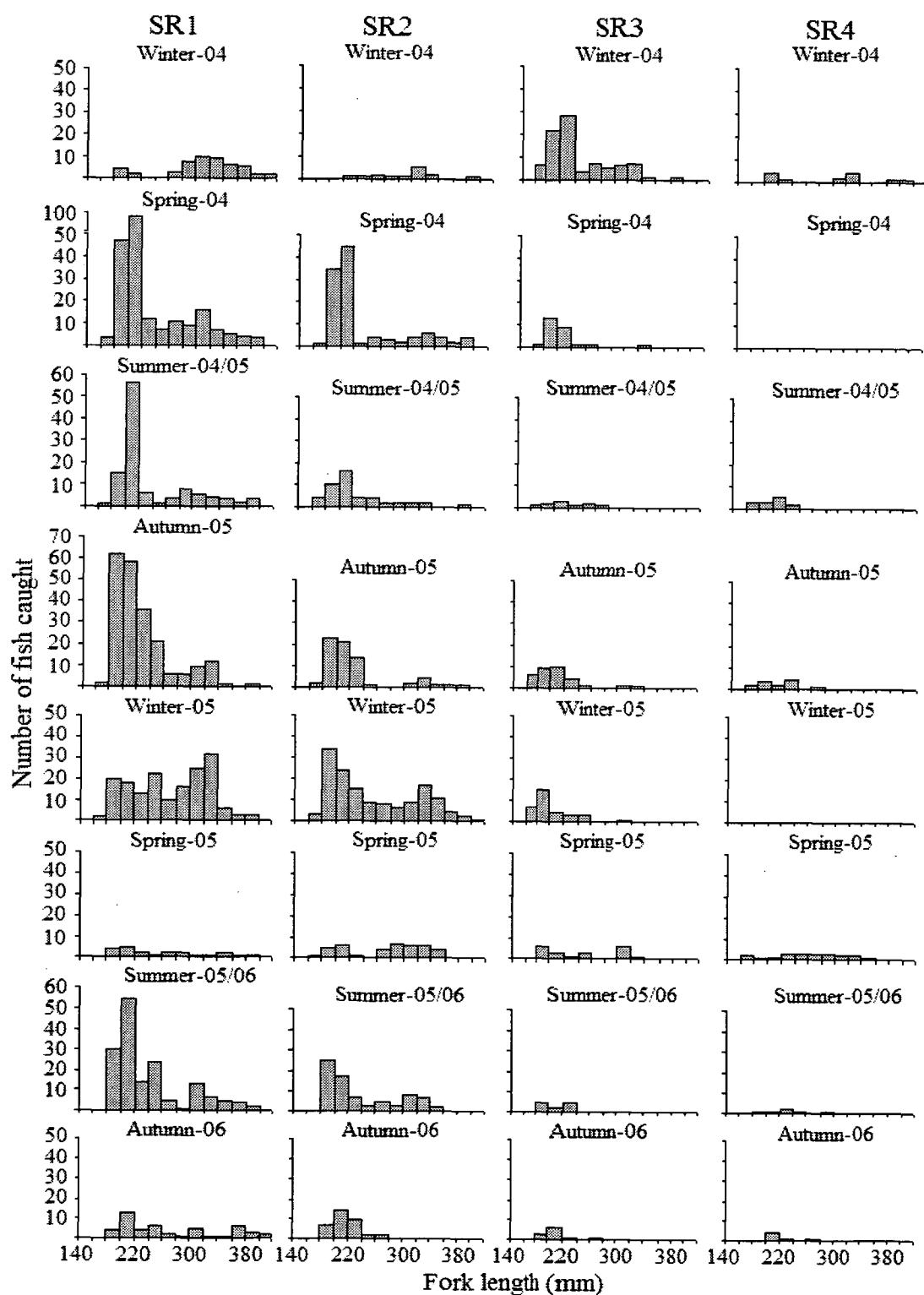


Figure 2.11 Length frequency histogram of black bream caught by gill nets at SR1, SR2, SR3 & SR4 from June 2004 to May 2006. Winter (June + July + August); Spring (September + October + November); Summer (December + January + February); Autumn (March + April + May).

2.3.5.3. Size compositions of juveniles

Beach seine samples from LSP1 between late spring and late summer contained high numbers of new recruits (0^+ age class) ranging from 10 to 60 mm (Fig. 2.12). The number of fish less than 50 mm fork length increased dramatically in January 2005 to 254 individuals. In contrast, relatively small numbers of fish were taken between February and July 2005 and no fish were caught between August and November 2005. A comparatively large number of individuals exceeding 90 mm, possibly representing the 1^+ and/or 2^+ age classes (see Chapter 3 & Chapter 4), were found in December 2005. New recruited fish of less than 40 mm were first caught in November 2004 with marked abundance in January 2005, but very few were recorded in the following spawning season. First evidence of 0^+ during the spawning season of 2005/06 was in January 2006 with only one fish recorded.

Length frequency histograms for juveniles collected from LSP2 did not show clear seasonal trends (Fig. 2.13). No fish <70 mm were recorded while fish larger than 100 mm dominated at that site. All fish caught at LSP2 were assumed to be represented by $>1^+$ age classes (see Chapter 3 & Chapter 4).

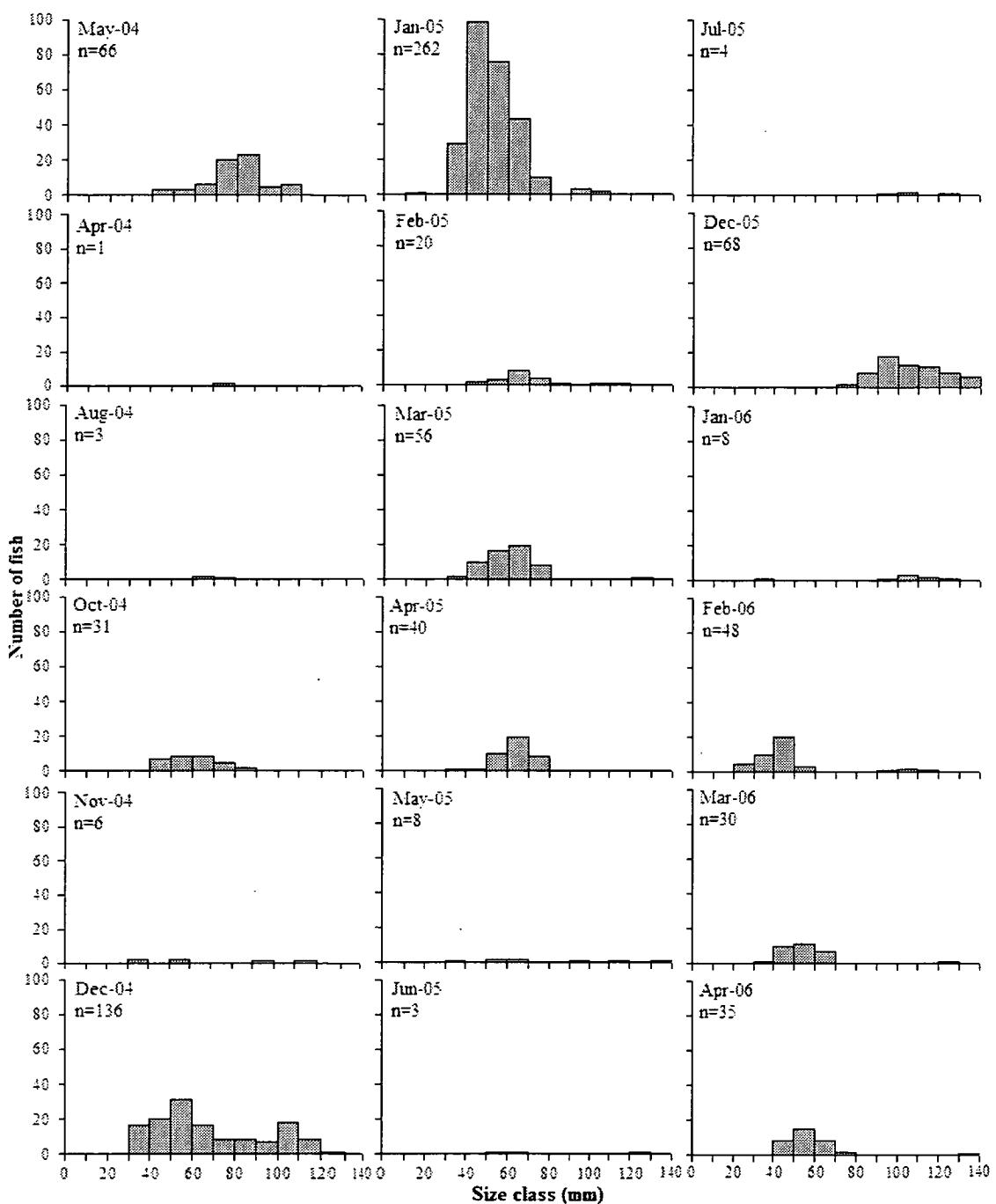


Figure 2.12 Size compositions (fork length) of juveniles caught by beach seines at LSP1 between May 2004 and April 2006. No fish were caught in June, July, September 2004 and between August and November 2005. Number represents sample size.

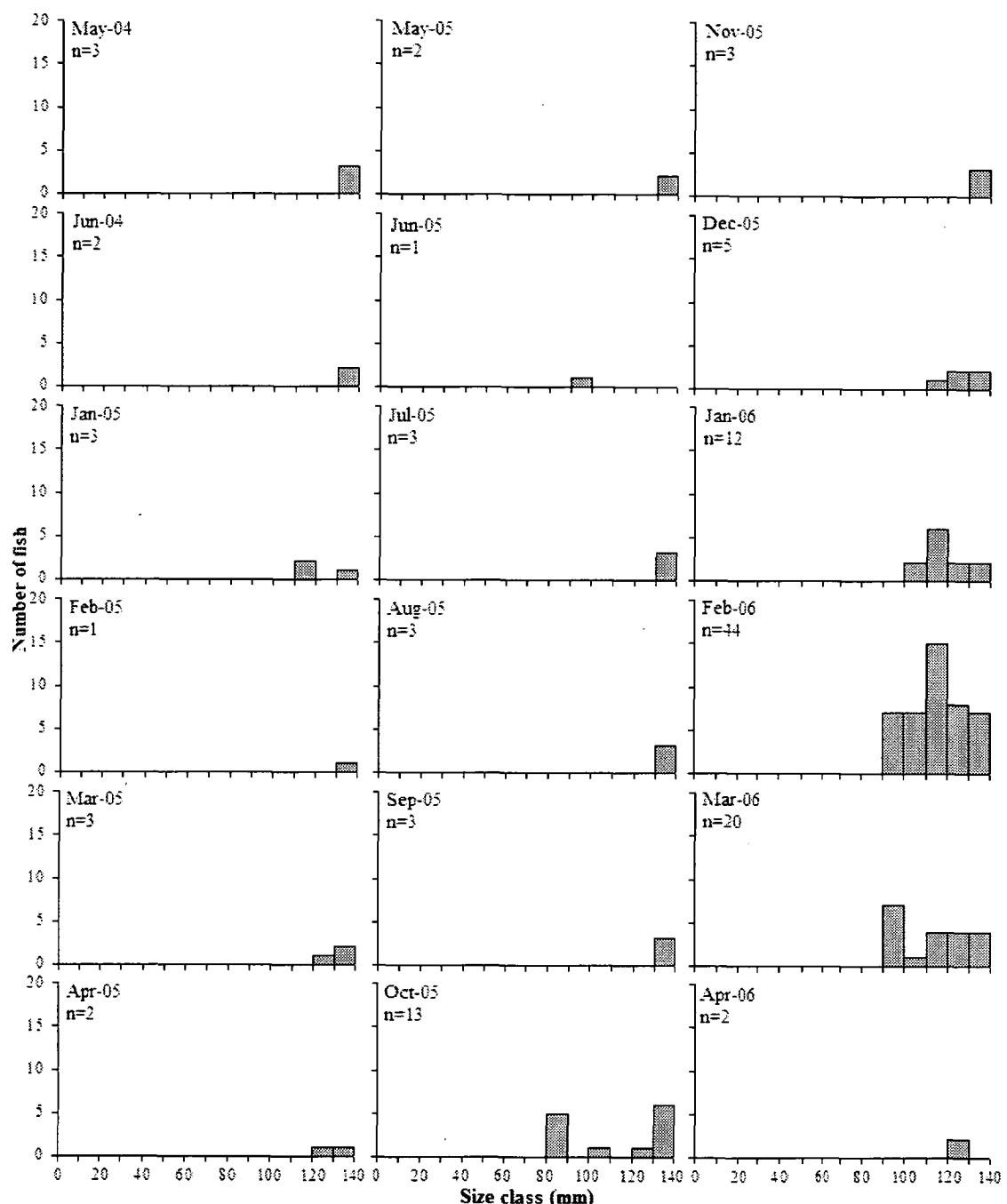


Figure 2.13 Size compositions (fork length) of juvenile caught by beach seines at LSP2 between May 2004 and April 2006. No fish were caught in October 2004 and no sampling was conducted between July and September 2004, and in November and December 2004. Number represents sample size.

2.3.6. Influence of salinity and water temperature

The abundance of black bream collected by gill net samples showed significant correlations with bottom temperature and surface and bottom salinity (Table. 2.6) when data from all sites in both estuaries were amalgamated. The abundance of black bream correlated negatively with the surface and bottom salinity while it correlated positively with the bottom temperature.

Table 2.6 Relationship (Pearson's correlations coefficient, n = 96) between number of black bream caught at each site and each sampling occasion and abiotic environmental factors (** P<0.001 and * P<0.05).

Number of <i>A. butcheri</i>	Temperature		Salinity	
	Surface	Bottom	Surface	Bottom
	0.114	0.256*	-0.292**	-0.338**

2.4. DISCUSSION

2.4.1. Distribution and abundance of sub-adult and adult fish

The distribution of black bream within the estuarine systems was not uniform, with greatest numbers present in the upper and middle regions of the Little Swanport Estuary and the upper region of the Swan River (SR1 & SR2). In contrast, very low abundances were recorded in the lower Little Swanport Estuary (LSP3 & LSP4) and in the middle and lower estuary regions of the Swan River (SR3 & SR4). These observations are consistent with the findings of Loneragan et al. (1989) who established that black bream abundance in the Swan Estuary, Western Australia, increased progressively with increasing distance upstream from the estuary mouth.

Abundances within the upper and middle regions of the Little Swanport Estuary exhibited seasonal variation, with a marked increase in catch rates in the upper estuary during spring in 2004 (September to November). There was a dramatic increase in catch rates in the middle

estuary and minor increases at the lower estuary sites between mid-summer and early-autumn (January and March 2005). These findings imply an upstream migration between late-spring and early-summer followed by downstream movement in late-summer. The increasing abundance in the upper estuary corresponded with the approach and onset of the spawning season (see Chapter 4), with sexually active fish observed to form large aggregations at the upper estuary site. Large numbers of recently settled juveniles were also present in the upper estuary during the same period. The increased abundance in the middle estuary in late-summer implied downstream movement of adults at the end of the spawning season. By contrast no fish were recorded in the upper estuary in September and October 2005, but large numbers of fish were observed in November and December 2005, indicating that increases in abundance occurred later in 2005, probably influenced by the heavy freshwater discharges that occurred in September and October 2005, which suppress spawning behaviour of this species (see Chapter 6). Alternatively, small floods may be beneficial to black bream because an increase in water level could open more areas for spawning.

Such a seasonal pattern in abundance was not evident in the Swan River. Black bream were abundant in the upper estuary (SR1 & SR2) in most months, whereas no significant increase in abundance was observed either in the middle (SR3) or lower estuary (SR4) after the spawning season. Large numbers of black bream aggregated in the upper estuary throughout the year, implying that the majority of the population in the Swan River occupies the upper estuary. Although the factors that contribute to these differences between the estuaries are unclear, habitat structure and prey availability are potential factors. In the Little Swanport Estuary there is a very shallow point approximately 500 m downstream from LSP1 which probably represents a natural physical barrier to fish migrating further upstream. Freshwater discharge

and/or high tides are required to facilitate passage upstream. Anecdotal reports from local residents indicate that large numbers of black bream often aggregate just below the shallow point. In contrast, there is a continuous deep water channel (>2 m) throughout the length of the Swan River. Consequently, there are no physical barriers to access between the upper and middle estuary regions in the Swan River and fish thus can migrate upstream more easily. There are also major habitat differences between the upper regions of each estuary. In the upper Little Swanport Estuary, the habitat consists of rocks with very sparse *Ruppia* seagrass beds while silty habitat with very dense beds of *Ruppia* seagrass and substantial quantities of submerged woody debris are found in the upper Swan River. Denser seagrass beds probably provide more habitats for prey species such as crustaceans as well as an increase in food availability (Stoner, 1980). Submerged structure is very important in providing refugia and stable habitats for fish and invertebrates (Johnson et al., 2003; Scealy et al., 2007), as well as enhancing secondary production of macroinvertebrates (Smock et al., 1989). This observation is supported by the fact that the presence of large woody debris has a positive influence on fish abundance and distribution in black bream (Hindell, 2007) as well as other species (McMahon & Holtby, 1992; Roni & Quinn, 2001).

In the Little Swanport Estuary, the slightly higher abundance at LSP4 compared with the LSP3 may be explained by habitat differences. There is a large area of oyster leases around the lower site (LSP4) which presumably provide an extra food source and structurally complex habitat to which black bream are attracted (Hindell, 2007).

Salinity seems to a key factor influencing the distribution of this species, although factors such as temperature, dissolved oxygen, food availability and habitat type may also be involved. This study demonstrated a strong negative correlation between salinity and abundance. There

was a positive correlation between bottom temperature and abundance, but this may reflect greater susceptibility to capture during warmer months, especially during the spawning season. The negative correlation with salinity broke down at salinities of <10 due largely to the influence of freshwater flows in the estuary; it is well-known that the species can tolerate a wide range of salinity (Hoeksema et al., 2006). For example, when atypically heavy freshwater discharge and, thus reduced salinities occurred in September and October 2005, few or no fish were recorded in the upper regions of the estuary and there was clear evidence of movement further downstream to areas of higher salinities. In fact, at times when the entire water column was fresh (e.g. October 2005), no fish were caught in the upper regions of both estuaries, whereas numbers of fish caught in the middle estuary regions had increased slightly. However, in situations where salinity stratification was evident, with fresh surface waters and the bottom water above salinities of around 10 (e.g. November 2005), substantial number of fish remained within the upper estuary. This observation suggests that black bream will remain in areas of increased freshwater discharge as long as they are able to access subsurface waters of at least 10. Thus black bream will presumably seek refuge in the deep holes where higher salinities are maintained, and remain there until the salinity regime returns to favourable (see Chapter 6). Although Cossack & Roennfeldt (1987) concluded that some black bream are able to withstand the effects of heavy freshwater discharge and remain in the upper estuary, this study suggests that their distribution is more likely to depend on salinity levels within the water column.

2.4.2. Distribution and abundance of juveniles

The abundance of juveniles decreased significantly from late-autumn to late-winter as temperatures fell to their lowest levels. During the cold months, juveniles possibly seek out

and remain in the deeper waters (>3 m) where temperatures were slightly warmer than in the shallow waters. If this is the case, the capture of juveniles using beach seines would be virtually impossible, resulting in the apparent changes in seasonal abundance observed during this study, although abundance of juveniles in the upper estuary may be consistent throughout year. This suggestion may also explain the very low numbers of juveniles captured from the middle and lower estuary sites. For instance, habitat availability was limited in the upper estuary with its large areas of shallow waters. In contrast, there were more complex habitats with deeper waters in the middle and lower estuary regions, making it more difficult to sample juveniles.

Assuming that sampling error mentioned above is not the case, in the Little Swanport Estuary the distribution of juveniles was restricted to the upper and middle regions of the estuary, implying that as fish grow, they utilize a wider range of habitats and move into deeper water, which is common feature for fish species (Hyndes et al., 1996; Potter & Hyndes, 1999). The distribution of post-settlement fish (<40 mm) only in the upper estuary is consistent with spawning in the upper estuary rather than throughout the estuary. A number of other studies have established that spawning occurs in the upper estuary near the interface with freshwater (Neira & Potter, 1992; 1994; Newton, 1996; Walker & Neira, 2001). Beach seine catches of black bream in the Little Swanport Estuary suggest that dispersal of juveniles is quite limited with 0^+ and 1^+ fish largely restricted to the upper estuary. This observation is consistent with the results of tagging studies of black bream in the Swan River, Western Australia which showed restricted movement patterns of juvenile black bream (Dibden et al., 2000). Furthermore, Neira & Potter (1994) found that larvae tended to be concentrated in the upper region of the Nornalup-Walpole Estuary, WA. Since more interspecific competition can be

expected to be higher in the middle and/or lower estuary regions because of increased species diversity (Marais, 1981; Loneragan et al., 1989; Potter et al., 1993), this strategy may act to reduce such competition. In contrast, another sparid species, *Rhabdosargus holubi*, in the East Kleinemonde estuary South Africa spawns in nearshore waters, and the larvae, ranging from 9 to 12 mm, occur extensively within the surf zone adjacent to the estuary mouth. Juveniles of this size are swept into the estuary on flood tides, while larger individuals (15-150 mm) remain in the lower estuary (Cowley et al., 2001). The pikey bream, *Acanthopagrus berda*, in the Kosi Estuary, South Africa also moves to the lower estuary to spawn (Garratt, 1993).

The abundance of juveniles in shallow waters of the upper region of the Little Swanport Estuary underwent seasonal changes. Peak abundances occurred between summer and early autumn, furthermore the dramatic increase of juvenile abundance in December 2004 reflecting the recruitment of the 0⁺ age class (<40 mm). By contrast, the significant increase in juvenile abundance in December 2005 was due to the aggregations of 1⁺ fish (>90 mm). The timing of the appearance of newly recruited fish in February 2006 was two months later than in the previous year, suggesting a delay in spawning or a high mortality of eggs and larvae, possibly linked to high freshwater inflows, during the early part of the spawning season (September–December) (see Chapter 4).

2.5. CONCLUSION

Black bream can be found widely throughout an estuary, since they are able to tolerate a wide range of salinities. However, salinities lower than about 10 strongly influence its distribution patterns. This species clearly prefers certain parts of an estuary with life history stage and seasonal abundance are influenced by environmental factors such as freshwater inflows. Black bream generally utilize the middle estuary from late summer to winter, and spend more time in

the upper estuary during spring-early summer for spawning. But the differences observed here between the two studied estuaries suggest these patterns may vary from estuary to estuary. The upper estuary is probably the most important region both for spawning adults and juvenile nursery areas. The middle estuary also plays an important role for adults in providing general habitats, feeding habitats and refugia during heavy freshwater discharges (see Chapter 6). This study indicated that juveniles were restricted to the upper estuary, where there were more variable environmental conditions and presumably less food availability, but reduced competitions compared with the middle and lower estuary regions. Future studies on the distribution of black bream, especially juveniles, in relation to physical environmental conditions should be done to gain a more comprehensive understanding of the factors affecting the use of habitat by this species.

CHAPTER 3

Comparison of Age and Growth of Black Bream between Two Adjacent Populations

3.1. INTRODUCTION

Rate of growth is a key life history characteristic underpinning stock resilience and hence the management of fish stocks (Suryanarayana et al., 2008). Assessing age is critical to estimate growth rate, and analysis of otoliths is well known to provide reliable estimates of age for many species of teleosts (Campana & Thorrold, 2001). Although there are no published accounts of ageing black bream in Tasmania, otoliths have been used to age the species in several studies conducted on mainland Australia (Harbison, 1973; Morison et al., 1998; Sarre & Potter, 2000). These studies have indicated that black bream show considerable variability in growth amongst different locations. Such differences may relate to biological and/or ecological characteristics of the estuaries, such as prey availability, salinity and temperature (Stewart & Grieve, 1993; Sarre & Potter, 2000). Variability in growth rates may also reflect differences in the genetic composition of the various populations.

Unlike mainland Australia, commercial fishing for black bream is prohibited in Tasmania, and the recreational-only status of the species avoids much of the problem of overfishing experienced elsewhere. Over the past decade the sporting qualities of black bream have been increasingly recognized amongst recreational anglers. With an increasing number of articles about this species in recreational fishing magazines and newsletters and a number of recreational fishing competitions occurring in Tasmania, recreational fishing pressure on this species is undoubtedly increasing. There is a need, therefore, to understand the species' life history and population dynamics, including age and growth, in particular to inform the appropriateness of current management arrangements which are based on legal minimum length and possession limits.

The present study was undertaken to determine the growth of black bream in two east coast Tasmanian estuaries, where this species is abundant and contributes to the recreational estuarine fishery, and aimed to examine whether the growth rates differ between the adjacent populations and to compare growth rates between Tasmanian and Australian mainland populations. The temporal pattern of the marginal increments on sagittal otoliths was used to validate the periodicity of increment formation and the position of the first annual increment was determined by analysing transverse radii of whole sagittae from fish aged 0⁺ and 1⁺.

3.2. MATERIAL & METHODS

3.2.1. Sampling

A total of 1342 black bream were collected between May 2004 and April 2006 from the Little Swanport Estuary and Swan River on the east coast of Tasmania (see Fig. 2.1). Sampling was conducted on a monthly basis. Larger fish (>150 mm fork length (FL)) were captured using gillnets, or rod and line-fishing in waters up to 10 m depth. Smaller fish (<150 mm FL) were caught by beach seine and rod and line-fishing in shallow waters (<2 m) (see Chapter 2).

3.2.2. Age determination

Fork length (FL) and total wet weight were recorded to the nearest 1 mm and 0.1 g, respectively. Fish were sexed if the gonad could be differentiated macroscopically as either ovary or testis, which was usually possible in fish >120 mm. Both sagittal otoliths were removed, cleaned, dried, and stored in plastic vials. An otolith from each fish was mounted in polyester casting resin and cut to a thickness of 250-300 µm in a transverse section, using a lapidary diamond saw. Transverse sections were taken through the primordial region and mounted on a glass slide with polyester resin. Each section was then examined with a stereomicroscope at ×5 magnification to count opaque zones for aging. Age was determined

without reference to fish length, weight and sampling date. If the increment structure was optically unclear or if the primordium could not be identified, otoliths were rejected. The marginal increment, i.e. the distance from the outer edge of the outermost opaque zone to the otolith growing edge, was measured using image analysis software to determine the periodicity of opaque zone formation. Indices of completion (C) were calculated using the formula:

$$C = W_n / W_{n-1}$$

where W_n is the width of the marginal increment (distance from the growing edge to the centre of the outermost complete opaque zone) and W_{n-1} is the width of the previous complete increment (distance from the centre of the outermost complete opaque zone to the centre of the second from outermost opaque zone) (Tanaka et al., 1981). An opaque zone was considered complete if translucent material was detectable between it and the otolith edge. Indices of completion by month were compared using analysis of variance following $\log_{10}(C+1)$ transformations, which were applied to produce acceptable homogeneity of variances and distribution of residuals.

The timing of the first annual increment was determined by examining otoliths from fish aged as 0^+ and 1^+ . To confirm whether fish were 0^+ and 1^+ , analysis of daily rings was conducted for juveniles caught from the spawning ground of the Little Swanport Estuary. Both sagittae were extracted, rinsed in water, cleaned and dried. Each sagitta was embedded in thermoplastic resin on a microscope slide, and ground from anterior end towards the primordium using 1200 grade wet and dry sandpaper and then polished with 2000 grade wet and dry sandpaper using wetted alumina powder. The polished facet was then mounted to the center of a microscope slide and the otolith ground from posterior end towards the centre of sagitta. The sagitta was

polished until increments were clearly visible. Finally either side of the polished facet was covered with a thin layer of thermoplastic resin. Distinguishing daily rings became very difficult in fish with about 150 rings, and in such instances otoliths were sectioned using the same procedure as described above. If an opaque zone was not present on the sectioned otolith and/or daily rings were readable, the fish was confirmed as 0^+ . The maximum transverse radii of whole otoliths judged to be 0^+ and 1^+ were measured to the nearest micron using image analysis software, and mean sagittal radius was plotted by sample month. These radii were then compared with the radii of the first two opaque growth zones of 100 sectioned otoliths from individuals judged to be older than 2 years.

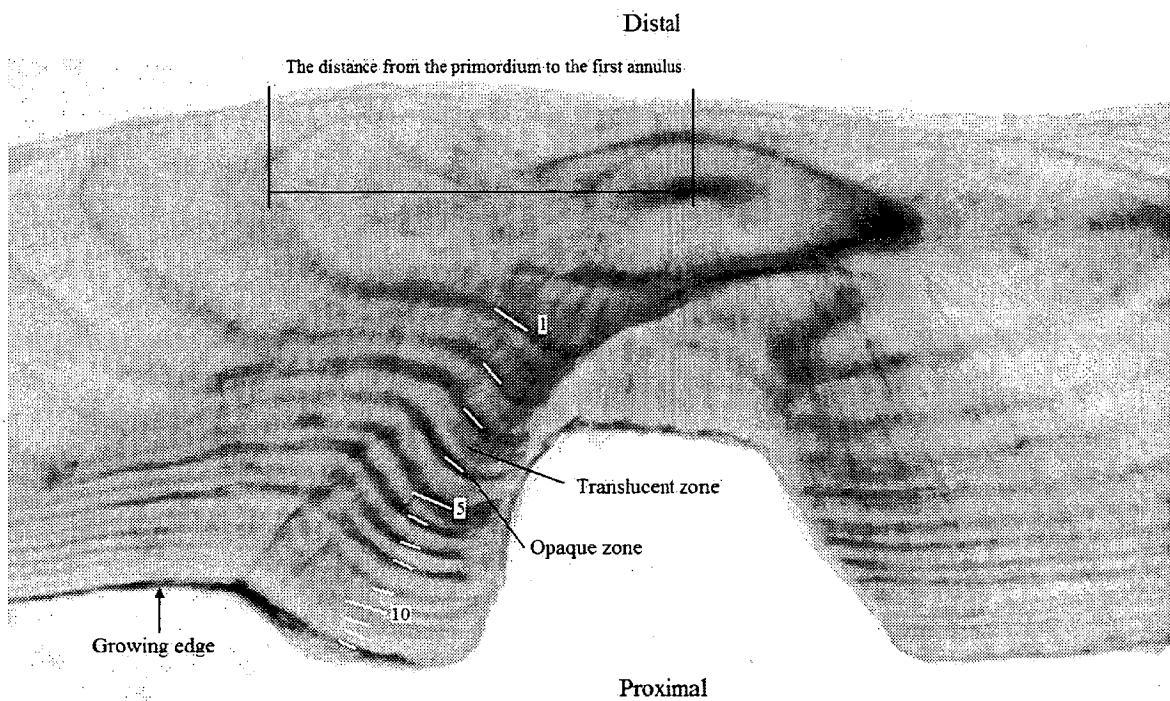


Figure 3.1 Photomicrograph of a transverse otolith section from black bream. Translucent zone refers to a zone that appears brighter and opaque zone that appears darker under transmitted light. The first annulus was determined from examination of the otoliths of 0^+ and 1^+ fish. Age was estimated at 13 years.

To validate the precision of age estimates, the primary reader (Reader A) aged all otoliths and then re-read a random subsample of 200 otoliths. A second experienced reader (Reader B) read a subsample of 115 otolith sections. The variation between and within readers was examined using the index of average percent error (APE) as a measure of precision (Beamish & Fournier, 1981). The APE is calculated by the following formula:

$$APE_j = 100 \times \frac{1}{R} \sum_{i=1}^R \frac{|x_{ij} - \bar{x}_j|}{\bar{x}_j}$$

where R is the number of times fish are aged, x_{ij} is the i th age determination for the j th fish, \bar{x}_j is the mean estimated age of the j th fish. The precision of age estimates between and within readers was also examined visually using age-bias plots (Campana, 2001).

The age assigned was a function of the number of opaque zones counted including the first annual zone, the edge interpretation criterion (narrow, medium or wide) and the time of sampling with respect to the arbitrary birth date of 1st November (Refer to Chapter 4). The von Bertalanffy growth curve was fitted to individual lengths of males and females at the estimated age at capture using least-squares estimation procedures. The von Bertalanffy equation is

$$L_t = L_\infty [1 - e^{-K(t-t_0)}]$$

where L_t is the mean length at age t (years) and L_∞ is the mean asymptotic length, K is the growth coefficient, and t_0 is the hypothetical age at which fish would have zero length if growth followed that predicted by the equation (Francis, 1995). Growth parameter estimates by sex and estuary were compared using likelihood ratio tests (Kimura, 1980).

3.3. RESULTS

3.3.1. Precision of age estimate

An age bias plot between readings showed no evidence of bias relative to a 1:1 correspondence line (Fig. 3.2a). The APE between first and second readings for the primary reader was 0.2%, with 96% of readings in agreement and the largest difference between age determinations being one year. These results indicate that otolith increment counts by the primary reader were repeatable with little variation in the reading process. The APE between readers was 1.27% with 79% agreement. A plot comparing count estimates of increments between readers also showed a high level of agreement between readers and a maximum difference of two zones (Fig. 3.2b).

3.3.2. Validation of first annual increment

In December, otoliths of newly hatched fish (mean FL = 33 mm ± 3.6) had a mean transverse radius of 513 µm (S.E. = 26.67 µm, n = 10), and by May (mean FL = 65.9 mm ± 2.1) a mean of 895.7 µm (S.E. = 28 µm, n = 12) (Fig. 3.3). In the following October, fish aged 0⁺ (mean FL = 70 mm ± 2.6) had a mean transverse sagittal radius of 936.5 µm (S.E. = 29.95 µm, n = 6) and by December when aged 1⁺ (mean FL = 93 mm ± 1.8) they had a mean sagittal radius of 1020 µm (S.E. = 18.25 µm, n = 39). By the following October the mean otolith radius had increased to 1319 µm (Fig. 3.3). The first two opaque zones of 100 older black bream had mean radii of 967 µm (S.E. = 10.3 µm) and 1447 µm (S.E. = 8.9 µm), respectively. The mean distance between the primordium and the first annulus was not significantly different to the mean transverse otolith radius at the end of first year of growth (T-test: P = 0.28). The mean radius of the second opaque zones of older fish did not differ significantly from the mean otolith radius of fish aged 1⁺ caught in October (T-test: P = 0.14). Since no growth zone was

present in the otoliths of the 0^+ age class, and the mean transverse radius of sagittal otoliths at birth date of 1^+ year old fish ($973 \mu\text{m}$) corresponded to the radius of the first opaque zone in transverse otolith sections from older fish ($967 \mu\text{m}$), it is likely the first opaque zone became delineated when the species was one year old.

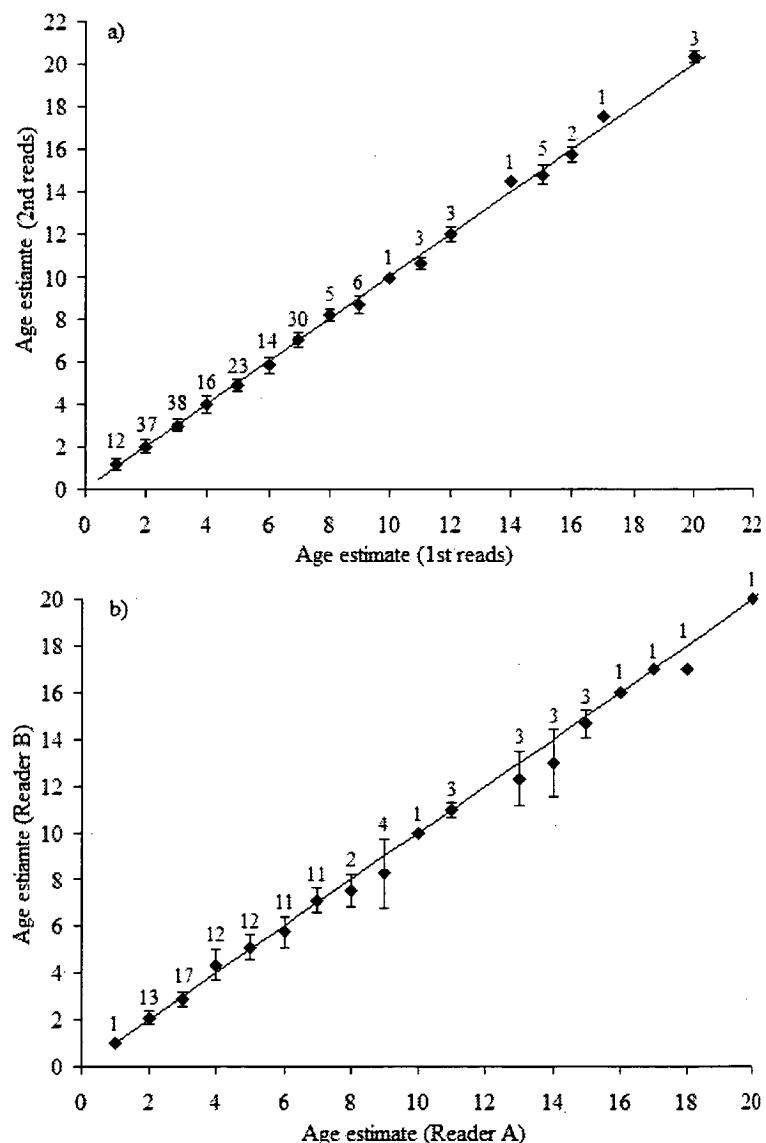


Figure 3.2 Precision of increment counts of black bream. a) Repeat counts by the primary reader (Reader A) ($n=200$) and b) Comparison of age estimates for primary (Reader A) and secondary (Reader B) readers ($n=100$). Line and error bars are 1:1 line and standard deviation, respectively. Value labels are sample size.

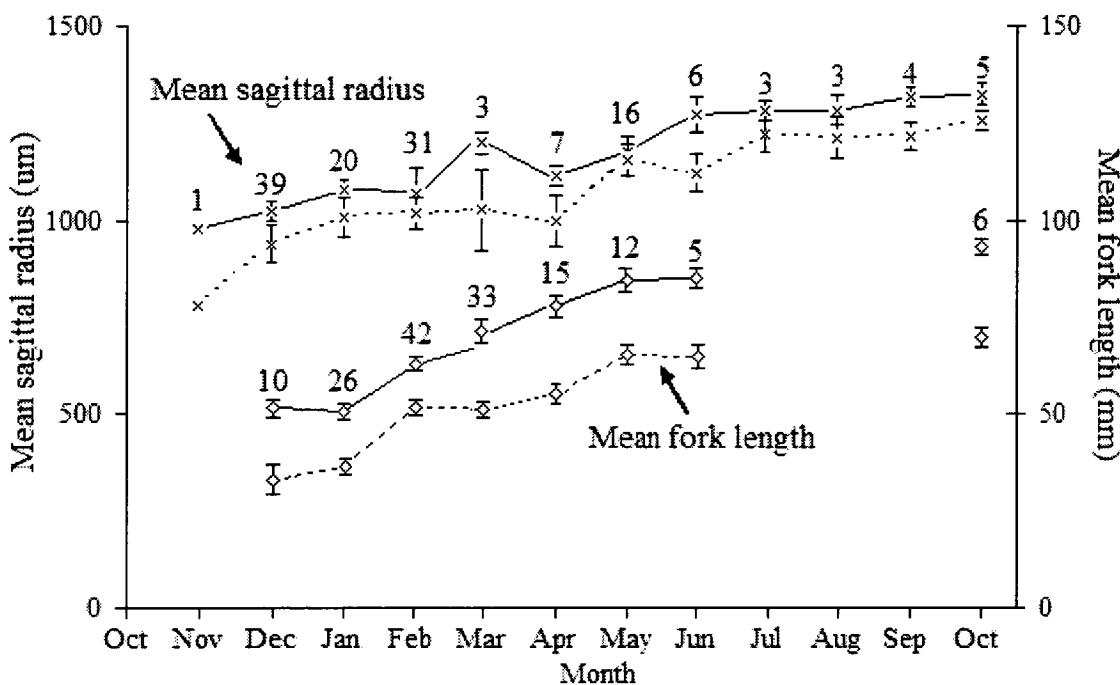


Figure 3.3 Monthly progression of mean sagittal radius and mean fork length (\pm S.E.) of 0^+ and 1^+ fish. Error bars indicate standard error and values indicate sample size.

3.3.3. Marginal increments

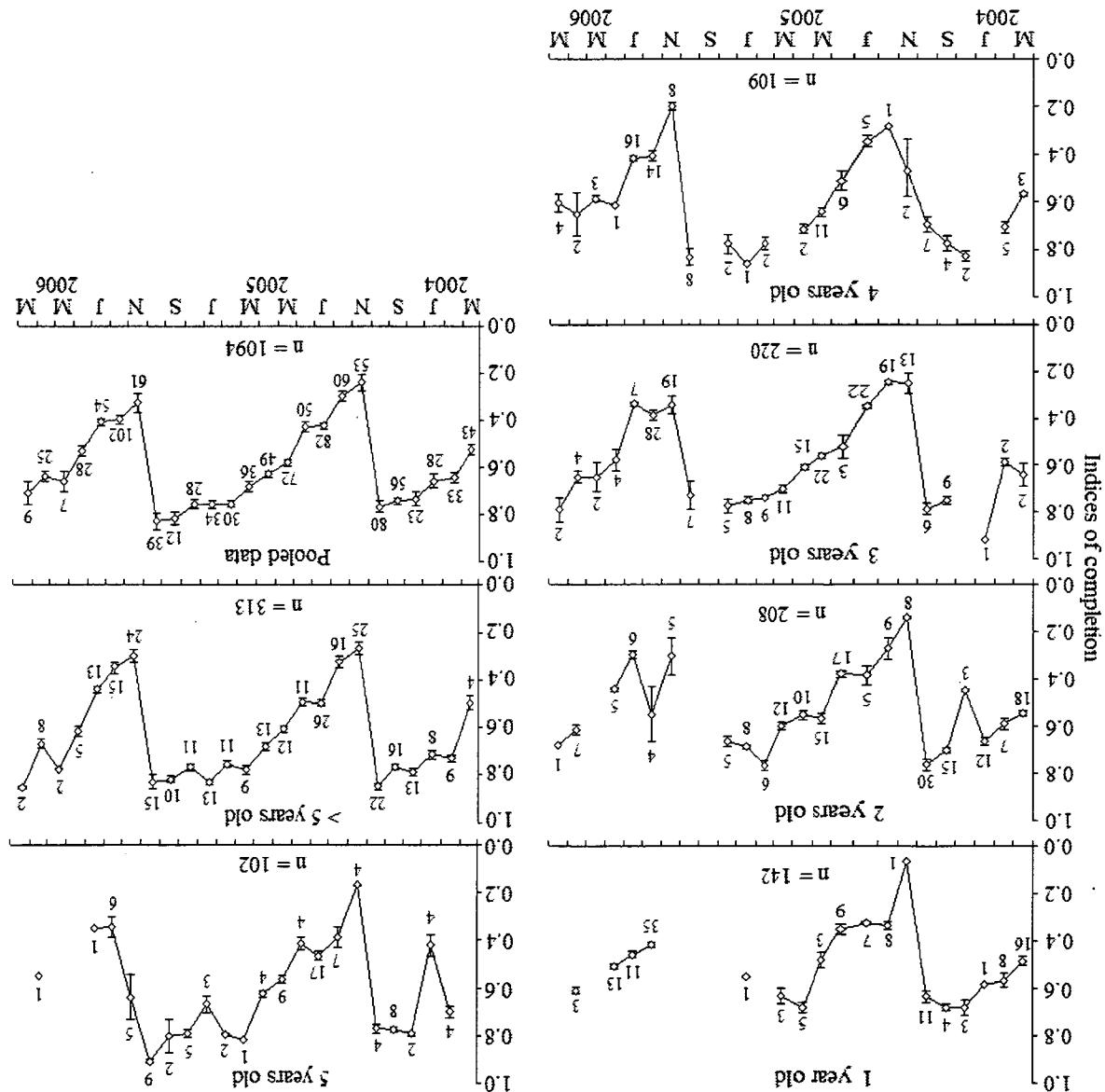
A two-factor ANOVA of $\log_{10}(X+1)$ transformed C values by month showed significant differences ($F_{11, 1082} = 107.233, P < 0.001$) in all age classes. Post hoc tests (Scheffe's test) indicated that C values recorded in November and December were significantly lower than those recorded in other months ($P < 0.05$). Annual trends in the mean indices of completion (C) for sectioned otoliths with one opaque zone decreased markedly from 0.63 in October 2004 to 0.07 in November 2004 and increased gradually from 0.34 in December 2004 to 0.63 by March 2005 (Fig. 3.4). The trends exhibited by the mean monthly marginal increments on otoliths with two, three, four and five opaque zones were similar to those for otoliths with one opaque zone, with a marked decrease in C values in November 2004. A similar marked decrease was also evident in 2005 with lowest C values during November. Marginal increments subsequently increased consistently across each of the age classes and years

through the summer months, before levelling off in late autumn and winter (Fig. 3.4). Since the number of otoliths with six or more opaque zones was small, the mean indices of completion on all such otoliths were pooled. The monthly trend shown by C values for this group was similar to that for otoliths with 1-5 opaque zones. Based on this analysis of marginal increments it has been possible to validate the assumption that opaque zones are formed annually across all age groups, with the opaque zones being completed in October or November (Fig. 3.4).

male examined were 403 mm (21 years old) and 374 mm (18 years old), respectively, both be sexed were included in both male and female growth functions. The largest female and in the Little Swanport Estuary (Fig. 3.5a) and Swan River (Fig. 3.5b). Fish that were unable to The von Bertalanffy growth function was fitted separately to male and female length/age data

3.3.4. Estimated ages and growth curves

Figure 3.4 Mean monthly marginal increments \pm S.E. for sectioned sagittal otoliths of black bream caught from the Little Swanport Estuary and Swan River. Value labels are sample size for each month.



caught in the Swan River. The maximum ages were 23 for females and 18 years for males, both caught in the Swan River (Table 3.1).

Kimura's likelihood ratio test showed a significant difference between the male and female growth functions in the Little Swanport Estuary ($\chi^2 = 12.26, P = 0.007$) and Swan River ($\chi^2 = 7.69, P < 0.001$). L_∞ differed significantly between females and males in the Little Swanport Estuary ($\chi^2 = 4.006, P = 0.045$) and Swan River ($\chi^2 = 11.411, P = 0.001$), while the estimates of k and t_0 were not significantly different between sexes in both estuaries ($P > 0.05$). The von Bertalanffy growth equation indicated that females grow towards larger asymptotic sizes (L_∞) than males (Table 3.1). Individual lengths at the end of their second year of life in the Little Swanport Estuary and Swan River were 141-193 mm and 142-189 mm, respectively for males, and 159-183 mm and 133-198 mm, respectively, for females. At the end of their third year of life, individual lengths in the Little Swanport Estuary and Swan River were 189-227 mm and 170-227 mm, respectively for males, and 193-237 mm and 165-237 mm, respectively for females.

Growth functions for the Little Swanport Estuary and Swan River were compared by sex and were found not to be different (females: $\chi^2 = 4.043, P > 0.05$; males: $\chi^2 = 0.611, P > 0.05$), with no significant difference in each of the three von Bertalanffy growth parameters (Fig. 3.6).

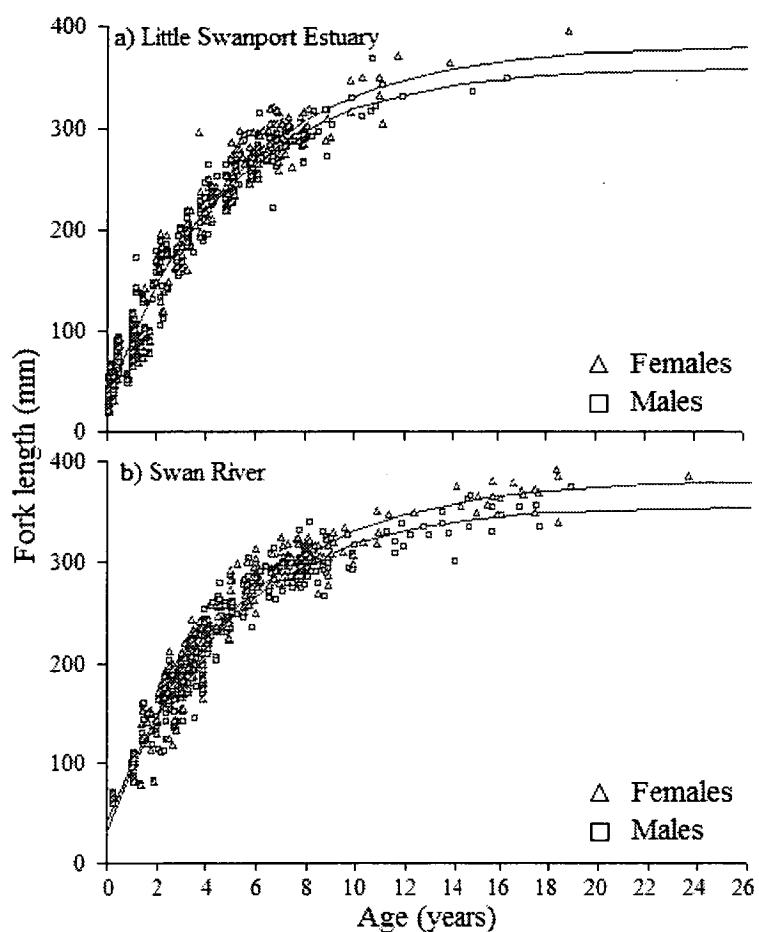


Figure 3.5 von Bertalanffy growth functions (lines) fitted to length at age data (symbols) for male and female caught in a) the Little Swanport Estuary and b) Swan River.

Table 3.1 von Bertalanffy growth parameters derived from length at age data for black bream collected in the Little Swanport Estuary and Swan River. L_{∞} is the asymptotic length; k is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length. N is sample size, L_{\max} is the maximum observed length (mm) and A_{\max} is the maximum observed age.

	N	L_{\max}	A_{\max}	von Bertalanffy parameters		
				L_{∞}	k	t_0
Little Swanport Estuary						
Females	386	397	18	380.3	0.194	-0.467
Males	353	368	16	358.9	0.208	-0.482
Sexes combined	739	397	18	364.6	0.208	-0.467
Swan River						
Females	352	403	23	381.8	0.191	-0.582
Males	301	374	18	355.2	0.216	-0.427
Sexes combined	653	403	23	369.8	0.201	-0.540

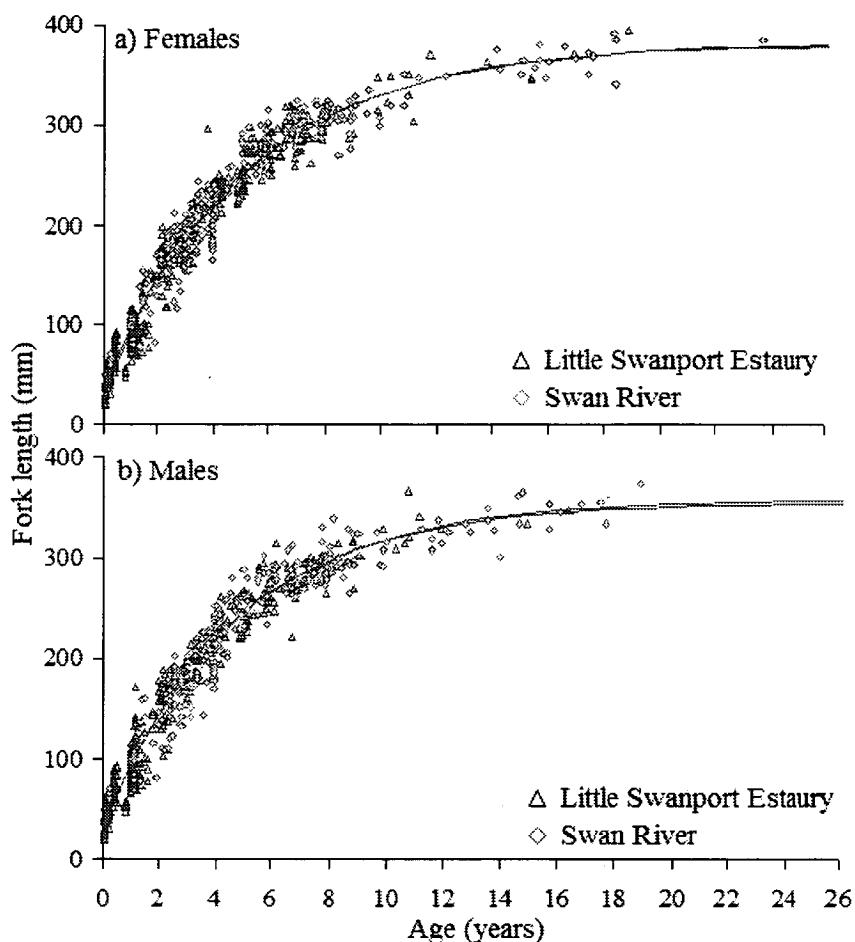


Figure 3.6 Comparison between von Bertalanffy growth curves (lines) fitted to length at age data for (a) females and (b) males between the Little Swanport Estuary and Swan River.

3.4. DISCUSSION

This is the first study to validate the timing of the first annual zone formation in black bream. Determination of the first opaque zone is important for ageing accuracy and must be included in validation of an ageing methodology (Francis et al., 1992; Campana, 2001). Since sub-annual macrostructure before the first increment is formed has been reported in several marine species (e.g. Mann Lang & Buxton, 1996; Karlou-Riga, 2000; Stokie & Talman, 2003), over-ageing may occur if its timing is not validated.

Marginal increment analysis demonstrated that a single annulus is formed each year in black bream, with the completion of the opaque zone occurring in October or November across all age classes and over both years sampled. This timing is consistent with that for black bream from Western Australia where opaque zone deposition is completed by November (Sarre & Potter, 2000).

Interpretation of incremental structure can vary with repeated counts within and between readers, which can lead to errors in age determination (Morison et al., 1998). Fortunately, the increment structure in sectioned otoliths of black bream was very clear and readily interpretable, even for older fish. APEs for repeated readings within and between readers in this study were low (0.2 within a reader and 1.27 between readers) compared with other studies (e.g. Ewing, 2003; Brouwer & Griffiths, 2004), indicating that increment structure was consistently interpreted.

This study shows that growth of black bream in the Little Swanport Estuary and Swan River is slow and the species has a life span of at least 23 years. In fact, a specimen of black bream sampled from the North West Bay River ($43^{\circ} 01'S$ and $147^{\circ} 16'E$), located approximately 20 km south of Hobart, was aged by the author at 31 years old (unpublished data). Maximum longevity in black bream populations has been reported as 29 years from Victoria (Morison et al., 1998) and 21 years from Western Australia (Sarre & Potter, 2000). Since commercial fishing for black bream is prohibited in Tasmanian waters, fishing pressure on the species is likely to be lower than for mainland stocks, potentially contributing to greater longevity in some Tasmanian populations. Recruitment variability is very common in this species (Hobday & Moran, 1983; Morison et al., 1998; Sarre & Potter, 2000) due to unfavourable environmental conditions during a spawning season (see Chapter 4). A long life span increases

the number of spawning seasons of an individual fish providing the population with resilience against recruitment variability.

The estimated von Bertalanffy growth functions provided a close fit to the lengths at age data for black bream in the Little Swanport Estuary and Swan River. Although the likelihood ratio test showed that there was no significant difference between growth coefficients (k) and hypothetical age (t_0) of the males and females in the Little Swanport Estuary and Swan River, asymptotic lengths (L_∞) were found to be significantly different in both estuaries, with females growing to larger sizes than males. The maximum observed lengths were also greater in female than male fish in the both estuaries. This result parallels the findings for black bream in the Gippsland Lakes, Victoria (Morison et al., 1998) and in several Western Australian estuaries (Sarre & Potter, 2000). Larger females yield larger eggs and higher quantities of eggs, increasing the survivorship of larvae (Beckman et al., 1989). Thus, achieving greater size in females is advantageous, and such sexual dimorphism exhibited by females is common among fish (Cazorla & Sidorkewicj, 2008). Because estuarine environments are unstable with occasional unpredictable floods, which may cause mass mortality of eggs and/or larvae, higher quantities of eggs is critical for estuarine-spawning fish.

The growth rates estimated in the present study were slightly slower than those in the Swan River Estuary in Western Australia (Sarre & Potter, 2000), but were much faster than those in the Gippsland Lakes (Coutin et al., 1997; Morison et al., 1998). Differences in growth rates between Tasmanian, Western Australian and Victorian populations may reflect differences in environmental and/or biotic factors, and they may also be due to genetic differentiation between locations. However, Partridge et al. (2004) demonstrated that juvenile black bream cultured from broodstock in the Swan River and Moore River, Western Australia showed

similar growth rates, although there were marked differences between the growth rates of these wild populations (Sarre & Potter, 2000), suggesting that differences in growth rates reflect the environmental variability between the two estuaries, rather than potential genetic variations of these populations (Partridge et al., 2004).

Temperature and food availability are among the most important factors contributing to spatial variation in fish growth rates (Jennings & Beverton, 1991; Bailey & Heath, 2001; Fox et al., 2003). Growth rates of fish are typically slower at lower temperatures (Simpson, 1979), which may explain the slower growth observed in Tasmania compared to the Western Australian population. However, the growth rates of black bream in the Gippsland Lakes were slower than the studied Tasmanian populations despite the lower temperatures experienced in Tasmania. Limited food availability may mean that surplus energy is not available for growth and an increase in temperature may cause a further decrease in growth due to an increase in metabolism (Wootton, 1990). The observed differences between Tasmania and the Gippsland Lakes are most likely attributed to a combination of factors including temperature, food availability, density of fish and salinity and/or narrow sizes and age ranges of the fish sampled in the Gippsland Lakes.

Although there were differences in growth rates between sexes, there was no evidence of different growth rates between the two estuaries sampled in this study. The Little Swanport Estuary and Swan River are closely situated systems, separated by just 50 km and therefore subject to similar environmental conditions, such as water temperature and salinity regimes (see Chapter 2). These factors are therefore unlikely to contribute to any marked difference between the growths of black bream between these two populations. Sarre & Potter (2000) also reported that growth rates in the Swan River Estuary, Western Australia were more

similar to those in Lake Clifton, located only 90 km further north, than those in other estuaries separated by greater distances.

In summary, this study has shown that black bream are relatively slow growing and moderately long lived, taking between 4 and 6 years to reach the current legal minimum length (250 mm total length). These biological characteristics are common to black bream throughout south-eastern Australia and Western Australia where studies have also revealed slow growth and a natural life span of at least 25 years of age (Hobday & Moran, 1983; Morison et al., 1998; Sarre & Potter, 2000) (Table 3.2). A management strategy, for example minimum size and bag limits, should be considered carefully for such slow growing fish species to ensure sufficient numbers of mature fish remain in each estuary. Since population replenishment depends on its own recruitment due to limited movements between populations (see Chapter 6), high longevity is critical adaptation to buffer against population collapse.

Table 3.2 A summary of parameters for the von Bertalanffy growth equation from other studies of black bream.

Authors	Location	von Bertalanffy Growth Parameters					
		Sectioned otolith used					
		Female			Males		
		t_0	k	L_∞	t_0	k	L_∞
Sarre & Potter (1999)	Swan River, Western Australia	-0.13	0.3	438	-0.15	0.31	419
Morison et al. (1998)	Gippsland Lakes, Victoria	-5.21	0.04	545	-3.7	0.08	382
Sakabe	Little Swanport Estuary, Tasmania	-0.47	0.19	380	-0.48	0.21	359
Sakabe	Swan River, Tasmania	-0.59	0.19	382	-0.43	0.21	355
Sex combined							
		t_0	k	L_∞			
Coutin et al. (1997)	Gippsland Lakes, Victoria	-3.0	0.09	360			
Scale annuli used (Sex combined)							
		t_0	k	L_∞			
Hobday & Moran (1983)	Gippsland Lakes, Victoria	-0.59	0.28	249			

CHAPTER 4

Reproductive Biology of Black Bream in Tasmanian Estuarine System: Influence of freshwater inflows on Recruitment

4.1. INTRODUCTION

Black bream, *Acanthopagrus butcheri* are common in temperate estuaries of Australia. They are euryhaline fish, tolerating a wide range of salinities from fresh to hypersaline conditions (Hoeksema et al., 2006). Spawning takes place in the upper region of estuaries near the interface between fresh and brackish waters (Walker & Neira, 2001). Black bream is a multiple spawner, spawning over a relatively long time period, although the actual timing of the spawning season differs between locations (Stewart & Grieve, 1993; Sarre & Potter, 1999). For examples, Victorian and South Australian populations spawning occur between August and December, whereas in Western Australia, spawning starts as early as mid-July and extends to November (Harbison, 1973; Coutin et al., 1997).

Since black bream populations in different estuaries are effectively isolated from each other (Chaplin et al., 1998; Burridge & Versace, 2007), information on the reproductive biology needs to be examined at the individual population level. In the case of Tasmanian populations, black bream reproductive biology is poorly understood, with the only available published information provided by Haddy & Pankhurst (1998), who examined seasonal changes in gonadosomatic indices, gonadal stages and plasma concentrations of sex steroids. They did not examine size or age at sexual maturity that are important for fishery management, particularly for setting minimum legal lengths to ensure individuals spawn at least once (Hancock, 1992).

The increment structure of the otoliths from larvae and juvenile fish has been used to provide information on age (Jordan, 1994), growth (Jenkins et al., 1993; Fowler & Short, 1996) and the timing of spawning (Fowler, 1989; Francis, 1994a; Fowler & Jennings, 2003) of an individual. Analysis of the microstructure of otoliths of larval and juvenile fish can thus be a

useful tool in understanding early life-history characteristics and be informative about the timing of spawning.

Early life stages of fish are the most susceptible to environmental condition (Kucera et al., 2002). Lower Salinities have been shown to affect many properties of fish eggs including the diameter, loss of neutral buoyancy, a decrease in protein content and reduction in fertilization of eggs (Thorsen et al., 1996; Haddy & Pankhurst, 2000), and changes in fish egg properties can negatively influence recruitment success. Marked recruitment variability has been reported in black bream populations (Sarre & Potter, 2000), and freshwater discharge (salinity) has been suggested as the main factor influencing recruitment success (Hobday & Moran, 1983), however, there is little empirical information available on the influence of freshwater inflows on the recruitment success of black bream.

The main objective of this study was to investigate the effect of freshwater discharge (salinity) on recruitment success of black bream in the Little Swanport Estuary. Information on the reproductive traits (spawning period and size and age at sexual maturity) was also gained from two black bream populations in two estuaries on the east coast Tasmania.

4.2. MATERIAL & METHODS

4.2.1. Field collections and treatment of gonads of adults

Large black bream (>150 mm) were collected by gill nets and line-fishing in the Little Swanport Estuary and Swan River on monthly basis between May 2004 and May 2006 (Fig. 4.1). Each fish was measured to the nearest 1 mm fork length and weighed to the nearest 0.1 g. Sex was determined macroscopically on the basis of the shape, appearance and structure of

gonads. Gonads were removed and weighed to the nearest 0.1 g and gonadosomatic index (GSI) was calculated from the equation

$$Wg/Wt \times 100$$

where Wg is wet weight of gonad and Wt is wet weight of fish. The analysis of the reproductive cycle was based on the monthly variation in GSI and gonad maturity stages. Gonad maturity stages are presented in Table 4.1.

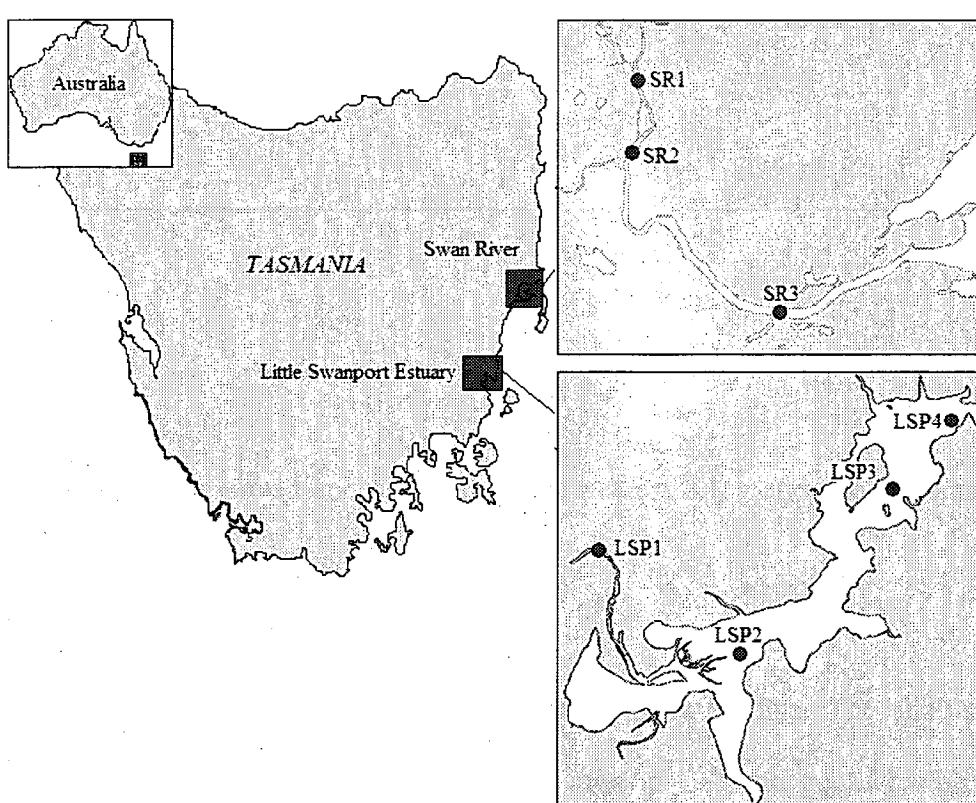


Figure 4.1 Map of study locations. Circles represent sites where fish were captured. LSP1 was located in the spawning ground where large numbers of newly recruited fish and adults with full developed gonads were caught.

Table 4.1 Maturity scales used in the classification of black bream gonads (modified from Haddy, 2000).

		Female	Male
Stage I	Juvenile	Gonads too small to distinguish between sexes	
Stage II	Immature	Ovary small and clear	Testis thin white threads
Stage III	Mature or Resting	Ovary orange with opaque oocytes visible	Testis firm and white
Stage IV	Prespawning	Ovary orange with hydrated oocytes visible	Testis firm and white with viscous milt
Stage V	Spawning	Hydrated eggs are clearly visible extruded with gentle pressure	Testis firm and white with free flowing milt
Stage VI	Spent	Ovary flaccid and dark pink to bloody	Testis grey to bloody and flaccid

4.2.2. Size and age at first maturity

The mean size and age at which 50% of the black bream population reaches sexual maturity (L_{50}) was estimated (Sarre & Potter, 1999; Sinovcic & Zoriac, 2006) on a sample of 209 individuals from the Little Swanport Estuary and 466 individuals from the Swan River collected during the spawning period (September-December). Fish were aged using the protocols described in Chapter 3. To estimate the length and age at first maturity for males and females in each estuary, the fraction of fish which had gonads at stages III-VI per 10 mm fork length or by age class was fitted to a logistic function. The logistic equation is

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

where P_L is the predicted proportion at size or age class L and a and b are constants. The length or age at which 50% of the fish possesses mature gonads was derived from the equation $L_{50} = -a/b$.

4.2.3. Collection of juveniles

Juvenile sampling was restricted to the Little Swanport Estuary due to lack of suitable shallow waters in the Swan River. Newly recruited black bream (0^+) were sampled in the upper estuary (LSP1) between September and March of 2004/05 and 2005/06 using a beach seine hauled

during daylight hours or fyke nets which were left over night. If large numbers of fish were caught, a minimum of 20 individuals were randomly selected. Otherwise all fish were retained for catches of <20 fish. Fish were euthanased using AQUI-S (anesthesia), held on ice and transported to the laboratory for examination.

4.2.4. Otolith preparation and analysis

Each fish was measured to the nearest 1.0 mm fork length and weighed to the nearest 0.01 g. Both sagittae were extracted, rinsed in water, cleaned and dried. To achieve more reliable counts of daily increments, a transverse section of the sagitta was prepared, this providing the best plane for resolving the otolith microstructure (Fowler & Short 1996). Each sagitta was embedded in thermoplastic resin on a microscope slide, and ground from anterior end towards the primordium using 1200 grade wet and dry sandpaper and then polished with 2000 grade wet and dry sandpaper using wetted alumina powder. The polished facet was then mounted to the center of a microscope slide and the otolith ground from posterior end towards the centre of sagitta. The sagitta was polished until increments were clearly visible. Finally either side of the polished facet was covered with a thin layer of thermoplastic resin.

Each sagittal section was examined using a compound microscope at 250-400X magnification with image analysis software (LEICA IM50) and measured from the primordium, along the radius of maximum growth, to the nearest 0.01 µm. For each section of a sagitta, the total number of increments from the first visible increment near the primordium to the growing edge (ventral side) were counted. Increment counts were repeated until two counts agreed to within 5 increments. The mean of the two closest counts was accepted as the best estimate.

The precision of daily increment counts was tested within and between readers by randomly selecting 123 sagittal otoliths for re-reading by the primary reader, and 51 sagittal otoliths by a second reader. The precision of age estimates between and within readers was examined visually using age-bias plots (Campana, 2001). Otolith increment reads by the primary reader were used to determine age estimates and back-calculated spawning date.

4.2.5. Validation of daily increment using oxytetracycline

Newly recruited black bream (31-43 mm) were collected by beach seine from Browns River, Kingston Beach and transported to the Tasmania Aquaculture & Fisheries Institute on 10th January 2006. To stain their otoliths, the fish were placed in a solution of 500 mg/L oxytetracycline (OTC) in brackish water (salinity of 20) (25ml.L^{-1} of Ilium Oxytet-200 L.A. containing 200 mg. ml^{-1} OTC as the base) for 24 hours. They were then removed from the OTC solution and held in a 200 L tank of brackish water with air flow. The tank contained shelters (concrete bricks) and was housed outside under cover, exposed to ambient natural light cycles. Fish were fed *Artemia* spp. daily. A sub-sample of these post-settlement fish was euthanased using AQUI-S 8, 15 and 22 days after exposure to OTC to determine whether increments were deposited daily. Otoliths were prepared in the same manner as described above, but viewed under blue light.

4.2.6. Calculation of birth date

Although the timing of the first increment was unknown because larval rearing was not conducted, it was assumed to have been formed at the time of first feeding, which, based on other species from the same regions (Jordan, 1994; Fowler & Jennings, 2003), probably occurred approximately two days after hatching. Jenkins et al. (1999) reported that hatching time in black bream is dependent on temperature, with larvae hatching in approximately 20

hours at 26°C. Given lower temperatures in the upstream region of the Little Swanport Estuary (see Chapter 2) hatching is likely to be delayed and thus, for the purpose of calculating birth dates, ages were calculated by number of increments plus four days.

4.2.7. Analysis of growth of 0⁺ fish

Growth was described for the 0⁺ fish by the relationship between fish size and age (number of increments + 4). Data from fish collected in 2004/05 and 2005/06 spawning seasons were analysed independently by regression analysis. Analysis of covariance (ANCOVA) was used to compare the relationships between years. Prior to all analyses, the data were tested for homogeneity of variances, and where appropriate, data were transformed by $\log_{10}(x+1)$.

4.3. RESULTS

4.3.1. Size and age at first maturity

Size and age at sexual maturity showed a clear difference between males and females with 50% maturity occurring at smaller sizes and younger ages in males in both estuaries (Fig. 4.2 & 4.3).

In the Little Swanport Estuary, the smallest mature male and female were 170 and 174 mm fork length, respectively, and aged 2 years (Fig. 4.2). At the end of third year, 60% of males had reached sexual maturity; whereas only 25% of females were mature. The mean size and age at 50% maturity in the Little Swanport Estuary were 185 mm and 3.0 years for males and 219 mm and 3.5 years for females. All males larger than 230 mm and age 5 and females larger than 250 mm and age 6 were mature.

In the Swan River; the size and age at first maturity were 160 mm and 3 years for males and 180 mm and 3 years for females (Fig. 4.3). The mean size and age at 50% maturity for males

was 181 mm and 3.2 years and for females 227 mm and age 4.1 years. All males larger than 250 mm and older than 5 years of age and females larger than 290 mm and 6 years of older were mature.

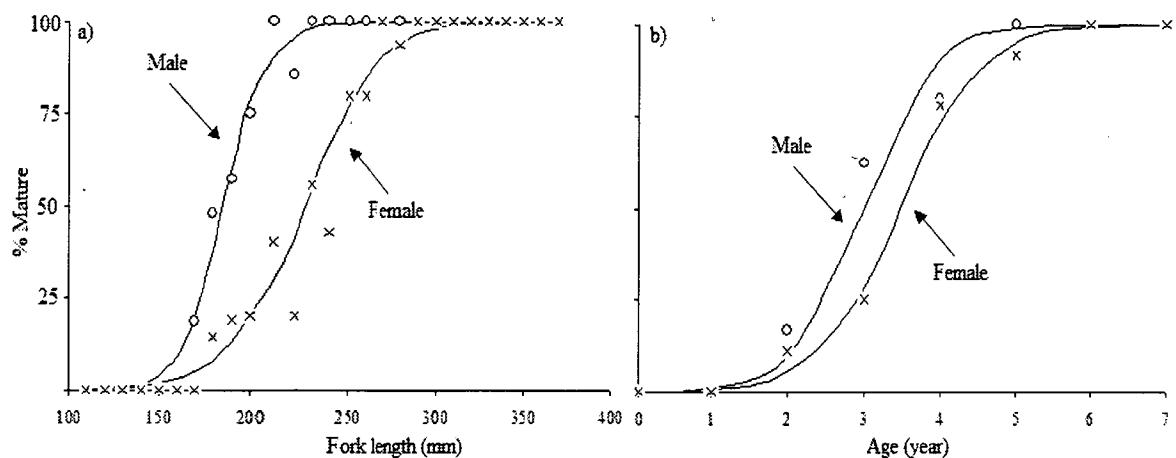


Figure 4.2 Logistic functions fitted to percentage mature by a) 10 mm length classes and b) age of male ($n = 136$) and female ($n = 73$) black bream caught in the Little Swanport Estuary during spawning seasons (September and December) of 2004 and 2005. Symbol \circ and \times represent male and female, respectively.

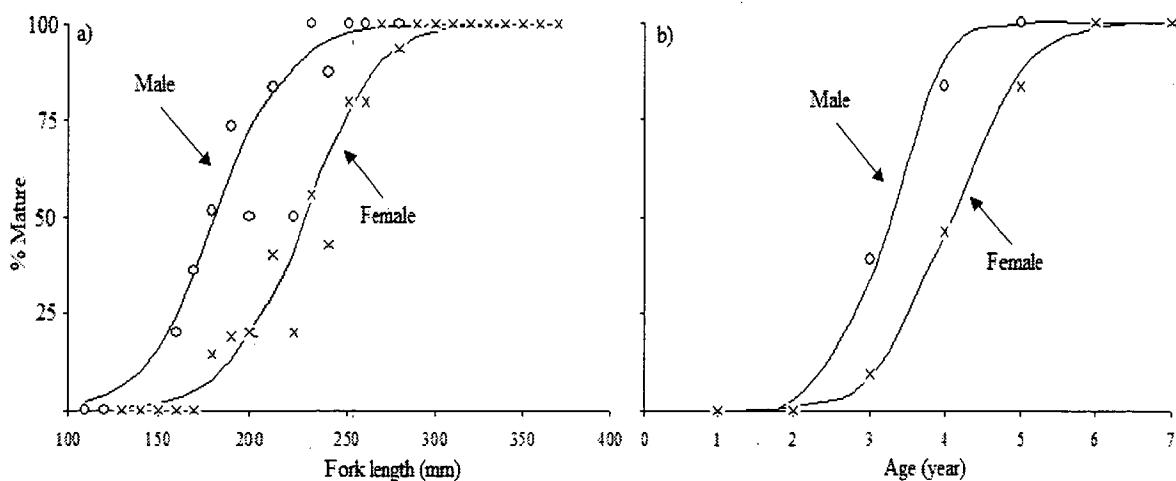


Figure 4.3 Logistic functions fitted to percentage mature by a) 10 mm length classes and b) age of male ($n = 196$) and female ($n = 282$) black bream caught in the Swan River during spawning seasons (September and December) of 2004 and 2005. Symbol \circ and \times represent male and female, respectively.

4.3.2. Seasonal gonad development

The monthly mean GSI values for males and females based on fish greater than or equal to the size at 50% maturity from the Little Swanport Estuary and Swan River showed a seasonal pattern involving raised GSIs between August and December (Fig. 4.4 & 4.5). Overall, male GSIs were between 0.11 and 5.53 and females' between 0.75 and 6.58 in the Little Swanport Estuary, and between 0.19 and 7.28 for males and between 0.72 and 10.77 for females in the Swan River. The peak in GSI values during September to December was followed by a sharp decline thereafter.

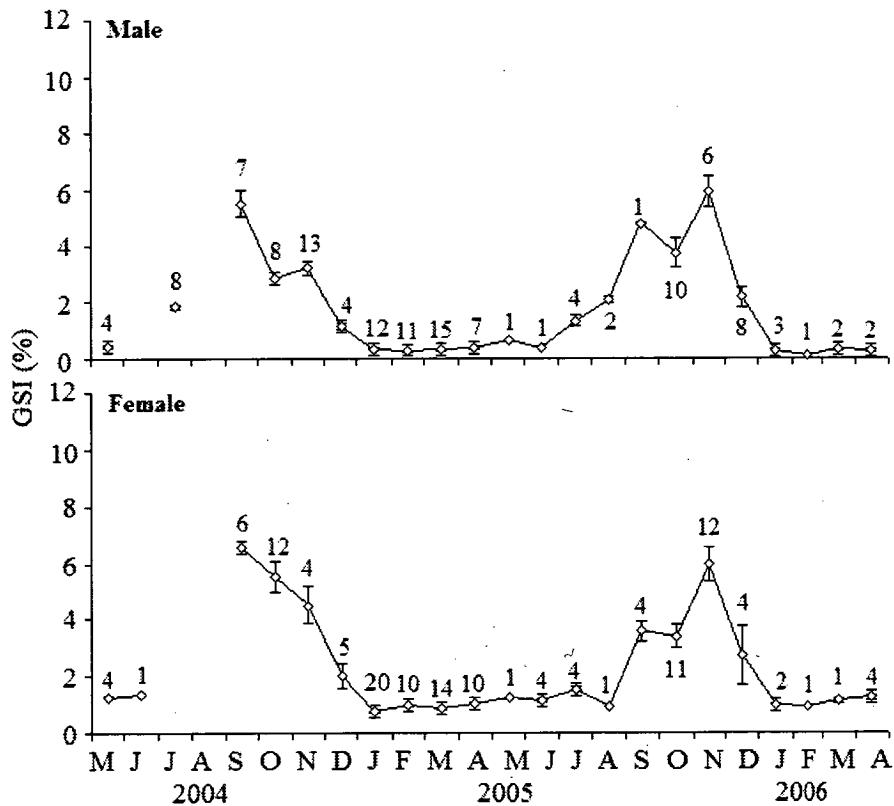


Figure 4.4 Mean gonadosomatic indices (\pm S.E.) for those male and female black bream whose lengths were \geq the L_{50} at sexual maturity caught in the Little Swanport Estuary. Sample sizes are shown at each month.

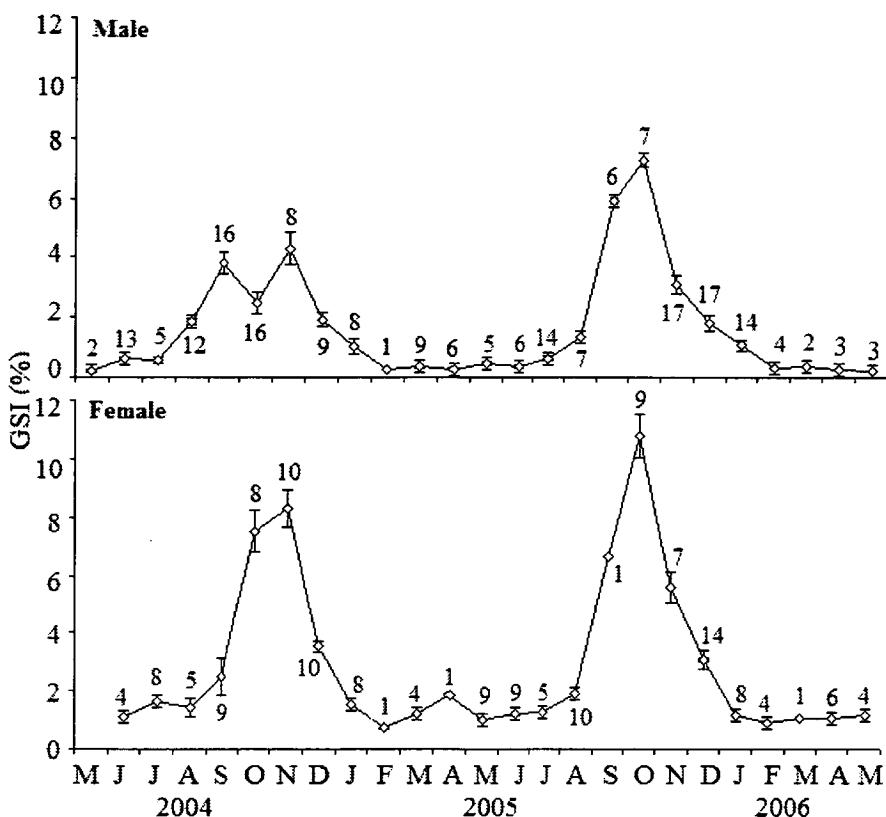


Figure 4.5 Mean gonadosomatic indices (\pm S.E.) for those male and female black bream whose lengths were \geq the L_{50} at sexual maturity caught in the Swan River. Sample sizes are shown above each month.

In the Little Swanport Estuary, pre-spawning and spawning condition males (stages IV and V) were present between July 2004 and January 2005 and between July and December 2005 while pre-spawning and spawning females were found between September and December in both years (Fig. 4.6). Over half of the adult males were stage V (spawning) between September and December 2004, and between August and November 2005, while over half of the females sampled between October and November 2004 and during November 2005 were running ripe. Spent males (stage VI) were found in varying proportions between December 2004 and February 2005 and between December 2005 and January 2006 while spent females were evident between November 2004 and March 2005 and between December 2005 and

January 2006 (Fig. 4.6). Most black bream were sexually inactive (stages II and III) between January and July, when GSI values stabilized at very low levels.

The seasonal pattern of gonad development in the Swan River black bream followed similar trends to those described for fish from the Little Swanport Estuary (Fig. 4.7). In the Swan River, males in spawning condition (stage V) were found between September and January in both sampled years while spawning females were found between October and December 2004 and November and December 2005. Spent fish were first evident in December 2004, and in November 2005 (Fig. 4.7).

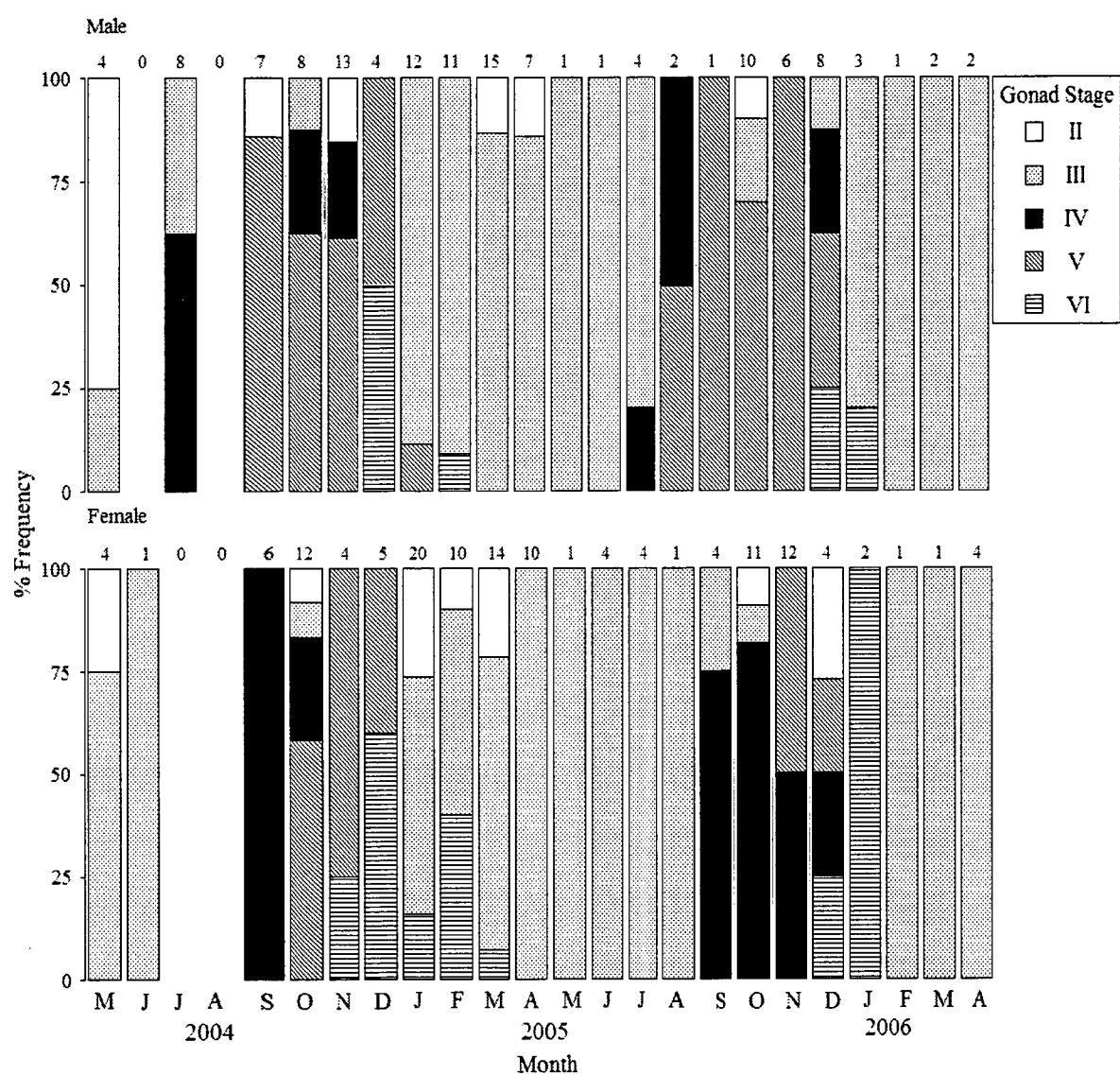


Figure 4.6 Monthly changes in the percentage frequency of occurrence of the gonad stages for male and female black bream whose lengths were $\geq L_{50}$ for the Little Swanport Estuary. Sample sizes are shown at each month.

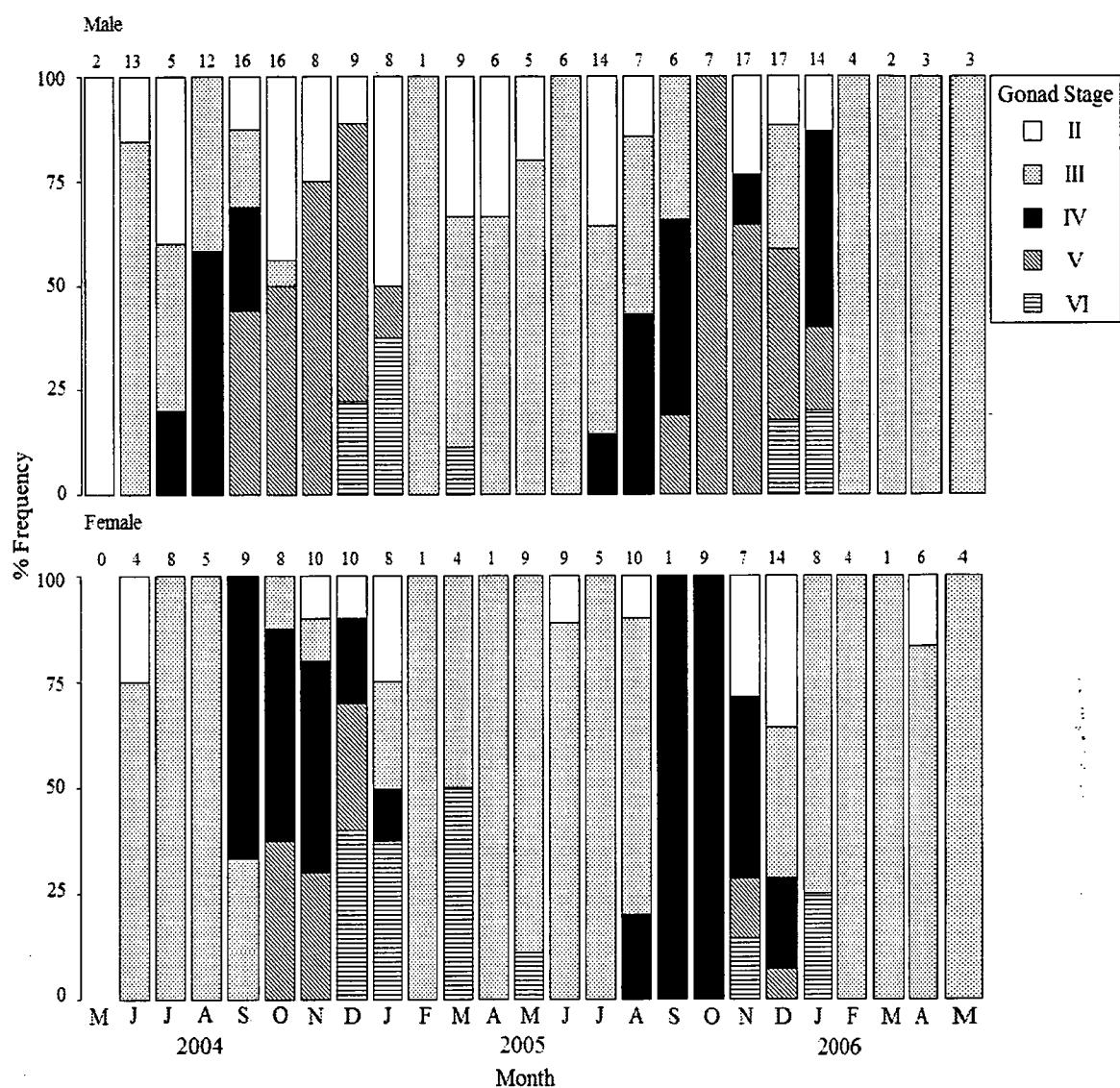


Figure 4.7 Monthly changes in the percentage frequency of occurrence of the gonad stages for male and female black bream whose lengths were $\geq L_{50}$ for the Swan River. Sample sizes are shown at each month.

4.3.3. Otolith characteristics and interpretation

The increment structure was very clear in the 0^+ fish otoliths (Fig. 4.8). The width of the first few increments was less than $5 \mu\text{m}$, after which they increased dramatically to a maximum of approximately $25 \mu\text{m}$, and then the width decreased gradually to 1.0 to $4.0 \mu\text{m}$. Initial growth increments were easily counted, but the resolution of increments in the outer region became

difficult and unclear for increment counts greater than approximately 100 due to narrowing of the increment widths.

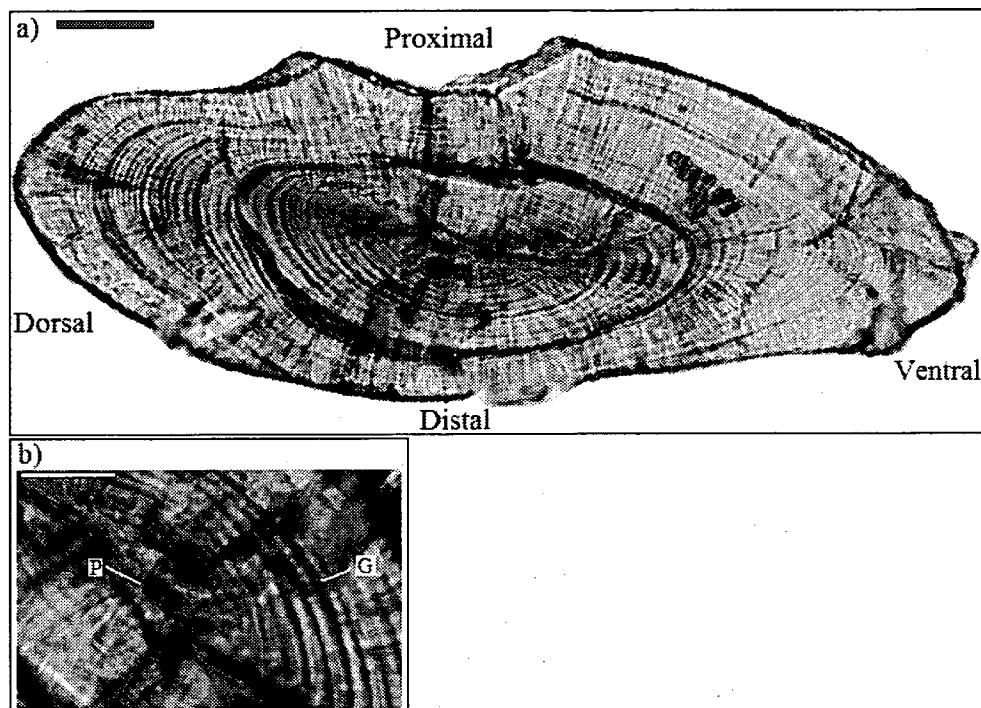


Figure 4.8 (a) A transverse section of a sagitta otolith from a juvenile black bream showing the opaque central region. (b) The central part of a sagitta from a juvenile showing primordium (P) and daily growth increment (G). Scale bars: 50 μ m.

Fork lengths of black bream exposed to OTC ranged from 31 to 43 mm. There was no mortality associated with OTC treatment and all fish survived to the end of the experiment. The transverse sagittal sections from 12 juveniles treated with OTC each showed a clear fluorescent band located some distance from the outside edge. This corresponded to a clear discontinuity in incremental structure, which presumably related to the stress of capture and timing of exposure. Ten fish had post-OTC increment counts equal to the number of days subsequent to exposure to OTC while two individuals had one less completed increment than number of days post exposure (Fig. 4.9). The result from the OTC validation confirmed that,

at least within the range of ages examined, the micro-increments in sagittae of juvenile black bream are formed on a daily basis.

The plots comparing count estimates of daily increments within and between readers showed no evidence of bias relative to a 1:1 correspondence line (Fig.4.10). Consequently otolith increment counts by the primary reader were considered consistent.

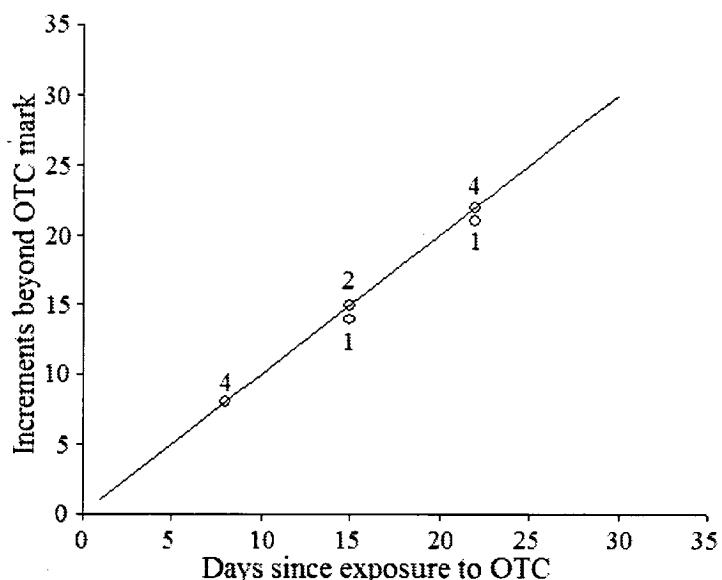


Figure 4.9 Relationship between the number of increments formed outside the OTC band and days since 0^+ black bream exposed to OTC (1:1 line is shown). The numbers adjacent to the symbol represent the number of fish.

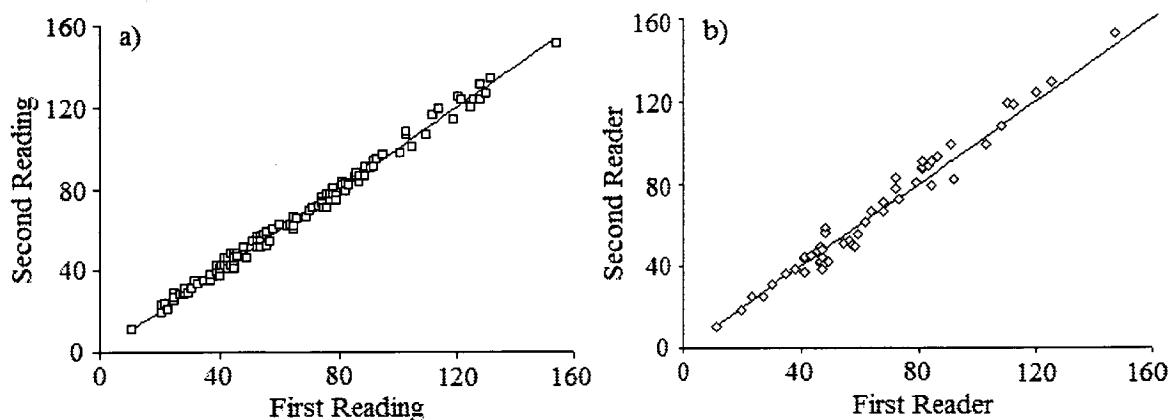


Figure 4.10 Precision of increment counts of 0⁺ black bream. a) Repeat counts by the primary reader and b) Repeat counts by the secondary reader (the 1:1 line is shown).

There was a highly significant linear relationship between sagittal radius and fork length in juveniles ($R^2 = 0.84$, $P < 0.001$) (Fig. 4.11a). Regression of sagittal radius against estimated age also showed a highly significant linear relationship ($R^2 = 0.66$, $P < 0.001$) (Fig. 4.11b). Fish with 16 mm fork length and age of 11 days had a minimum sagittal radius of 301.43 μm while the maximum radius of 893.49 μm was recorded from a fish that was 63 mm fork length and 126 days old.

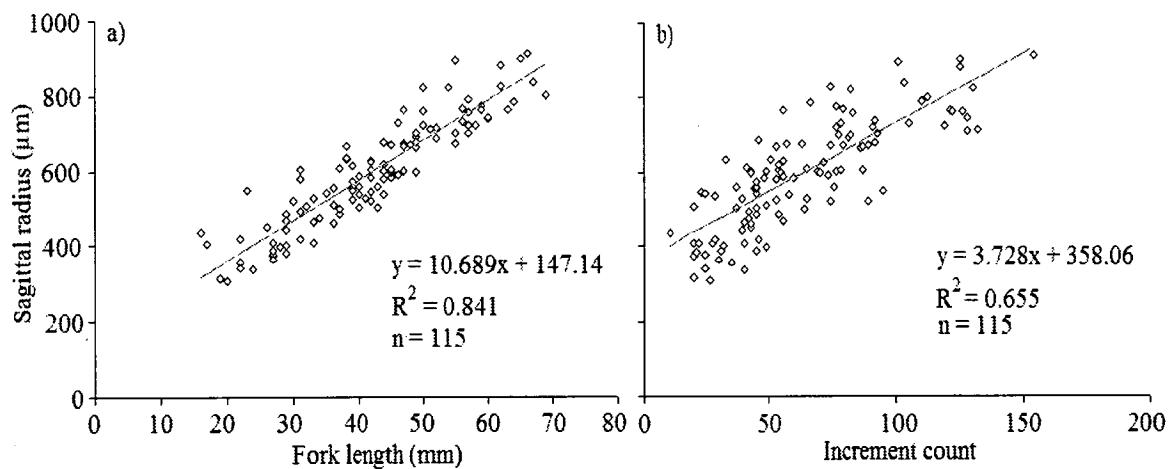


Figure 4.11 Relationships between a) fork length and sagittal otolith radius; and b) increment count and sagittal otolith radius of juveniles captured during the spawning seasons of 2004/05 and 2005/06.

4.3.4. Early life history characteristics based on otolith interpretation

Total daily increment count was regressed against fork length at capture for individuals in 2004/05 and 2005/06 (Fig. 4.12). The relationships were linear in both years ($P < 0.001$), with age accounting for 77% of the variance in length in 2004/05 and 89% in 2005/06. Growth relationships differed significantly between years (ANCOVA $F_{1,225} = 36.801$, $P < 0.001$), with a slower growth rate in 2004/05 (0.37 mm day^{-1}) compared with 2005/06 (0.58 mm day^{-1}). The intercepts were also significantly different (ANCOVA $F_{1,225} = 196.111$, $P < 0.001$). Residuals of length plotted against spawning date for the 2004/05 spawning season showed a significant positive relationship ($R^2 = 0.07$; $P = 0.002$; $n = 141$) (Fig. 4.13a), implying that later spawned fish tended to be larger at age than individuals spawned earlier in the spawning season. By contrast in 2005/06, there was no significant relationship ($R^2 = 0.038$; $P = 0.07$; $n = 85$), probably influenced by the shorter spawning duration (Fig. 4.13b).

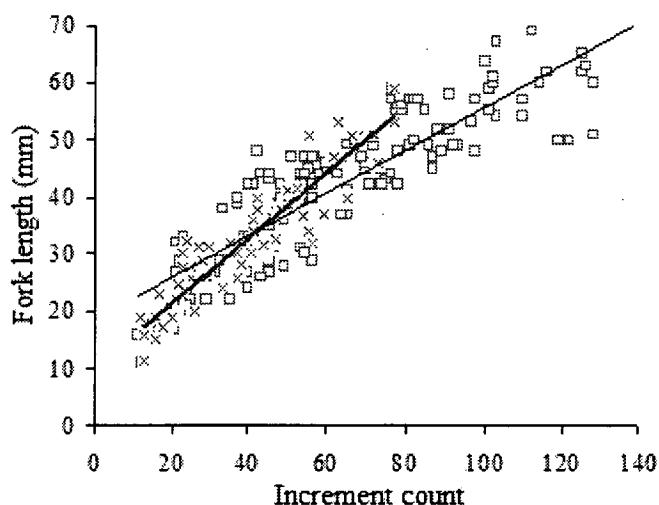


Figure 4.12 Relationship between fork length and increment count for 0^+ fish collected in (□) 2004/05 and (×) 2005/06. 2004/05: Fork length = $0.37x + 18.5$; $R^2 = 0.77$; $n = 141$. 2005/06: Fork length = $0.58x + 9.5$; $R^2 = 0.89$; $n = 85$.

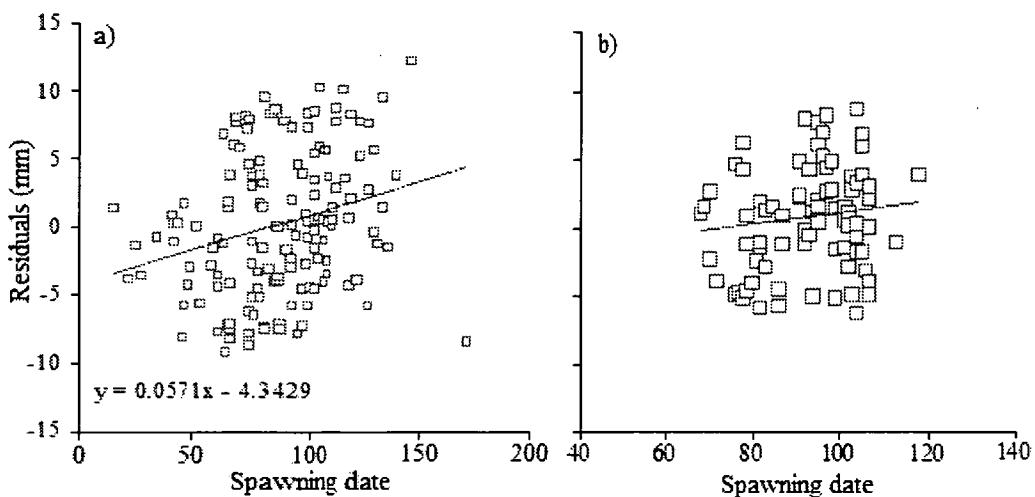


Figure 4.13 Effect of spawning date in a) 2004/05 and b) 2005/06 on residuals derived from Fig. 4.12. Spawning date is days from 1 October in each spawning season.

4.3.5. Spawning patterns

A total of 484 0⁺ fish were captured from the upper estuary of the Little Swanport Estuary in 2004/05, whereas only 103 fish were caught in the spawning season of 2005/06. Out of these, 141 and 85 otoliths, respectively were analysed and used to back calculate spawning dates. Back-calculated spawning date distributions indicated that the spawning season in 2004/05 started from late October and continued through to February with peaks occurring in December 2004 (68 fish), while in 2005/06 spawning occurred within a narrower time frame (December-January) (Fig. 4. 14). Spawning dates (days post 1st October) of black bream differed significantly between the years (Table 4.2), with mean spawning dates of 84.5 (± 2.01 S.E.) in 2004/05 and 99.4 (± 1.26 S.E.) days in 2005/06.

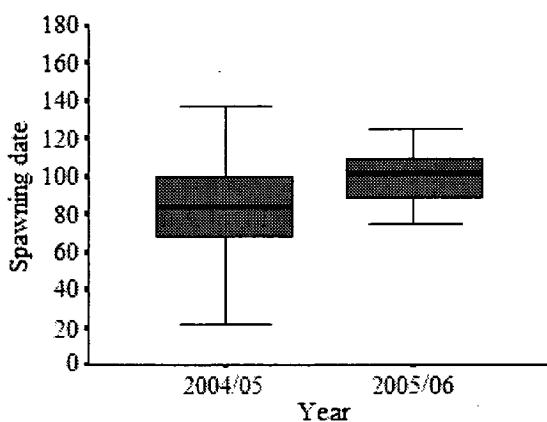


Figure 4.14 Box plots of back calculated spawning date distribution of juvenile black bream in the Little Swanport Estuary. Spawning date is days since 1 October in each year.

Table 4.2 Results of ANOVA comparing spawning date of black bream in the Little Swanport Estuary between years.

Source	Sum of Squares	df	Mean Square	F ratio	P
Between Group	11801.179	1	11801.179	28.974	<0.0001
Within group	91268.100	224	407.447		
Total	103069.3	225			

4.3.6. Influence of salinity on successful recruitment

During the 2004/05 spawning season the salinity on the spawning ground increased from around 10 at the beginning of October to above 20 by mid-November and increased slightly to approximately 30 for the remainder of the season, with the exception of inflows at around day 120 which corresponded with the effective end of the spawning period (< 1% spawned after this date). Daily freshwater discharges into the estuary were consistently low throughout the spawning period (Fig. 4.15a). During the 2005/06 spawning season however the salinity remained below 7 between October and November, and daily freshwater discharges during the period were relatively high (Fig. 4.15b). Salinity increased rapidly to 20 during December, and then gradually rose to 34 by the middle of February. The result suggests that successful recruits occurred when salinities were relatively high, with range of 20-30 during periods of low daily freshwater discharges (Fig. 4.15). In 2004/05 successful recruits were derived from

spawning that occurred from late October 2004 to January. In the second spawning season, successful recruitments were only achieved between mid-December 2005 and the end of January 2006, and corresponded with the period during which there was a sharp increase in salinity on the spawning ground and low daily freshwater discharges (Fig. 4.15).

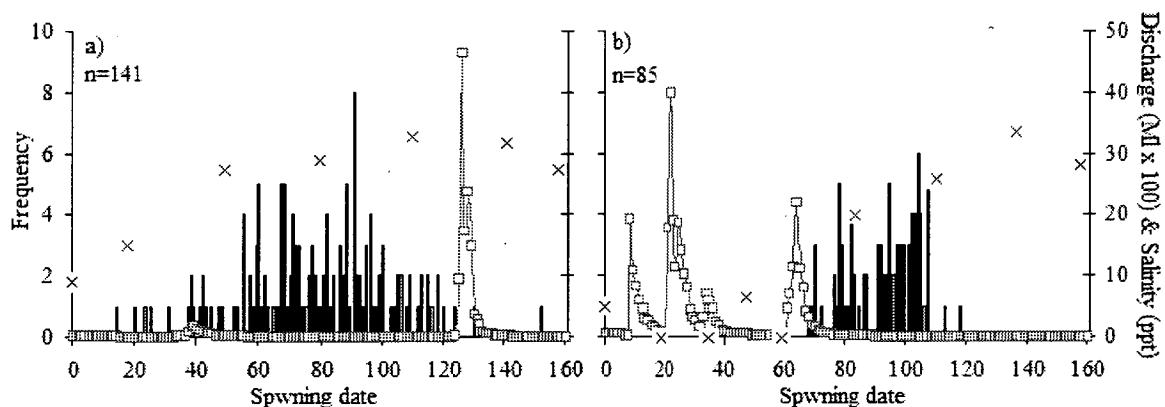


Figure 4.15 Distributions of back-calculated spawning dates for 0+ collected during (a) 2004/05 and (b) 2005/06. Date is arbitrarily depicted as days since 1 October each year. Bottom salinities (x) on the spawning ground at each sampling occasion, and daily freshwater discharges (□) to the Little Swanport Estuary are shown.

4.4. DISCUSSION

This study represents the first study to provide data on early life characteristics of black bream using daily increment analysis and to demonstrate the link between salinity, freshwater inflows and spawning success. Since black bream are commercially and recreationally important species that frequently shows interannual variability in recruitment success, information on such reproductive dynamics is particularly important for the fishery management.

4.4.1. Sexual maturity

In other Australian states, black bream, particularly the females, matured at smaller size and younger age than in Tasmania. In Western Australia, 50% of female and male black bream in

the Swan River Estuary, Western Australia reached maturity at 218 mm total length (approximately 196 mm fork length) and 212 mm total length (approximately 191 mm fork length), respectively at the end of their second year of life (Sarre & Potter, 1999). Furthermore, 50% of female black bream in the Gippsland Lakes, Victoria, underwent sexual maturation at approximately 155 mm fork length (Coutin et al., 1997). Intraspecific variations in the length and/or age at sexual maturity have been observed in other fish species (Beverton, 1987; Jennings & Beverton, 1991; Stergiou, 1999; Hesp, 2003; Abaunza et al., 2008) and may be a response to physical and biological characteristics such as temperature and food availability (Jennings & Beverton, 1991). Fishing pressure can also contribute to differences in size and age at maturity. Since there is no commercial fishery of black bream in Tasmania, fishing pressure on this species is likely to be less intense than in Western Australia. High fishing pressure may result in fish maturing at smaller size and younger ages (Lorenzen & Enberg, 2002; Ziegler et al., 2007). Extreme environmental fluctuations may also cause relatively small sizes and early ages at maturity as consequence of selection pressures in response to the high mortality caused by extreme weather (Sarre & Potter, 1999).

Females matured slightly older and at a larger size than males, which was inconsistent with the previous observations of Sarre & Potter (1999) for Western Australian populations. However, Weng (1971) reported that male black bream in South Australian populations tended to reach maturity slightly earlier than females. Sexual dimorphism in terms of size at maturity has also been observed for other long-lived species, such as red bass, *Lutjanus bohar* (Marriott et al., 2007), lane snapper, *Lutjanus synagris* (Luckhurst et al., 2000) and marine species, including striped seabream, *Lithognathus mormyrus* (Lorenzo et al., 2002).

4.4.2. Spawning Activity

Spawning occurred between September and January, with peak activity during late November–December. Although the timing of the spawning season is similar to that of other black bream populations in Tasmania (Haddy & Pankhurst, 1998) and elsewhere (Butcher, 1945b; Newton, 1996; Sarre & Potter, 1999), spawning in the mainland populations occurs slightly earlier than in Tasmanian populations (Harbison, 1973; Coutin et al., 1997; Sarre & Potter, 1999). Water temperature has been consistently emphasized as an important factor triggering spawning in fish (Amara et al., 2000; Vinagre et al., 2008), and early spawning by mainland populations may be due to warmer temperatures being reached earlier than in Tasmania.

Spawning appears to take place mainly in the upper estuary as the majority of adults collected during the spawning season from this region possessed fully developed gonads. Furthermore, adult fish were observed to aggregate in relatively large numbers in this region and 0⁺ fish were also abundant during the spawning season. Such reproductive behaviour is consistent with other studies of this species (Neira & Potter, 1994; Walker & Neira, 2001).

There are a number of potential advantages of spawning in the upper estuary. Firstly, predators of larval and juvenile fish tend to be less abundant in the upper estuary (North & Houde, 2003). In fact, during the study period, no large predatory marine fish, such as Australian salmon (*Arripis trutta*), were captured in the upper estuary region whereas relatively large numbers of this species were observed in the middle and lower estuary (personal observation). Secondly, within the thermal limits of a species, growth rates are positively correlated with temperature (Francis, 1994b; Brander, 1995; Taylor et al., 2007; Azaza et al., 2008; Li & Leatherland, 2008; Moreira et al., 2008) and the elevated temperatures and lower salinities of the upper estuary may offer better growth conditions for larvae and juveniles (Velez et al., 2005). Lower

salinities may also reduce the energetic cost of osmoregulation, saving further energy for growth (Boeuf & Payan, 2001; Imsland et al., 2008). Specifically, Partridge & Jenkins (2002) indicated that the maximum growth rate was observed in juvenile black bream reared in salinities of 24, which is similar to the mean bottom salinity in the upper Little Swanport Estuary (see Chapter 2), though there was no statistically significant difference in growth rates of fish reared in salinities of 12-48 (Partridge & Jenkins, 2002). A further reason for spawning in the upper estuary may be to minimize the possibility of embryos being swept away into the downstream regions and out of an estuary by tidal flushing. Black bream have a preference for the upper and middle estuary regions and tend to remain within an estuary (see Chapter 6), and thus upstream spawning may be an important reproductive strategy to retain their offspring within the system. However, environmental conditions, especially salinity, in the upper estuary tend to be more variable than the downstream regions and may pose limitations on spawning success and survival of eggs and larvae, especially due to the strong impacts of freshwater discharge in the region. Early life stages, such as embryos and juveniles of black bream can survive in a wide range of salinities (Haddy & Pankhurst, 2000; Partridge & Jenkins, 2002) and thus are well adapted to such environment variability; an exception being the influence of heavy freshwater discharges.

A relatively protracted spawning period is an important adaptation to reduce the impact of environmental variation on reproductive success (Bobko & Berkeley, 2004; Tracey et al., 2007), and other estuarine dependent fish species such as striped mullet, *Mugil cephalus* (McDonough et al., 2003) and white mullet, *Mugil curema* (Marin et al., 2003) also exhibit such reproductive adaptation. If conditions are unfavourable for periods within a spawning season, spawning activity may be delayed and/or high mortality of eggs and/or juveniles may

occur, but with a protracted spawning period they can still spawn successfully during periods of favourable conditions. Thus an extended spawning period provides insurance against recruitment failure; however, it is not always successful. Marked interannual variability in recruitment success is a common feature of black bream populations (Hobday & Moran, 1983). For example, black bream collected from the Wellstead Estuary in Western Australia in 1995 and 1996 did not contain any individuals from the 1984, 1985, 1986, 1987 and 1989 year classes, suggesting that very little recruitment had probably occurred during the later half of the 1980s (Sarre & Potter, 2000). Morison et al. (1998) reported that recruitment of black bream in the Gippsland Lakes, Victoria was also highly variable. There was very poor recruitment in 1990-1992 whereas large numbers of fish were recruited to the population in 1987 and 1989.

4.4.3. Juvenile growth

Growth in newly recruited black bream was effectively linear, a characteristic of the fast-growing juvenile phase that precedes the usual asymptotic growth phase of older fish (Hoedt, 1992). Faster growth is the basic survival strategy in the early life stages of fish (Islam et al., 2006). There were, however, substantial differences in growth rates between years, which appeared linked to variation in the timing of spawning. In 2004/05 most 0⁺ fish were spawned prior to mid-December whereas in 2005/06 all 0⁺ fish examined were spawned after mid-December. Growth rates of 0⁺ fish in 2005/06 were faster, presumably due to initial exposure to warmer water and increased food availability during the summer period. Water temperature has already been recognised as the main factor regulating fish metabolic rates, with available oxygen, salinity, food and other factors interacting with temperature to generate spatial and temporal variations in fish growth (Phelan et al., 2000; Neill et al., 2004). Furthermore, since

newly recruited fish in the 2005/06 spawning season were much less abundant than in 2004/05 (see Chapter 2), intraspecific competition for food was also potentially lower.

Spawning time can also affect the post-settlement performance of fish. For example, Welsford (2003) indicated that temperate wrasse, *Notolabrus fucicola*, which were spawned later were more likely to survive the planktonic larval phase because they spent less time in the unpredictable planktonic environment and grew faster than individuals spawned earlier in the spawning season. The present study also indicated that later spawned fish in 2004/05 tended to grow at a faster rate than those spawned earlier in the spawning season. Although a faster growth rate achieved by later spawned fish is advantageous, there are also advantages for fish spawned earlier in the season. If survival over winter is directly linked to size, it is important to reach as large a size as possible prior to winter. Even though earlier spawned fish grow slower than those spawned later in the season, they are more likely to gain a size advantage due to the longer period of growth before reduced food availability and temperatures take effect. The advantage of size is also important when competing for food as larger juveniles tend to be more dominant and restrict the feeding opportunities of smaller fish (Jenkins et al., 1999). Timing of spawning and size attained prior to winter have been found to significantly affect the probability of survival in other species of first year fishes in estuarine waters (Munch et al., 2003; Lanier & Scharf, 2007).

4.4.4. Effect of freshwater discharge on successful recruitment

Recruitment variability, as determined either by variable survivorship of eggs, larvae or post-settlement fish, appears to be strongly influenced by environmental conditions, especially salinity on the spawning ground. Hobday & Moran (1983) indicated that the most successful year classes in the Gippsland Lakes were spawned during periods of low riverflow. They

suggested that the absence of certain year classes was the result of unfavourable environmental conditions such as heavy freshwater discharge causing low salinity on the spawning ground which impacted on spawning success as well as survival of eggs and larvae. The results of this study support their suggestion. Regular heavy freshwater discharge occurred from September to November 2005 in the Little Swanport Estuary and presumably impacted spawning activity and survival of any eggs or larvae. Newly recruited fish collected in 2004/05 were primarily spawned between the mid-October and the mid-February when there were relatively low freshwater inflows and salinity remained consistently above 15 on the spawning ground (LSP1). By contrast, in the following spawning season new recruits were spawned between the mid-December and the late January. The lack of successful recruitment from the early spawning activity (October and November) during the 2005/06 spawning season corresponded with a period of relatively high inflows and salinities below 10-15 in the upper estuary. The possibility that successful early season spawning occurred in 2005/06 cannot, however, be completely discounted. Spawning could have occurred further downstream where environmental conditions may have been more favorable, but given the absence of 0⁺ fish from sampling sites in the middle and lower estuary (LSP2, LSP3 & LSP4) during the spawning season (see Chapter 2), this suggestion seems unlikely. Haddy & Pankhurst (2000) found that fertilization of black bream eggs was significantly reduced at low salinities due to a reduction of sperm activity, lower survival rates of eggs and reduction in the proportion of larvae hatched from eggs. Low salinity also causes the loss of egg buoyancy for estuarine or marine spawners (Hassell et al., 2008a). Eggs that lose buoyancy will sink to the bottom, where they are exposed to lower dissolved oxygen concentration water and anoxic sediments (Newton, 1996; Hassell et al., 2008a), which significantly increase mortality of eggs (Hassell et al., 2008b). Furthermore, heavy freshwater inflows may also cause a delay in

upstream migration of adults and/or the retreat of adult fish from the spawning ground (see Chapter 6) and/or eggs and larvae to be flushed out of the estuary.

The heavy freshwater discharges that occurred between September and November 2005 may also have influenced spawning success by suppressing spawning behaviour and/or by flushing eggs and larvae out of the system. This implication is supported by Strydom et al. (2002) who have indicated that larvae and juveniles of an estuarine resident, *Gilchristella aestuaria*, in the Great Fish Estuary appeared to be flushed out of the system during periods of excessive freshwater discharge.

Sarre & Potter (1999) found that black bream in the Moore River Estuary, Western Australia spawn in salinities ranging from 5.5-6.8, while spawning in the Wellstead Estuary, Western Australia occurs in salinities of 40.7-45.2, suggesting that this species is capable of spawning in a wide range of salinities. Considering their findings and the results of this study, the most important factor for successful spawning of black bream appears to be stable environmental conditions prior to and during a spawning period. If there is a dramatic environmental change, such as floods during and/or prior to the spawning season as observed in 2005/06, it can significantly impact on the recruitment success.

While heavy freshwater discharge has a negative impact on the spawning activity of black bream, a reduction of freshwater inflows may also be deleterious. Since freshwater inflows are important for water exchange processes in estuarine ecosystems, providing additional nutrients (Drinkwater & Frank, 1994), a reduction in freshwater flows may result in marked changes in temperatures and reduction in dissolved oxygen levels, factors which are often the cause of fish die-off (Phan-Van et al., 2008), degraded estuarine habitats (Gillanders & Kingsford,

2002), and changes in general community composition such as phytoplankton, crustaceans and fish (Jassby et al., 1995; Loneragan & Bunn, 1999; Pierson et al., 2002). For some commercially important estuarine species a reduction of large flow events has been found to impact negatively on catch levels (Meynecke et al., 2006).

4.5 CONCLUSION

This study has indicated considerable interannual variability in the timing of successful spawning with implications for recruitments, and provides evidence that recruitment success of black bream is significantly influenced by environmental factors. Freshwater inflow is probably a major factor influencing spawning success of black bream, and also important determinant of distribution of fish eggs and larvae in estuarine environments (Nicholson et al., 2008). Since the estuarine environment is variable and unpredictable, the prolonged spawning period is particularly important to deal with instability of the environment in order to minimize recruitment failure. A longevity of this species (Sarre & Potter, 2000) increases the number of spawning seasons of an individual fish providing the population with resilience against recruitment variability.

CHAPTER 5

Feeding Ecology of Black Bream in Tasmanian Estuarine Waters

5.1. INTRODUCTION

Estuaries contain a variety of habitat types, supporting productive biological communities (Faria et al., 2006), and providing important nursery grounds for many fish and crustacean species (Elliott & McLusky, 2002). Estuarine environments are characterised by marked seasonal and/or regional fluctuations in abiotic conditions, such as salinity, temperature and turbidity due to influences of freshwater inflows (Bennett & Branch, 1990; Kimmerer, 2002) causing temporal and spatial changes in invertebrate communities (Miller & Dunn, 1982). Such changes would be expected to be reflected in site- and temporal specific differences in the dietary composition of estuarine-dependent fish.

The composition of the diet reflects the distribution, behaviour and morphological adaptation of fish, and is dependent on the availability of prey taxa and primary habitats used for foraging (Taylor et al., 2006). As such, studies of feeding habits provide insights into many aspects of the biology, ecology and behaviour of fish (Sá et al., 2006).

The estuarine resident fish fauna of temperate Australia is largely comprised of small and short lived species; however, the black bream, *Acanthopagrus butcheri*, is an exception, growing to relatively large sizes and living for 30 or more years (Young & Potter, 2002). This species is endemic to temperate Australia, occurring between Shark Bay in Western Australia and southern New South Wales, including Tasmania (Gomon et al., 1994), and is the subject of major recreational and commercial fisheries throughout its distributional range. Previous studies have shown the species to be an opportunist, feeding mainly on molluscs, crustaceans and plant material, and the species has shown ontogenetic changes in diets to reduce intraspecific competition with an increase in amounts of plant material consumed as fish grow (Thomson, 1957; Wallace, 1976; Sarre et al., 2000; Benjamin et al., 2007). Such flexibility has

undoubtedly contributed to the success of this species in estuarine environments, where invertebrate communities may change dramatically in space and time (Miller & Dunn, 1982).

Although the dietary compositions of mainland Australian populations of black bream have been well documented, no similar studies have been undertaken in Tasmania. The specific purpose of this study was to examine how feeding is influenced by seasonal, regional, and ontogenetic factors and to compare these findings with other populations of black bream throughout its distributional range.

5.2. MATERIAL & METHODS

5.2.1. Sampling regime

Black bream were collected during day light hours from the Little Swanport Estuary (LSP), Swan River (SR) and North West Bay River (NWR) ($43^{\circ} 01'S$ and $147^{\circ} 16'E$) (Fig. 5.1) using gillnet, beach seine, or rod and line-fishing (also see Chapter 2 for further details of the sampling methods and study areas). Sampling was conducted seasonally between the winter of 2004 and autumn of 2006 at the upper, middle and lower estuary regions of the Little Swanport Estuary and Swan River (Fig. 5.1). Fish were collected from the North West Bay River in the summers of 2004/05 and 2005/06. Since black bream were only found around submerged dead trees near the river mouth in the North West Bay River, samples were collected from a single site. After capture the fish were immediately euthanased using AQUI-S (anesthesia), held on ice and transported to the laboratory for examination.

5.2.2. Feeding periodicity

During the summer and winter of 2005, gill net sampling was conducted over a twenty-four hour period in the middle estuary of the Little Swanport Estuary in order to establish diurnal

feeding periodicity. Gill nets were set every three to four hours for 15 minutes and were reset until at least two black bream were captured for each time period. Samples were immediately euthanased, held on ice and transported to the laboratory for examination.

5.2.3. Laboratory analysis of diet contents

Each fish was measured for fork length (FL) to the nearest 1 mm, weighed to the nearest 1 g. (wet weight, WW), and the contents of whole digestive tract were removed and the total weight of the dietary contents measured to the nearest 0.1 g (total wet gut contents weight, TGW) and then stored in 70 % ethanol. Empty digestive tracts were noted and discarded. The bait used for line-fishing was removed before weighing and if bait was the only item in the gut, the gut was considered empty. The gut content index (GCI) was calculated using the following equation (Hyslop, 1980);

$$\text{GCI (\%)} = \text{TGW} / \text{WW} \times 100.$$

GCIs were compared between the study estuaries and seasons using the Scheirer-Ray-Hare test (non-parametric two-way ANOVA). The Kruskal-Wallis test (non-parametric one-way ANOVA) was used to examine differences in the gut content index (GCI) over 24 hours. Empty guts were included to calculate GCI.

Gut contents of each fish were examined under a dissecting microscope at $\times 6-50$ magnification. Dietary items were sorted, identified to species wherever possible, and counted. If dietary items were not whole, numbers were based on countable parts, such as operculum, carapace, legs and claws. Items that could not be identified to species were classified to the lowest possible taxonomic level. After sorting and identification, dietary items were rinsed with fresh water, dried with a paper towel and then weighed to the nearest 0.01 g. Four different indices were used to describe the gut contents; percentage by weight (%W);

percentage frequency of occurrence (%F); percentage by number (%N); and index of relative importance (IRI) (Pinkas et al., 1971; Hyslop, 1980). Since magnoliophytes and algal material could not be counted, the percentage by number and index of relative importance for those dietary items were not calculated. Percentage by weight was obtained by dividing the total weight of a dietary item or category by the total weight of all dietary items multiplied by 100. Percentage frequency of occurrence was calculated by dividing the number of guts containing a dietary item or category by the total number of non-empty guts, multiplied by 100. Percentage by number was calculated by dividing the total number of dietary items or prey categories by the total number of all prey items, multiplied by 100. An index of relative importance (IRI) of each dietary item is a combination of the previous three measures calculated using following the equation;

$$\text{IRI} = (\%W + \%N) \times \%F$$

The IRI of dietary items in the gut contents of black bream from the North West Bay River was not calculated due to the small sample size.

5.2.4. Ontogenetic variation in dietary composition

In order to examine possible changes in diet with size, dietary items from each of the studied estuaries were pooled and the mean percentage weight (%W) of major dietary categories were calculated for fish sizes <50 mm, 50-99 mm, 100-149 mm, 150-199 mm, 200-249 mm, 250-299 mm and >300 mm. For this analysis, weights of items which made a relatively small contribution and were closely related (e.g. same class) were combined. The mean percentage weights were transformed by $\log(x+1)$, and subjected to classification analysis to explore the extent of any ontogenetic changes in the dietary composition. Classification, which was derived from the Bray-Curtis dissimilarity matrix and used cluster analysis with group average

linking, was performed on the log transformed mean percentage dietary data using Primer 5 (Clarke & Warwick, 1994).

5.2.5. Multivariate analyses

The dietary compositions were compared between estuaries (Little Swanport Estuary vs Swan River), regions (upper vs middle vs lower) and season (spring vs summer vs autumn vs winter). Since sample sizes were small for some seasons, especially winter, seasonal data were combined across the two years. The percentage weight of the dietary items were transformed to $\log(x+1)$ and then subjected to non-metric multidimensional scaling (MDS) derived from the Bray-Curtis dissimilarity matrix to describe similarities in diets between estuaries, regions and season. Two-way analysis of similarities (ANOSIM) based on the R statistic using ranks of Bray-Curtis dissimilarities were employed to test the hypothesis of no differences in the composition of the diets among seasons, regions and estuaries. Similarity percentages analysis (SIMPER) was used to determine the contribution of dietary items and categories to the dissimilarities (Clarke, 1993). Since there were no seasonal dietary data from the North West Bay River, this area was excluded from these analyses.

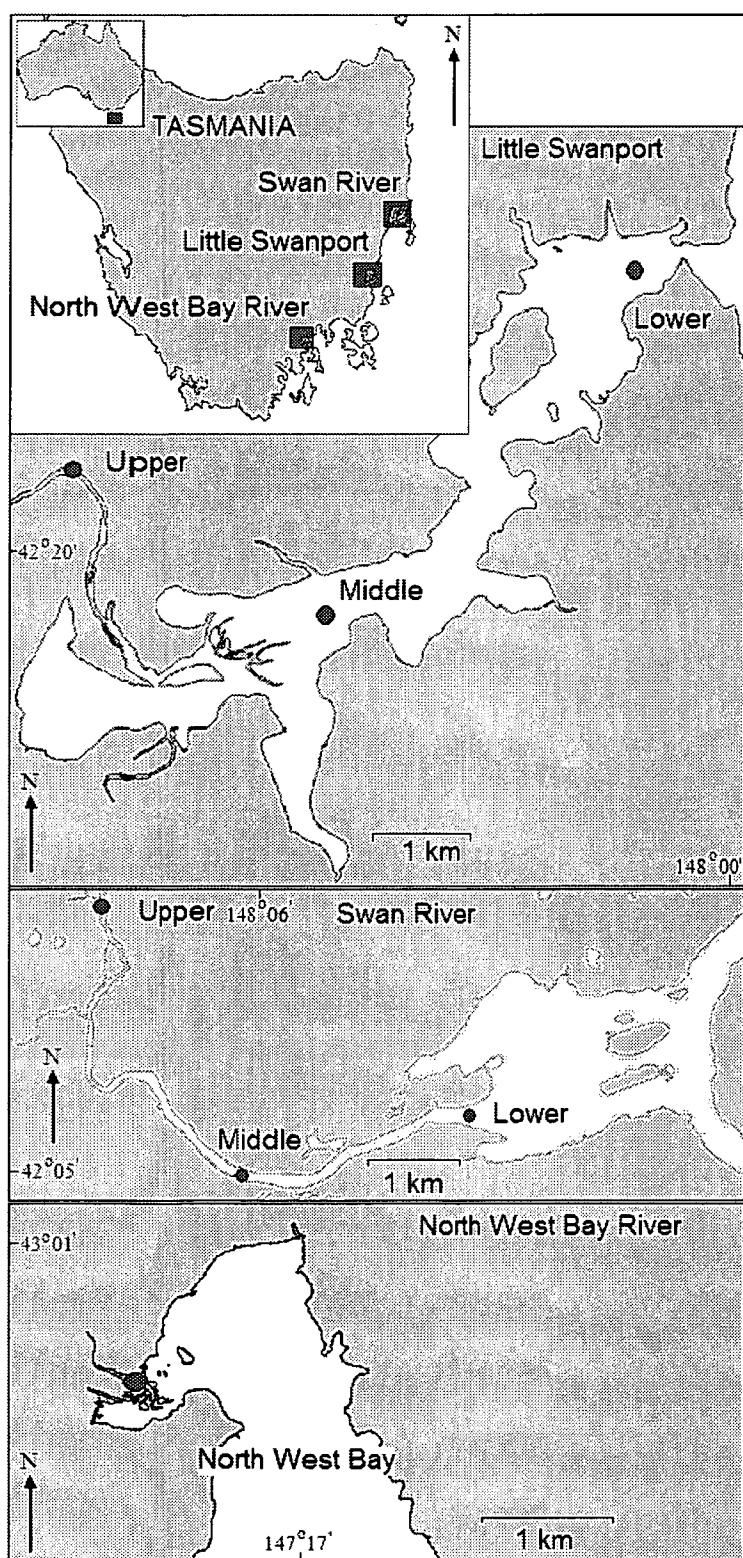


Figure 5.1 Study locations. Sampling sites are indicated by the enclosed circles.

5.3. RESULTS

5.3.1. Seasonal variation of feeding activity

A total of 1,180 fish (Little Swanport Estuary: N = 538, mean FL = 189 mm, range 19-395 mm; Swan River: N = 642, mean FL = 228, range 61-403 mm) were examined in the two years of sampling; 641 individuals (58%) contained food in their guts and the remainder (42%) were empty.

In the Little Swanport Estuary, the proportion of fish with empty guts fluctuated between about 25 and 60% and, although there was a tendency for proportions to be relatively low during summer, no clear seasonal pattern was apparent. The proportion of fish with empty guts was highest in the upper site with over 30% of fish caught being empty. By contrast, the proportion of fish with empty guts from the Swan River generally increased over the study period, from less than 25 to over 75%, with well over half of all fish examined having empty guts from autumn 2005 onwards. The proportion of fish with empty guts (>40%) was also highest in the upper site of the Swan River.

The feeding activity in the Little Swanport Estuary and Swan River showed marked differences in GCI values, with consistently higher values for the Little Swanport Estuary and lower values in the second year in both locations (Fig. 5.2). Peak values in the Swan River were generally one half to one third of corresponding levels for the Little Swanport Estuary. The mean GCI in the Little Swanport Estuary increased progressively from 1.4 in the winter of 2004 to 2.1 in the summer of 2004/05 and remained at this level in autumn 2005, before falling sharply in winter of 2005. GCI values then increased to a peak of 2.2 during the summer of 2005/06 (Fig. 5.2). By contrast, mean GCIs for the Swan River were generally consistent across all seasons in the first and second year, although values in the second year

were substantially lower than those for the preceding 12 month period. The Scheirer-Ray-Hare test indicated that differences in feeding intensity were significant between estuaries ($F_{1,1164}$, $P < 0.001$) and seasons ($F_{7,1164}$, $P < 0.001$) and also indicated a significant interaction between estuary and season ($F_{7,1164}$, $P < 0.01$).

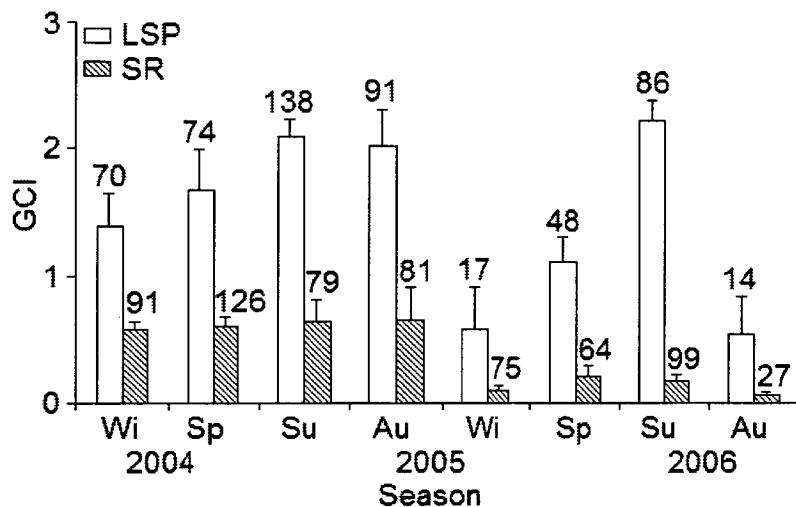


Figure 5.2 Seasonal variation of feeding activity (mean GCI+S.E.) of black bream in the Little Swanport Estuary (LSP) and Swan River (SR) (Data were pooled for all sites in each estuary). Numbers above each histogram represent sample size. Wi = winter, Sp = spring, Su = Summer, Au = Autumn.

5.3.2. Diurnal feeding activity

The 24-h cycle sampling performed in January (summer) and June (winter) indicated that black bream fed intensively prior to sunset, with GCI values declining during the night and morning periods (Fig. 5.3). The pattern of empty guts followed an inverse trend to GCI, with an increase in the proportion of empty guts during late-morning to early afternoon and a decrease of empty guts in the evening. The GCI values over the 24 h sampling period were significantly different (Kruskal-Wallis test, Summer: $df = 8$, $P < 0.001$; Winter: $df = 7$, $P < 0.001$). There was no significant correlation between GCI values and the tide height in each of the 24-h cycles (Spearman correlation, $P > 0.05$).

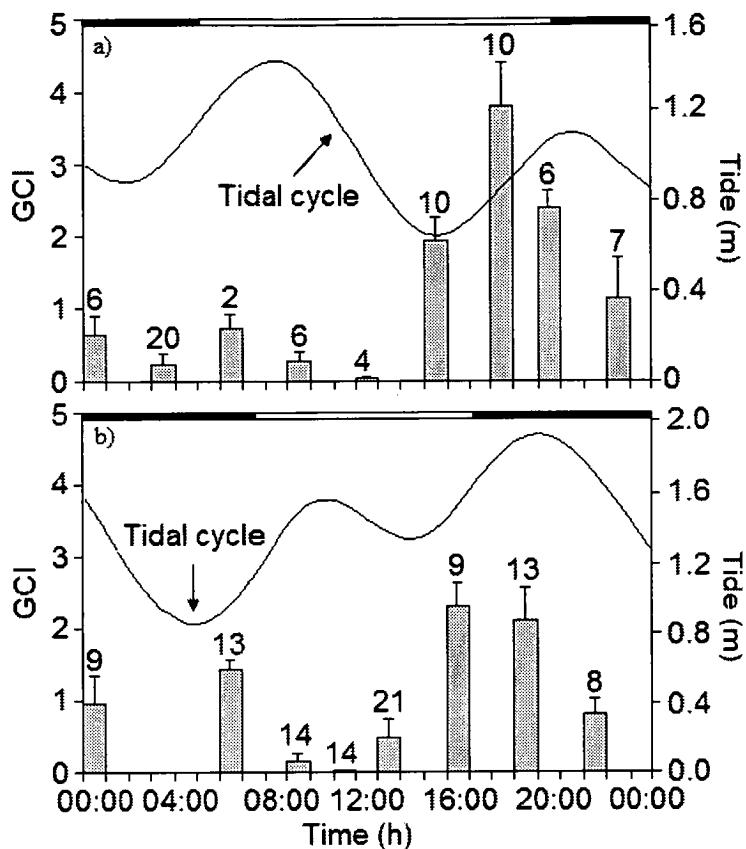


Figure 5.3 Diurnal pattern of feeding activity (mean GCI+S.E.) (vertical bars) of black bream in the Little Swanport Estuary, over 24-h cycles performed in a) January 2005 and b) June 2005. Tidal cycle is indicated. Numbers represent the sample size and horizontal black and white bars indicate periods of night and day times, respectively.

5.3.3. Diet composition

The diet consisted of a wide diversity of prey types, dominated by benthic invertebrates and algae, with 60 prey taxa identified (Table 5.1). Molluscs were clearly the dominant food group in the Little Swanport Estuary scoring the highest values of %W and %N. Crustaceans (mostly decapods and amphipods) were the most frequently consumed major prey group, being recorded in over 50% of guts with food, followed by molluscs (41%), algae (34%), magnoliophytes (11%) and teleosts (3%). Amongst the crabs, *Paragrapusp gaimardii* and *Amarinus laevis* were the most important contributors to the weight of diet and frequency of occurrence, while amphipods made the greatest contribution in terms of numbers. Amongst

the molluscs, gastropods especially *Zeacumantus diemenensis*, *Salinator solida* and *Tatea rufilabris*, were more important than bivalves, in particular by numbers. Fish, fish eggs and scales and crab zoea along with a variety of other invertebrates were also consumed but represented very minor components of the diet (Table 5.1).

The most frequently consumed item in the Swan River was seagrass (48%), followed by crustaceans (42%), algae (38%), and molluscs (23%). The seagrass, *Ruppia megacarpa*, and crab, *Amarinus laevis*, were the most important food items, accounting for 38% and 27% by occurrence and 16% and 30% by weight, respectively. Numerically the gastropods, *Salinator solida* and *Tatea rufilabris* and bivalve, *Xenostrobus inconstans* were important species, constituting 37%, 26% and 11% of the total number of prey items respectively, although due to their small sizes, they did not contribute greatly by weight (Table 5.1).

Algal material was very abundant in the gut contents of black bream from the North West Bay River, being found in 53% of the guts with food and accounting for 68% by weight. Amphipods were the second most frequent and most numerous ingested taxon, contributing 48% and 55%, respectively. The gastropod *Salinator solida* was the only molluscs species consumed by black bream in this estuary, occurring in 23% of the guts and contributing 15% by weight, and 32% by number (Table 5.1).

Table 5. 1 Percentage weight (%W), percentage of frequency (%F) and percentage number of prey items found (%N) in the diets of black bream.

	Little Swanport Estuary N = 396			Swan River N = 272			North West Bay River N = 60		
	%W	%F	%N	%W	%F	%N	%W	%F	%N
Algae	35.1	33.6	-	31.8	37.9	-	73.5	58.3	-
Filamentous algae 1	7.9	8.6	-	17.0	11.1	-	0.1	1.7	-
Filamentous algae 2	4.3	4.3	-	4.6	13.4	-	5.3	3.3	-
<i>Chaetomorpha sp</i>	4.0	3.5	-	0.7	1.5	-			
<i>Cladophora sp</i>	10.8	7.8	-	1.5	4.6	-			
<i>Gracilaria secundata</i>	0.2	2.5	-	1.6	6.9	-			
Algal material	7.9	12.4	-	6.4	1.8	-	68.1	53.3	-
Magnoliophyta	3.7	10.9	-	22.3	48.3	-	0.5	3.3	-
<i>Zostera muelleri</i>	3.5	10.9	-	5.9	18.4	-	0.5	3.3	-
<i>Ruppia megacarapa</i>	0.1	0.3	-	16.3	37.9	-			
<i>Halophila australis</i>	0.1	0.1	-	0.1	0.4	-			
Crustaceans	21.2	52.3	39.0	32.1	41.5	21.5	10.2	51.8	67.6
Decapoda	19.3	37.1	21.4	30.9	30.1	8.6	0.6	3.3	11.9
<i>Amarinus laevis</i>	8.1	11.6	0.7	30.1	25.4	2.6			
<i>Carcinus maenas</i>	0.8	2.0	0.1	0.6	1.1	0.1			
<i>Paragrapuspus gaimardi</i>	9.1	8.1	0.4						
<i>Bifurrius ceramicus</i>	1.1	0.3	0.2	0.1	1.5	0.1			
<i>Macrobrachium sp</i>	0.1	1.8	0.1						
Crab zoea	0.1	3.8	19.9	0.1	2.2	5.8	0.6	3.3	11.9
Amphipoda	1.5	18.9	16.9	0.8	8.8	12.5	9.4	48.3	55.1
<i>Ampithoid sp</i>	0.1	0.8	0.7	0.1	0.7	0.1	0.1	1.7	0.2
<i>Byblis sp</i>	0.1	0.1	0.4	0.1	0.4	0.5	0.4	1.7	2.7
<i>Corophium sp</i>							2.2	21.7	9.3
<i>Gammarella sp</i>	0.1	1.5	1.1				0.7	8.3	6.9
<i>Maera sp</i>	0.3	7.1	6.1	0.1	2.2	1.8	3.6	23.3	30.5
<i>Melita sp</i>	0.5	9.6	5.9	0.4	5.9	9.4	1.4	13.3	4.0
<i>Orchestia sp</i>	0.2	2.5	2.5	0.1	1.1	0.5	0.6	5.0	1.5
Copepoda	0.1	0.3	0.1	0.1	0.4	0.1	0.2	3.3	0.6
Cyclopoid copepod	0.1	0.3	0.1	0.1	0.4	0.1			
Harpacticoid copepod							0.2	3.3	0.6
Mysidacea				0.1	0.7	0.1			
<i>Paramesodops is rufa</i>				0.1	0.7	0.1			
Isopoda	0.2	1.8	0.4						
<i>Zuzara venosa</i>	0.2	1.8	0.4						
Ostracoda	0.1	0.5	0.1						
Unidentified sp	0.1	0.5	0.1						
Insecta	0.3	1.8	0.3	0.3	1.8	0.7	0.5	1.7	0.2
<i>Pontomyia sp</i>	0.1	0.8	0.1	0.1	0.7	0.1	0.1	0.1	0.1
Terrestrial insect	0.1	0.8	0.1	0.1	0.7	0.1	0.4	1.7	0.1
Caddisfly larvae	0.1	0.3	0.1	0.1	0.4	0.5			

Table 5.1 (Continued)

	Little Swanport Estuary			Swan River			North West Bay River		
	<i>N = 369</i>			<i>N = 272</i>			<i>N = 60</i>		
	%W	%F	%N	%W	%F	%N	%W	%F	%N
Mollusca	37.6	40.9	60.7	11.2	22.8	74.9	14.8	23.3	32.0
Bivalvia	11.3	17.4	12.5	1.6	7.0	11.3			
<i>Dosinia coerulea</i>	2.3	2.5	1.3						
<i>Fulvia tenuicostata</i>	0.7	0.5	0.2						
<i>Modiolus albicostatus</i>	2.1	1.5	0.8						
<i>Modiolus areolatus</i>	1.9	1.5	0.8						
<i>Xenostrobus inconstans</i>	1.5	7.6	8.4	1.6	7.0	11.3			
<i>Callista diemenensis</i>	1.1	0.3	0.2						
<i>Venerupis anomala</i>	0.6	1.0	0.2						
<i>Tellina deltoidalis</i>	0.3	0.3	0.2						
<i>Mytilus edulis</i>	0.3	0.3	0.1						
<i>Crassostrea gigas</i>	0.1	0.5	0.1						
<i>Mactra rufescens</i>	0.3	0.5	0.1						
<i>Tawera lagopus</i>	0.1	0.3	0.1						
Gastropoda	26.3	26.5	47.0	9.6	14.7	63.6	14.8	23.3	32.0
<i>Zeacumantus diemenensis</i>	12.3	6.6	13.8						
<i>Astrocochlea brevis</i>	0.8	0.8	0.2						
<i>Astrocochlea concamerata</i>	0.2	0.5	0.2						
<i>Clanculus piebejus</i>	1.4	2.0	0.9						
<i>Clanculus undatus</i>	1.7	3.8	1.2						
<i>Clanculus alioystii</i>	0.7	0.8	0.5						
<i>Clanculus spp</i>	3.4	3.3	2.6	3.5	0.4	0.1			
<i>Salinator solidus</i>	2.9	8.6	14.9	3.4	9.9	37.1	14.8	23.3	32.0
<i>Tatea rufilabris</i>	2.7	7.6	12.5	2.7	9.6	26.4			
<i>Siphonaria sp</i>	0.2	0.3	0.2						
Annelida	0.6	0.5	0.2	0.8	0.7	0.8			
Polychaeta	0.6	0.5	0.2	0.8	0.7	0.8			
Syllid spp	0.6	0.5	0.2	0.8	0.7	0.8			
Teleostei	1.5	5.5	1.0	1.5	3.7	2.1	0.5	3.3	0.2
<i>Atherinosoma microstoma</i>	1.0	2.5	0.1	1.2	1.8	0.1			
<i>Vanacampus phillipi</i>	0.2	0.5	0.1						
<i>Venericardia bimaculata</i>	0.1	0.5	0.1						
<i>Pseudophritis urvilli</i>							0.4	1.7	0.1
Fish egg	0.1	0.3	0.5	0.1	0.7	0.5	0.1	1.7	0.1
Fish scales	0.1	1.3	0.2	0.2	1.5	1.5			

5.3.4. Relative importance of dietary items

Zeacumantus diemenensis was the most preferred prey species in the Little Swanport Estuary, but was not recorded in the diet of fish from the Swan River. *Salinator solidus*, *Tatea rufilabris*, *Amarinus laevis* and *Xenostrobus inconstans* were highly preferred by black bream in both locations (Fig. 5.4). Furthermore, crab zoea, *Paragrapus gaimardii*, *Melita* sp. and *Maera* sp. in the Little Swanport Estuary and *Melita* sp. in the Swan River appeared to play an important secondary role in the diets.

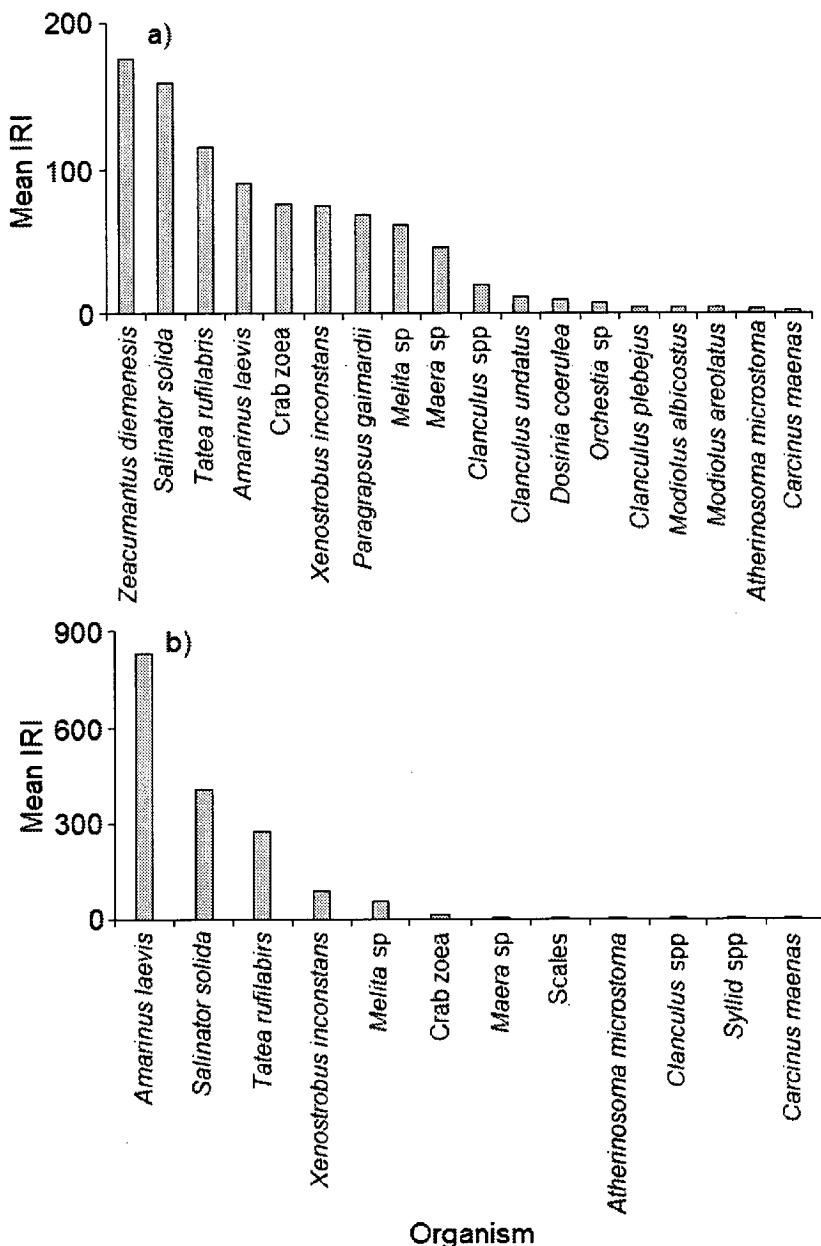


Figure 5.4 Diet preference of black bream by IRI values for prey organisms for a) the Little Swanport Estuary and b) Swan River. Note: y-axis scales are different between (a) and (b).

5.3.5. Ontogenetic change in diet

In the Little Swanport Estuary, amphipods were clearly the most important prey in the smallest length class (<50 mm), contributing 43% of the total gut content weight (Fig. 5.5). *Salinator solida* and *Tatea rufilabris* were the second (18%) and third (13%) most important

prey species in this size class. Amphipods and *Salinator solida* were also important prey items in the 50-149 mm length classes, though the proportion that these prey items represented decreased progressively in the size classes larger than 150 mm. In contrast, algae and seagrass became more dominant with increasing size, rising from approximately 10% in size groups less than 150 mm to over 35% in the larger size groups. The contribution made by decapods also increased with size. Collectively, algae, seagrass and decapods contributed over 50% of the diet in length classes greater than 150 mm and made up over 80% of the total weight of the gut contents in the largest length classes.

The diet by size class for the Swan River revealed a similar pattern (Fig. 5.5). Amphipods and bivalves were predominant prey items in the 50-99 mm length class, in conjunction with relatively large quantities of *Tatea rufilabris* and *Salinator solida*. The proportions of amphipods and bivalves consumed declined dramatically from the 50-99 mm size class to the 100-149 mm class; from 28 to 6% and 36 to 14% of the total gut content weight, respectively. The proportion of *Tatea rufilabris* and *Salinator solida* also decreased between these length classes, but increased slightly in the 150-199 mm size group. The proportion of algae, seagrass and decapods increased with increasing fish size, accounting for over 60% of the total diet weight in all size classes >200 mm.

The diet of the 50-99 mm length class in the North West Bay River was dominated by *Salinator solida* (53% of the total diet weight). Although fish in length classes between 100 and 249 mm also consumed this species, it represented only small proportion of gut contents. Amphipods were only found in the 50-99 and 150-199 mm length classes. The diets of fish >150 mm consisted mainly of algae, with values exceeding 80% in each of the size classes, though these findings were based on small sample sizes.

Cluster analysis based on the percentage by weight of major dietary groups and items in the two locations showed a clear separation of estuaries and size classes (Fig. 5.6). Generally the smaller size classes (<99 mm) were more similar regardless of estuary whereas the larger size classes separated out by estuary, with the exception of the largest size class of fish in the Little Swanport Estuary showing greater similarity with the larger fish in the Swan River than with smaller fish in the Little Swanport Estuary.

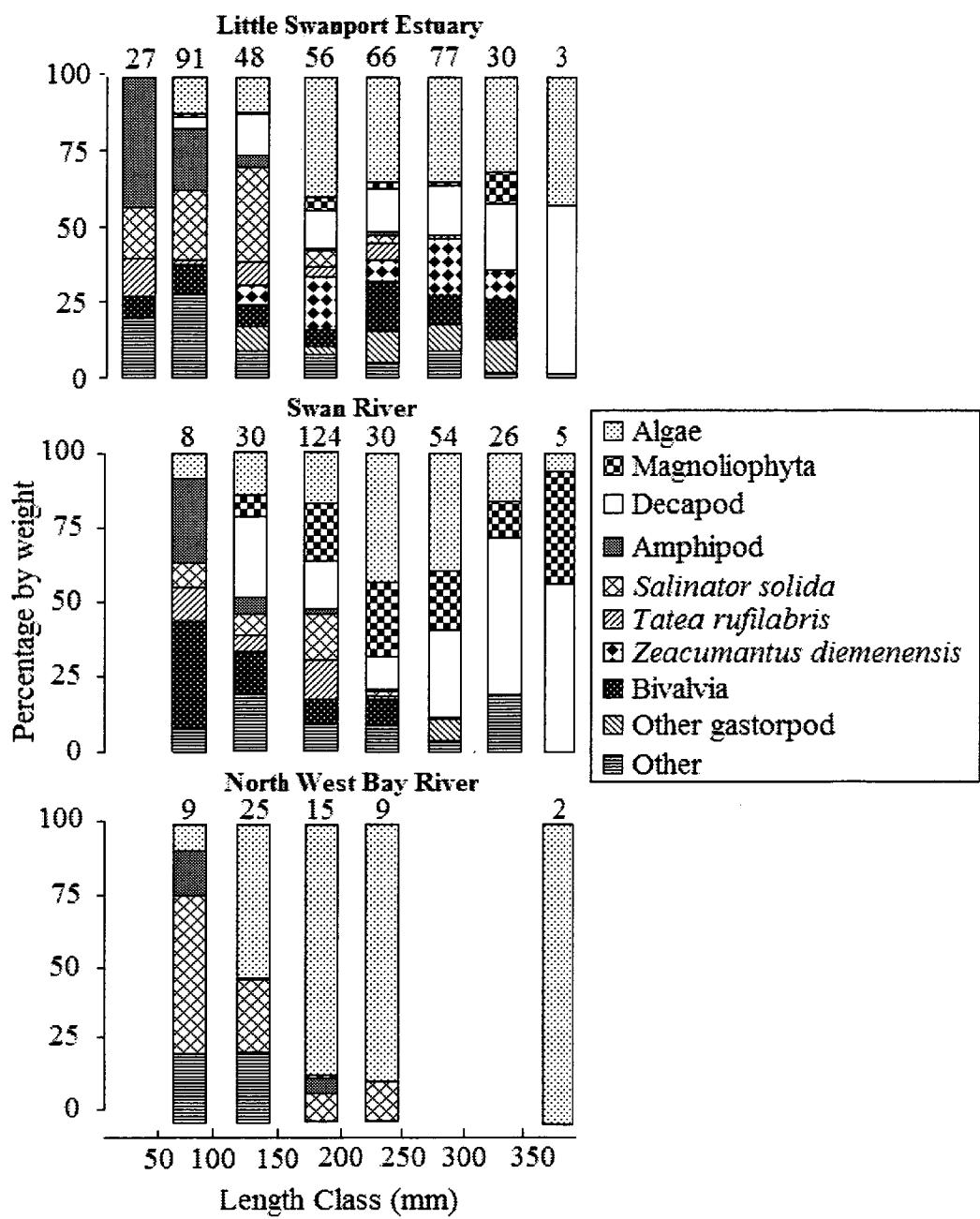


Figure 5.5 Percentage by weight of the different dietary items for 50 mm fork length classes of black bream caught from the Little Swanport and Swan River between the winter 2004 and autumn 2006, and from the North West River during the summer of 2004/05 and 2005/06. Algae include all algal materials. Numbers above each histogram represent sample size.

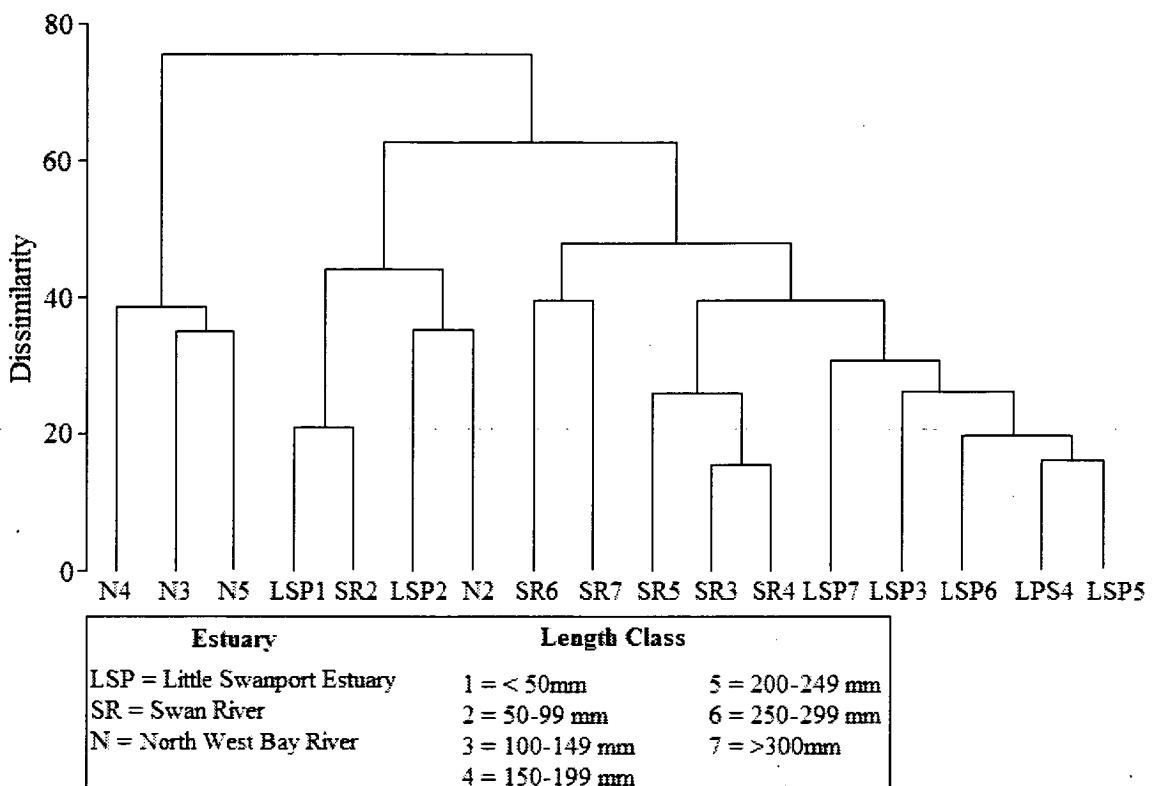


Figure 5. 6 Dendrogram of the cluster analysis for ontogenetic dietary changes of black bream in the three estuaries.

5.3.6. Diet composition by site, season and estuary

According to the ordination of the dietary data of all size classes in the Little Swanport Estuary and Swan River, each of the four samples from fish caught in the upper region in both locations tended to be grouped together (Fig. 5.7a & c). The sample obtained from fish caught in the lower estuary of the Little Swanport Estuary during summer was closely associated with samples from the middle estuary region of the same estuary (Fig. 5.7a & b). The samples from the lower region of the Swan River obtained during the spring and those from the middle region obtained during winter were more closely associated with the upper region group (Fig. 5.7c & d). The samples from each of the seasons in both estuaries tended to be widely distributed throughout the plot suggesting no close association with the season (Fig 5.7b & d). The dietary composition was significantly different among the sites ($R = 0.549, P < 0.05$), but

not seasons ($R = 0.059, P > 0.05$) in the Little Swanport Estuary, while there were no significant differences among the sites ($R = 0.141, P > 0.05$) or seasons ($R = 0.204, P < 0.05$) in the Swan River. In the case of the Little Swanport Estuary, the dietary composition of black bream in the upper site was significantly different from those in the middle ($R = 0.854, P < 0.05$) and lower sites ($R = 0.813, P < 0.05$), but there was no significant difference between the diet composition of fish in the lower and middle sites ($R = 0.167, P > 0.05$).

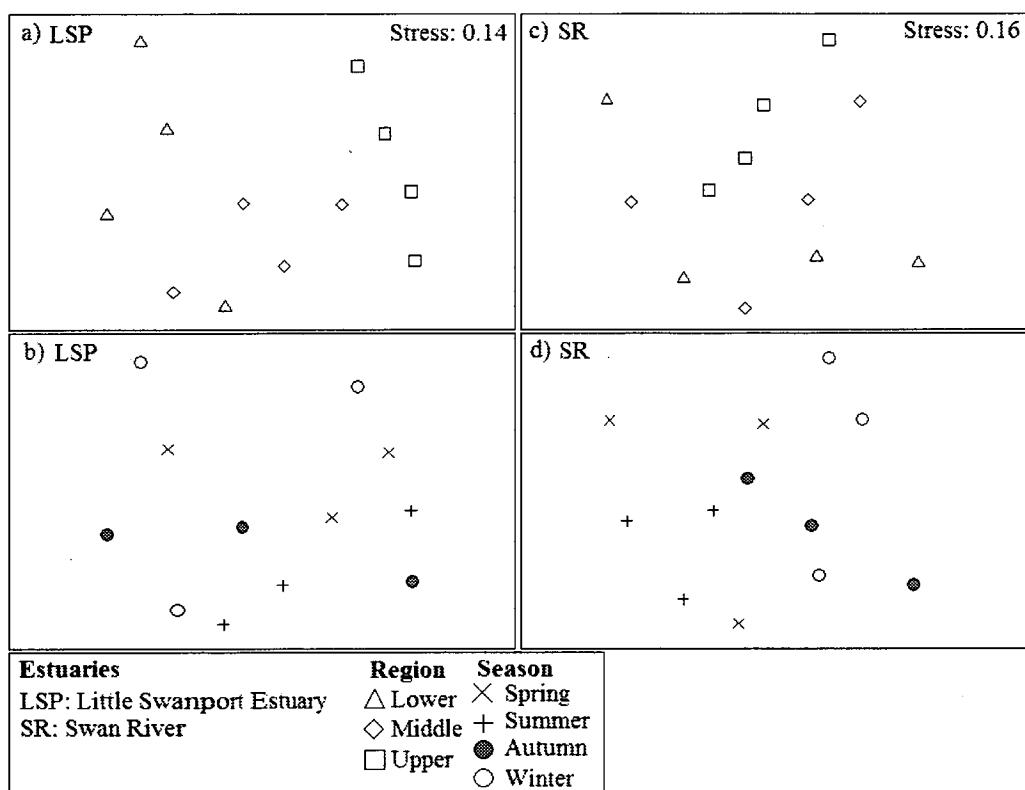


Figure 5.7 MDS plots based on the mean percentage weight of different dietary items of black bream for four seasons in the Little Swanport Estuary (a & b) and Swan River (c & d), coded separately for a & c region and b & d season.

Within the Little Swanport Estuary nineteen dietary items contributed 91% of the observed differences between the upper and middle regions, while twenty dietary items contributed 91% of the differences between the upper and lower estuary regions (SIMPER analysis, Table 5.2).

Amarinus laevis made the greatest contribution to the upper and lower estuary difference

while *Zeacumantus diemenensis* contributed most between the upper and middle estuary regions. Six dietary items each accounted for more than 5% of the observed differences between the upper and middle and upper and lower estuary regions. The dietary composition in fish collected from the upper estuary was characterised by higher abundances of *Amarinus laevis*, filamentous algae 1, *Cladophora* sp, *Salinator solidus* and *Tatea rufilabris* than in the other regions. Furthermore, while *Salinator solidus* and *Tatea rufilabris* were not found in the diets of black bream caught from the lower estuary, *Chaetomorpha* sp., *Clanculus* sp. and *Zeacumantus diemenensis*, which were abundant in the diet of fish from the lower estuary, were not recorded in fish from the upper estuary.

Table 5.2 SIMPER analysis by weight showing the 10 dietary items contributing most to the differences between a) the upper and middle regions, b) the upper and lower regions of the Little Swanport Estuary.

a)

Dietary items	Average abundance			Cumulative
	Upper	Middle	Contribution (%)	Contribution (%)
<i>Zeacumantus diemenensis</i>	0.00	21.77	11.05	11.05
<i>Parapgrapsus gaimardii</i>	0.24	14.70	7.82	18.87
Algal material	4.15	14.92	7.39	26.27
Filamentous algae 1	13.37	1.52	6.94	33.20
<i>Amarinus laevis</i>	32.03	6.90	6.52	39.72
<i>Cladophora</i> sp	8.48	1.67	5.03	44.75
<i>Salinator solidus</i>	6.95	3.47	4.93	49.68
<i>Zostera mulleri</i>	0.12	3.98	4.92	54.60
<i>Tatea rufilabris</i>	6.74	3.59	4.85	59.45
Filamentous algae 2	6.13	1.55	4.40	63.86

b)

Dietary items	Average abundance			Cumulative
	Upper	Lower	Contribution (%)	Contribution (%)
<i>Amarinus laevis</i>	32.03	4.93	17.99	17.99
<i>Chaetomorpha</i> sp	0.00	12.70	11.25	29.24
<i>Cladophora</i> sp	8.48	17.04	8.90	38.14
Filamentous algae 1	13.37	3.43	7.94	46.08
<i>Parapgrapsus gaimardii</i>	0.24	8.05	7.52	53.60
<i>Clanculus</i> sp	0.00	13.71	5.31	58.91
<i>Salinator solidus</i>	6.95	0.00	4.79	63.70
<i>Tatea rufilabris</i>	6.74	0.00	4.48	68.18
<i>Zeacumantus diemenensis</i>	0.00	8.37	4.40	72.57
<i>Dosinia coerulea</i>	0.07	7.12	4.26	76.83

Each of the dietary samples from the different sites in the four seasons from the Little Swanport Estuary and Swan River formed discrete groups on the MDS plot (Fig. 5.8), and ANOSIM demonstrated that the dietary composition differed significantly between estuaries ($R = 0.708$, $P = 0.029$). SIMPER analysis showed that twenty-five dietary items contributed 91% of this observed difference (Table 5.3). *Amarinus laevis* and *Ruppia megacarpa* made the largest contribution to the observed difference, followed by *Salinator solidus* and *Zostera muelleri*. The Little Swanport Estuary was characterised by relatively higher abundances of *Zeacumantus diemenensis*, *Paragrapsus gaimardi* and *Cladophora* sp in the diets while the Swan River was represented by relatively high abundances of *Ruppia megacarpa* and *Amarinus laevis*.

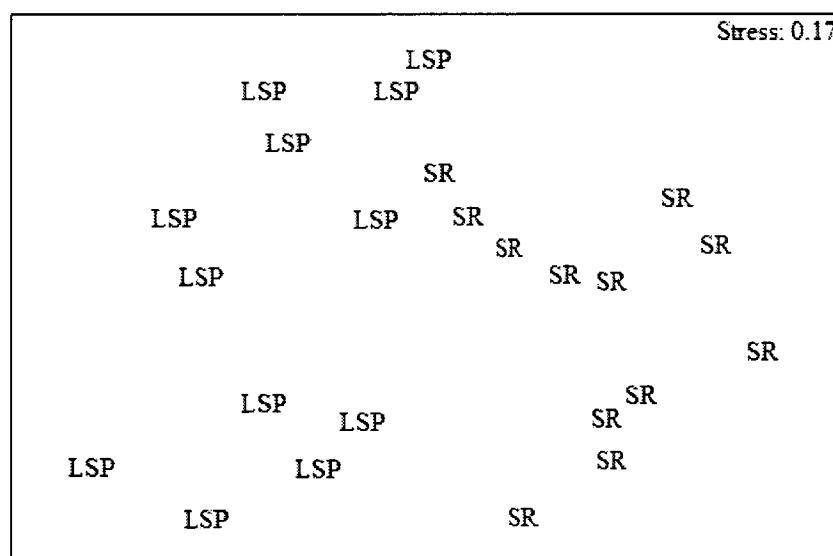


Figure 5. 8 MDS plots comparing the mean percentage weight of different dietary items of black bream of the three different sites at four seasons between the Little Swanport Estuary (LSP) and Swan River (SR).

Table 5.3 SIMPER analysis by weight showing the 25 dietary items contributing most to the differences between the Little Swanport Estuary (LSP) and the Swan River (SR).

Dietary items	Average abundance		Contribution (%)	Cumulative Contribution (%)
	LSP	SR		
<i>Amarinus laevis</i>	14.62	26.27	6.94	6.94
<i>Ruppia megacarpa</i>	0.01	14.51	6.94	13.58
<i>Salinator solidus</i>	3.47	9.69	6.45	20.03
<i>Zostera muelleri</i>	3.04	10.38	5.78	25.81
<i>Cladophora</i> sp	9.06	3.80	5.74	31.55
<i>Paragrapsys gaimardii</i>	7.66	0.00	5.58	37.14
Algal material	7.09	6.32	5.53	42.67
Filamentous algae 1	6.11	6.11	5.44	48.11
<i>Zeacumantus diemenensis</i>	10.05	0.00	5.31	53.42
<i>Tatea rufilabris</i>	3.44	4.48	4.73	58.15
Filamentous algae 2	2.67	4.14	4.44	62.59
<i>Chaetomorpha</i> sp	4.52	0.11	4.11	66.70
<i>Clanculus</i> sp	5.95	1.15	3.71	70.41
<i>Xenostrobus inconstans</i>	1.54	4.37	3.54	73.95
<i>Atherinosoma microstoma</i>	1.89	10.7	3.06	77.00
<i>Dosinia coerulea</i>	3.52	0.00	2.81	79.81
<i>Clanculus undatus</i>	1.32	0.00	1.93	81.74
<i>Gracilaria secundata</i>	0.21	0.46	1.34	83.08
<i>Modiolus albicostus</i>	0.98	0.00	1.26	84.34
<i>Melita</i> sp	0.35	0.18	1.18	85.52
<i>Carcinus maenas</i>	0.41	0.23	1.17	86.69
Polychaete worm	0.21	0.77	1.07	87.76
<i>Austrocochlea brevis</i>	0.90	0.00	1.04	88.81
<i>Clanculus plebejus</i>	0.74	0.00	1.00	89.81
<i>Modiolus areolatus</i>	0.87	0.00	0.97	90.78

5.3.7. Seasonal trend of plant material in the diet

In the Swan River, the proportion of guts containing plant material in each of the three regions exhibited the same seasonal trend, being highest in winter and falling to the lowest level in summer, before increasing slightly in autumn (Fig. 5.9). The seasonal pattern in proportion of plant material found in guts of black bream for the Little Swanport Estuary was less distinct though values generally decreased in summer and peaked in winter or autumn.

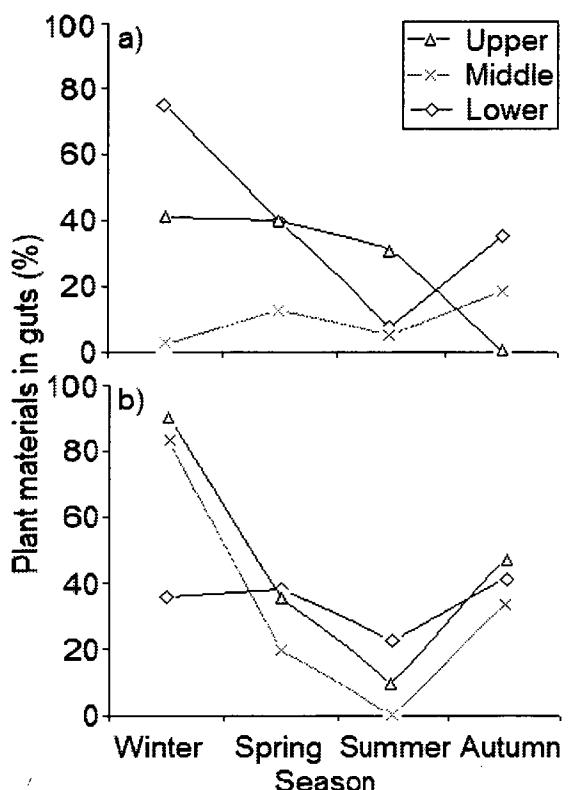


Figure 5.9 Seasonal change in the proportion of plant material in guts of black bream collected from three regions of the Little Swanport Estuary (LSP) and Swan River (SR).

5.4. DISCUSSION

5.4.1. Diet

Black bream were found to be a benthic omnivore, feeding on a variety of invertebrate prey including gastropods, bivalves, decapods and amphipods as well as seagrass and algae. These observations are consistent with previous studies on the species (Weng, 1971; Wallace, 1976; Sarre et al., 2000; Benjamin et al., 2007) as well as several other species of sparids (Beumer, 1978; Coetzee, 1986; Buxton & Clarke, 1989; Harrison, 1991). At the species level there were, however, differences in the composition of diets between estuaries, suggesting variability in prey abundance and availability between the systems. While small gastropods, *Salinator solida* and *Tatea rufilabris*, and the crab, *Amarinus laevis* played important roles in the diet of individuals from both estuaries, the Swan River was distinguished from the Little Swanport

Estuary by the relatively large amount of the seagrass *Ruppia megacarpa* in the diet. By contrast, the gastropod *Zeacumantus diemenensis* and crab *Paragrapus gaimardii* were relatively important items in diets of fish from the Little Swanport Estuary but were not recorded in fish sampled from the Swan River. Large numbers of *Zeacumantus diemenensis* were common in shallow waters of the middle estuary of the Little Swanport Estuary, but not in the Swan River (Sakabe personal observations), implying dietary flexibility necessary to exploit highly abundant resources available in the estuarine community.

As an opportunistic predator, black bream has the ability to utilise a variety of prey types. Such feeding flexibility is advantageous, enabling fish to switch between food sources if the relative abundance of the prey changes over time and in space. Feeding flexibility is particularly important in estuarine environments, where the abiotic conditions are unstable (Bennett & Branch, 1990) and there may be strong seasonal and/or annual fluctuations in the abundance of prey (Miller & Dunn, 1982). The structural morphology of the mouth and associated dentition represents an important adaptation for feeding. Black bream has a heterogeneous jaw dentition, which comprises six peg-like, bluntly-pointed incisors and four rows of molars with bluntly rounded crowns (Munro, 1949; Sarre et al., 2000), enabling the species to crush hard structures and allowing them to feed on a variety of invertebrate taxa.

Plant material was commonly present in the guts of adult fish, a phenomenon that has been reported in previous studies of the species (Thomson, 1957; Wallace, 1976; Sarre et al., 2000; Benjamin et al., 2007). Based on the observation that plant material appeared undigested in the stomach and intestine, Wallace (1976) hypothesised that it was ingested incidentally rather than consumed as an alternative dietary source. Elliott et al. (2007) on the other hand suggested that black bream may feed on the epifauna and periphyton associated with

macrophytes and algae. No data was available in this study to conclude whether the plant material, the attached bacteria, fungi or epiphytes actually contributed to energy uptake by this species. However, if plant material was simply taken incidentally with other prey, such large quantities of plant material in the absence of any obvious animal remains in many individuals would seem unlikely. Furthermore, as sparids possess the amylase required to digest the carbohydrates in plant material (Fernández et al., 2001), it is plausible that black bream are able to digest plants, and probably consume them as a secondary food source when more preferred prey taxa such as molluscs and crustaceans are not available. Further work is needed to elucidate the importance of plant material for this species.

Spatial variability in the composition of the diet within the Little Swanport Estuary was observed, with diets of fish from the upper estuary differing significantly to those from the middle and lower estuary, presumably reflecting differences in fauna assemblages throughout the estuary, and in particular within the upper estuary. Generally, invertebrate diversity decreases with decreasing salinity and increasing distance from the estuary mouth (Gaston et al., 1998; Giberto et al., 2004). In the middle and lower regions of the Little Swanport Estuary, salinities ranged between about 20 and 35 throughout the year, being less influenced by the effects of freshwater discharge than the upper estuary. Thus a wide variety of typically marine benthic invertebrate species, such as molluscs and decapod crustaceans characterised the diet of fish collected from these regions. In contrast, in the upper estuary where salinities varied between 0 and 34, invertebrate diversity was more limited to species capable of tolerating a wide range of salinities, for example *Macrobrachium* sp (shrimps) and *Amarinus laevis* (crabs), which were particularly abundant in the region (Smith, 1995, personal observation). The absence of regional differences in dietary compositions of black bream in the Swan River

may be explained by the fact that the sites sampled were in the upper estuary region and were more uniform in environmental conditions such as salinity and temperature and habitats, resulting in less variability in faunal community structure throughout the study area.

No significant seasonal differences were found in the overall composition of the diet within either estuary. This finding tends to indicate a lack of marked seasonality in the abundance of important prey taxa coupled with the fact that black bream feed on a wide range of prey species. Similarly, a lack of seasonality in diet of black bream from the Swan River, Western Australia was attributed to the fact that those benthic macroinvertebrates that underwent marked seasonal variations did not represent major components of the diet (Sarre et al., 2000). By contrast, Whitfield (1980) found that the diet of another sparid, *Rhabdosargus holubi*, switched from predominately epiphytic flora and fauna to benthic invertebrates when there was a dramatic decrease in the abundance of epiphytic flora and fauna resulting in seasonal variability in the diet compositions. Furthermore, the white seabream, *Diplodus sargus*, also showed marked seasonal variation in diets, feeding exclusively on algae during spring, algae, worms and amphipods during summer, and algae, barnacles and sea-urchins during autumn and winter (Figueiredo et al., 2005). The increased importance of urchins coincided with the peak in sea-urchin gonadosomatic index, implying that seabream selectively feed on sea-urchins when they are of higher nutritional value.

5.4.2. Seasonal and diel feeding activity

Feeding intensity varied seasonally for black bream from the Little Swanport Estuary, with highest GCI values during summer and lowest values during winter. By contrast, there was no clear seasonal pattern evident in the Swan River, influenced to some extent by the fact that the fish consumed large amounts of plant material. The noticeable increase observed in the

feeding intensity during spring to summer was probably linked to increased food availability with increasing water temperature and also coincided with gonad development in adults prior to and during the spawning period. Other estuarine-dependent species also show similar feeding patterns (Almeida, 2003).

Interestingly, this study indicated that GCI values in the Swan River were consistently lower than those in the Little Swanport Estuary and GCI values in the second year in both locations were consistently lower than those in the first year, except summer 2005/06 in the Little Swanport Estuary. These results reflect the higher proportions of fish with empty guts in the Swan River and in the second year in both locations. Since environmental conditions in the Swan River are more similar to the upper region of the Little Swanport Estuary, prey abundance and diversity throughout the Swan River are probably relatively low, resulting in the higher proportion of fish with empty guts.

Feeding activity in black bream was most intense in the afternoon prior to sunset, with a little evidence of night feeding activity. Although a strong diurnal pattern of feeding was observed, the role of the senses in prey capture is unclear. GCI trends observed during night time suggest that black bream possibly spend night to digest food and may rely heavily on visual cues to capture prey. Acoustic tracking data for adult fish tagged in the Little Swanport Estuary suggest that the species is more active during the daytime, with reduced movement from around sunset until dawn (Chapter 6). Conversely, Hindell (2007) and Hindell et al. (2008) suggested that black bream in the Gippsland Lakes, Victoria move from rivers to adjoining lakes at night to forage, although their hypothesis was based on movement data alone and they presented no empirical information on feeding activities.

No conclusions could be drawn on potential relationships between tidal influences and feeding activity of black bream due to the limited information available. However, acoustic tracking has established that this species does use tides to move throughout the estuary (see Chapter 6), movements that are presumably linked to searching for prey from different habitats. In several other estuarine-dependent species, tidal cycles have been shown to have a strong influence on feeding activity. For example, feeding activity in the thin-lipped grey mullet, *Liza ramada*, is significantly correlated with tidal cycle, the species feeding intensively on intertidal mud flats during tidal phases when these areas are inundated (Almeida et al., 1993). Since black bream have a sufficiently broad diet, enabling them to access prey from a wide range of habitats, tidal influences on feeding are expected to be less pronounced than for specialist feeders, such as the thin-lipped grey mullet.

5.4.3. *Ontogenetic changes*

Clear ontogenetic differences in the feeding habits of black bream were observed for the fish size classes used in this study. Ontogenetic changes in diet are important to reduce the potential for intraspecific competition for food. In general, smaller fish consumed small soft-bodied prey, such as amphipods and/or small molluscs, such as *Tatea rufilabris* and *Salinator solida*, while larger fish fed on large and hard-bodied prey, such as decapods, other molluscs and plant material. Diets of fish <100 mm were dominated by amphipods in each of the studied estuaries, but once fish had exceeded about 150 mm, amphipods played a minor role in their diets. A decrease in consumption of *Tatea rufilabris* and *Salinator solida*, was offset by an increase in larger prey items with increasing fish size. Such dietary changes probably reflect spatial structuring of the population (see Chapter 2), changes in the ability of fish to physically handle different types of prey (Willis, et al., 1999), and the fact that larger fish tend

to select for larger prey items (Gning et al., 2007). Juvenile black bream tended to occur in upper estuary regions whereas adults occupied a wider range of habitats within the estuary (see Chapter 2), and thus adult fish may have greater opportunities to exploit a broader range of food resources. The increase in large and hard prey item in the diets of black bream with size was facilitated by increases in mouth size and jaw strength (Sarre et al., 2000). Black bream develop larger molar teeth with increasing body size and this change facilitates handling hard-bodied prey items, enabling an exceptionally powerful bite capable of crushing the hard shells of gastropods and bivalves. In addition, black bream probably use ram feeding technique to capture prey, in which fish overtakes the prey with forward movement of the body combined with protrusion of the jaws (Wainwright & Bellwood, 2002).

The proportion of plant material in the diet rose progressively with increasing fish size. Algae and seagrass accounted for more than about 40% of the diets of fish size >150 mm in the Little Swanport Estuary, Swan River and North West Bay River. Willis et al. (1999) found that small crustaceans, such as copepods and amphipods were the major component of the diet of black bream <20 mm in the Hopkins River Estuary, Victoria and the relative proportion of algae increased in the stomach of the larger size classes. Juveniles may positively select animal prey items rather than plant material, reflecting their higher demand for protein.

5.5 CONCLUSION

This study confirms that black bream consume a wide range of prey types, including benthic invertebrates, epifauna and plant material. Such flexibility represents an important adaptation to life in the estuarine environment where environmental conditions are highly variable and temporal and spatial changes in benthic communities occur. Plant material represents an important food source for this species when and where the diversity of food items is limited,

and as fish grow. Like most other fish species, black bream exhibit ontogenetic change in the diets, with larger fish consuming larger and harder bodied prey items along with increasing quantities of plant material.

CHAPTER 6

Movement Patterns in Black Bream, *Acanthopagrus butcheri* (Munro) in a Tasmanian Estuary, Based on Acoustic Telemetry

6.1. INTRODUCTION

Estuaries contain a variety type of habitats including mangrove, seagrass beds and salt marshes which provide important habitats for many fish and invertebrate species (Franca et al., 2009). Estuarine environments are structured by vertical and horizontal gradients of salinity, temperature, dissolved oxygen, turbidity and other water quality variables (Whitfield, 1999). Tidal movements and freshwater inflows are main factors that determine spatial and temporal physical environmental characteristics, such as salinity and temperature, of estuaries which may influence the distribution and abundance of organisms. They are also essential for egg and larval dispersal (North & Houde, 2004) and upstream migrations (Zhong & Power, 1996) in some species of fish. Furthermore, excessive freshwater inflows can cause rapid change in environmental conditions, resulting in changes in the distribution of fauna due to individuals seeking out favourable conditions and/or being swept away from the upper estuary region.

Habitat selection of fish within an estuary may be related to structural complexity, prey and predator abundance and physical environmental conditions (Blaber & Blaber, 1980), and also varies at a range of temporal scales (Lucas & Baras, 2000; Miller & Skilleter, 2006), including diurnal and tidal (Morrison et al., 2002), and within and between seasons (Young & Potter, 2003). Characterizing fish movement and habitat utilization patterns can provide insights into the ecology of fish and guide conservation strategies (Humston et al., 2005; Semmens et al., 2007) and help predict stock responses to changes in their environment (Ault et al., 2003; Meynecke et al., 2008).

Black bream, *Acanthopagrus butcheri*, is a resident estuarine species distributed around southern Australia including Tasmania that is thought to complete their entire life cycle within a specific estuary (Potter & Hyndes, 1999). It is an important commercial, as well as

recreational, species in some states (Kailola et al., 1993), though in Tasmania, black bream are effectively a recreational-only species, ranking among the top five most frequently caught finfish by recreational fishers in that state (Lyle, 2005).

There have been significant advances in tagging methodologies for fish, including the development of acoustic tags. Acoustic tags allow tracking of fish movements at a range of spatial and temporal scales and can provide details of fish movement over long periods (Ehrenberg & Steig, 2003). By recording long-term movement patterns and associated environmental conditions, valuable information about how fish utilise their environment and which factors strongly influence movement and distribution can be gained.

There have been several previous tagging studies on black bream in southern Australia. An early study by Butcher & Ling (1962) used traditional tagging methods to examine movement in Gippsland Lakes, a complex of coastal lagoons, lakes and associated tributaries in south-eastern Australia. The resultant tag recoveries suggested that migratory movement of black bream was largely localised with limited movement between estuaries. More recently, Hindell (2007) and Hindell et al. (2008) used acoustic telemetry to assess patterns of habitat utilization and movement by black bream in the Gippsland Lakes and established that some individuals moved large distances within the system and the species spent more time in the rivers, but utilization of specific habitats varied seasonally.

Although spatial and temporal distribution patterns of black bream has been recently investigated (Hindell, 2007; Hindell et al., 2008), physical environmental factors, especially salinity influencing its movement and distribution patterns are still the subject of debate. The present study aims to investigate the selection of a specific habitat by estuarine resident

species, black bream, within a small temperate estuary located on the east coast of Tasmania by determining spatial and temporal movement and distribution patterns of the species in relation to tidal cycles, freshwater inflows, salinity and flood. Such information will contribute significantly to understanding how estuarine resident species cope with the environmental instability of estuaries.

6.2. MATERIALS AND METHODS

6.2.1. Study area

Black bream movement was studied in the Little Swanport Estuary which is a permanently open estuary that occupies an area of approximately 6.5 km² and length of approximately 8 km from the entrance to the further extent of tidal influence (Fig. 6.1). The estuary is relatively shallow, ranging from approximately 1 to 9 m in depth at high tide. The deepest waters (>7 m) are located in the middle estuary. The estuary has a very narrow entrance, approximately 30 m wide and 5 m deep, and a long channel with numerous shoals and irregular shape. In the middle to lower estuary, there is an extensive band of *Heterozostera tasmanica* and *Zostera muelleri* on soft muddy and sandy bottoms. *Heterozostera tasmanica* dominates and forms very dense seagrass beds in the middle estuary. The upper estuary, which included in the Little Swanport River and was located ca 8 km upstream from the estuary entrance, consisted of a rocky bottom and sparse *Ruppia megacarpa* beds in the shallow water. Extensive sand and mudflats were exposed throughout the system during low tide with clearly defined channels.

6.2.2. Equipment

VEMCO Model VR-2 acoustic receivers and VEMCO V8SC-2H-R04K coded acoustic transmitter tags operating on 69 kHz frequency with 147 dB power output were used to monitor individual black bream movements over periods of up to six months. Acoustic tags

were 30 mm long, 9 mm in diameter and weighed 3.1 g in water, with approximately one year battery life. The pinging sequence is repeated after a random delay of between 60 and 180 seconds; the random delay is to minimize the chance of signal collision if several tagged fish transmit simultaneously to the same receiver. Eight acoustic receivers were deployed in the Little Swanport Estuary and two in the Little Swanport River (Fig. 6.1) on 27th July 2005 and retrieved on 2nd February 2006. Each receiver was set with approximately 1 km interval throughout the estuary to examine small scale movement patterns of black bream in relation to tidal cycles and freshwater inflows. These receivers continuously monitored for the presence of unique, digitally coded transmitter signals emitted by the tags and recorded the date, time and identity of tagged fish within the detection range of the unit. Each receiver was shackled to a mooring and buoyed with a subsurface float to ensure that the receiver remained vertical in the water column.

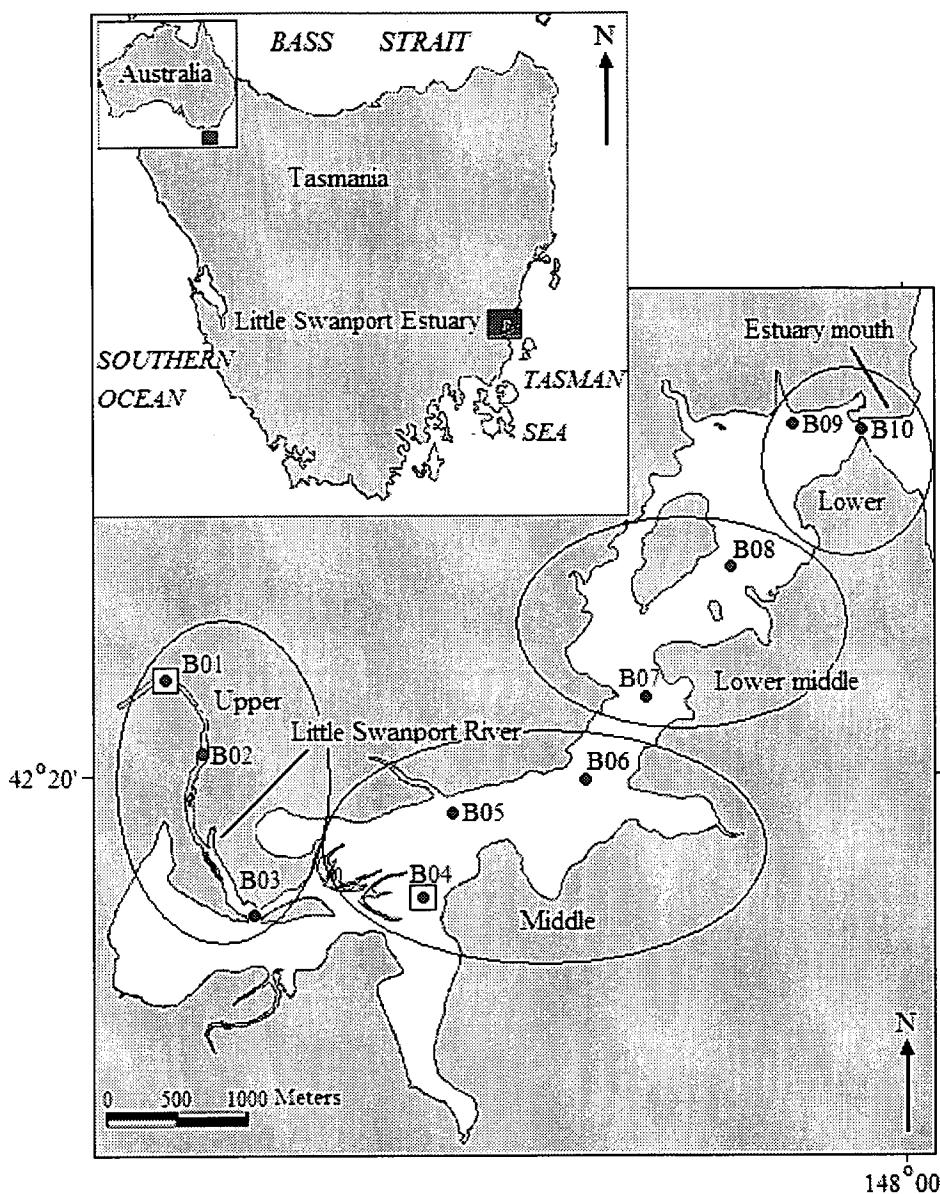


Figure 6.1 Map of the study area with individual VR-2 hydrophone receiver locations indicated by circles and numbers (B01-B10). Squares indicate the sites where tagged fish were captured and released. For reporting and analysis the system has been divided into the Upper estuary (including the Little Swanport River, receivers B01-B03), Middle estuary, (receivers B04-B06), Lower middle estuary, (receivers B07 & B08), and Lower estuary (receivers B09 & B10).

6.2.3. Detection range testing

The detection ranges of the VR2 receivers were tested by recording signals from a test transmitter at the surface and approximately 30 cm above the bottom. The test transmitter was

deployed from a boat at approximately 100 m intervals from the receiver for the first 300 m and at 50 m intervals between 300 m and 600 m from the receiver. The location of the boat was checked by global positioning system (GPS). To match the time of detection of the test transmitter at the receiver, the watch used during this study was synchronized with the receiver's initial clock. Range testing was undertaken within two hours of low tide.

6.2.4. Capture and surgical procedure of fish

Acoustic tags were surgically implanted into the peritoneal cavity of black bream. The fish were captured by gill net (three 10 m panels of mesh size 64, 89 and 105 mm) or by line fishing with bait. The gill net was set for no more than 30 minutes to minimize capture injuries and stress. All captured black bream were immediately placed in a tub of clean seawater (approximately 40 L) and transported to a shore-based 300 L fish holding tank. Fish were removed from the holding tank, anesthetized in a solution of 0.05 mL L^{-1} of Aqui-S in seawater and reached anesthesia stage 3 (MacFarland & Klontz, 1969) after 2-5 minutes. Fish were measured for fork length ($\pm 1 \text{ mm}$) and then placed ventral-side up on a V-shape surgical table. During surgery, normal seawater was supplied over the gills using a squirt bottle. The surgical table was sprayed with Vidalife, which contained a scavenger of heavy metals, and polyvinylpyrrolidone to protect exterior body surfaces from loss of natural coating. A 15-20 mm long incision was made with scalpel on the ventral midline between the pelvic fins and the acoustic tag was inserted vertically and gently pushed forward to be 20-30 mm anterior of the incision. The incision was closed with two stitches, using synthetic absorbable suture, and oxytetracycline, which prevents bacterial infections, was injected near the pectoral fin at a dosage of 50 mg kg^{-1} fish weight (Summerfelt & Smith, 1990). All fish were further identified with an external T-bar anchor tag (Hallprint Fish Tag) inserted below the dorsal fin. Following

surgery, fish were allowed to recover in a 70 L holding tank until they started to swim normally, and were then released near B01 or B04 receiver stations (Fig. 6.1).

Thirty-five black bream were tagged and released with acoustic tags in the estuary between late-July and early September, before the start of the spawning in October, to reduce possible negative effects on gonad development and spawning behaviour.

6.2.5. Tag retention and survival

Tag retention and survival were tested on wild black bream prior to commencing the field experiment. Black bream were captured by line-fishing in the Little Swanport Estuary and transported to the Tasmanian Aquaculture & Fisheries Institute. Fish were acclimatized in an outdoor 5000 L circular tank for a week prior to the experimentation. Dummy tags that were the same in size and weight as the acoustic tags were implanted using the surgical procedure described above. The tagged fish were stocked with five untagged individuals and supplied with a continuous flow of seawater for seven weeks. Fish were fed either prawns, crabs, horse mussels or gastropods every two days. The tank was checked daily for fish survival, and fish were removed from the tank and checked weekly for tag retention and healing process. Tag retention was also checked by searching for lost tags on the bottom of the tank. The incision was considered to be healed when the epidermis had closed up over the whole length of the incision.

No additional damage to the skin and fins of both control and surgical groups was noted subsequent to tagging. The tagged fish returned to normal feeding about 24 hours after implantation. There were no mortalities in either control or surgical groups during the seven week holding period and no tags were expelled. Seven days after tagging all tagged fish had

red or swollen incisions and new fibrous tissue had started to grow on the incisions. The site of the incision had effectively healed after 28-49 days.

6.2.6. Environmental data

Bottom salinities in the upper (near B03), middle (near B05) and lower (near B09) were recorded by an automatic environment data logger during some periods of this study. Daily freshwater discharge into the Little Swanport Estuary was estimated using river height data collected at the Department of Primary Industries and Water lower gauge (station No. 2235; 2 km upstream of B01) and upper gauge (station No. 2207; 20 km upstream of B01) stations in the catchment. In some instances when the rating curve for the lower gauge was exceeded, flow data from the Sinclair Knight Merz water balance model was used (SKM 2004) (data provided by DJ Ross, Tasmanian Aquaculture and Fisheries Institute).

6.2.7. Data analyses

Data were downloaded from the receivers at the completion of the study period using VEMCO's system hardware and software interface, and then transferred to Microsoft Access and Excel databases. Data from the first 24 hours following release of tagged fish were not used because of potentially atypical behaviour immediately following tagging. Movement patterns were inferred by the number and duration of visit events to individual receivers. A visit event was defined as a continuous string of detections at a receiver where there was no more than 30 min break between consecutive observations (Stark et al., 2005). Consequently, a visit event could comprise either one hit or a large number of continuous hits at one receiver. If an acoustic hit was registered on another receiver, this signalled the start of a new visit event at that receiver. Visit event duration was the time between the first and last detection of a visit event plus one minute, ensuring a minimum visit duration of one minute for a single hit. In

situations where fish were detected by a receiver, then recorded just once by an adjacent receiver within one minute, and then immediately redetected by the initial receiver, the data were treated as if the fish had remained continuously within the detection range of the initial receiver. This situation only applied to receivers B05 and B06 and may have been due to partial overlap in detection ranges.

This study provided information on the number of visit events and visit event duration for each tagged fish in each region of the estuary between August 2005 and January 2006. Data were assessed for normality and homogeneity of variance prior to analyses using box plots and residual plots. Data were $\log_{10}(X+1)$ transformed where necessary to produce acceptable homogeneity of variances and distribution of residuals. Number of visit events per month and duration of visit events per month were analysed using a three-factor randomized block ANOVA. Month and region were treated as fixed factors, with fish treated as random blocking factor.

To examine relationships between tidal cycle and movement, tidal influenced movement was assumed to have occurred if a fish was detected by more than one receiver during a given flood (incoming) or ebb (out-going) tidal phase, with detections that occurred 30 minutes either side of the predicted high or low tide excluded from this analysis. Whether net movement had occurred and its direction (upstream or downstream) was determined by reference to the receivers at which the initial and final detections within the given tidal phase had occurred. For example if initial detection occurred at B05 and final detection occurred at B03, an upstream movement of two receivers was recorded. Pearson correlation was used to determine whether there was significant relationship between tidal height and fish movements.

Pearson correlation was also used to examine relationship between salinities and movement patterns over the period of floods.

Fourier transformation analysis, which decomposes a regular time series into a finite sum of sine and cosine waves of different frequencies, was used to assess temporal periodicity in black bream movement. For each fish, the number of detections per hourly interval was calculated for each receiver. For every hourly interval, whether or not the fish was detected by the array was calculated as presence or absence. All data series were analysed using the software package XLSTAT (<http://www.xlstat.com/en/home/>).

6.3. RESULTS

6.3.1. Receiver detection range

Detection ranges for all VR2 hydrophones during low tide were highly dependent on the study site conditions, with maximum detection distances ranging from 200 to 600 m (Fig. 6.2). There was no overlap between the detection ranges of the VR2 receivers during low tide. However, based on the occurrence of more or less simultaneous hits on receivers B05 and B06 in a small number of instances, it was likely that under certain conditions the detection ranges for these receivers overlapped periodically. Overall there were thirty-six visit events (0.4% of total visit events and <0.001% of total detections) that appeared to have been affected by this phenomenon. The detection ranges of B04, B09 and B10 were relatively narrow due to the proximity of shallow banks, while B05 and B07 appeared to effectively detect the vast majority of tagged fish present in these areas. For instance, during the six month field experiment, 96.5% of all upstream and downstream movements involving tagged fish moving between B03 and/or B04 and B06 and/or B07 were also detected by receiver B05. Similarly,

all fish that were detected to have moved between the middle estuary (B04-B06) and lower middle and lower estuary (B08-B10) were also detected by receiver B07.

Unfortunately, the two upstream receivers (B01 & B02) flooded part way through the deployment, resulting in no movement information being available for the Little Swanport River. However, as B03 was positioned where the Little Swanport River entered the estuary, a width of approximately 10 m, it is highly probable that any fish moving further upstream into the river would have been detected at this point, though not all fish detected at B03 can necessarily be assumed to have moved further upstream. At the estuary mouth the detection range of B10 covered the deep entrance channel but did not extend to the adjacent shallow sand banks (<1 m) and thus it is possible that fish moving about on the shallow banks may not have been detected by this receiver.

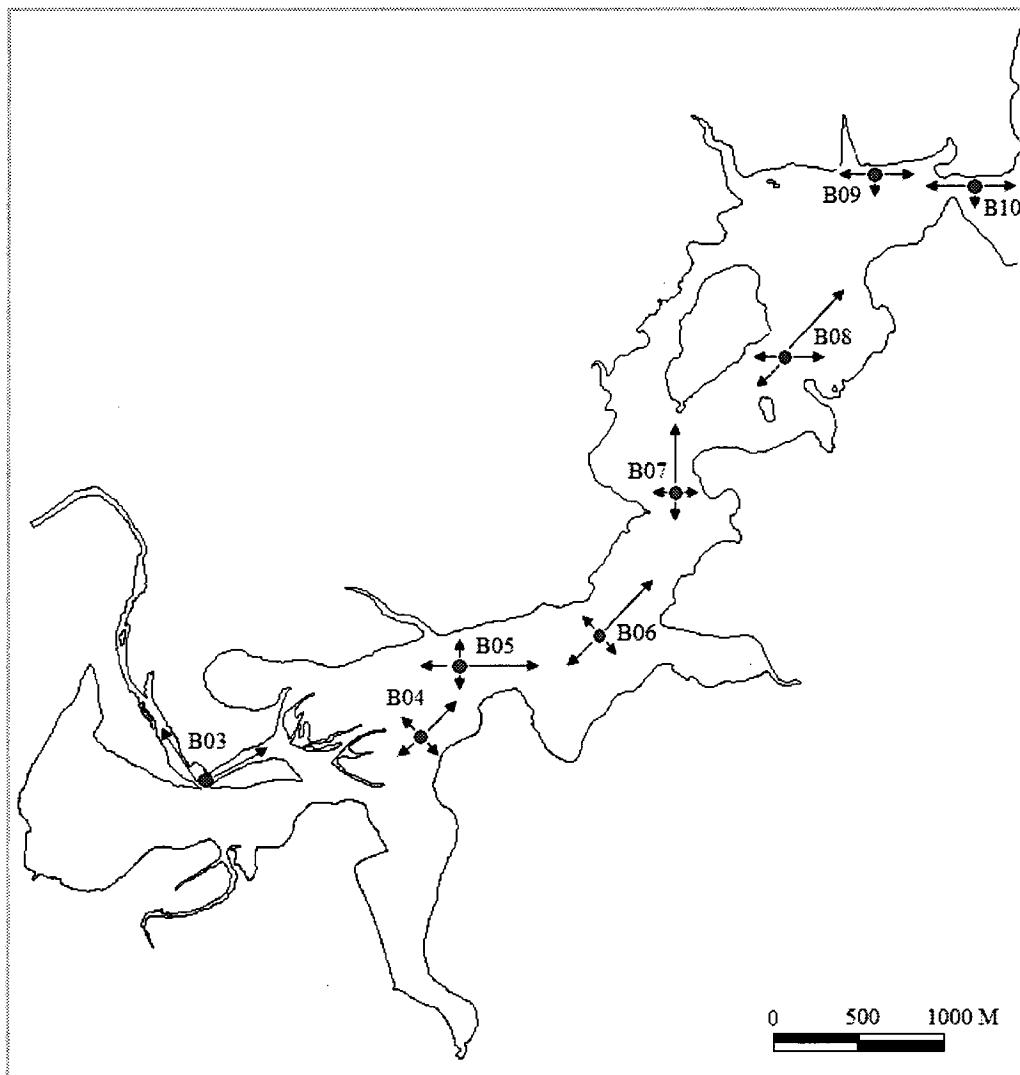


Figure 6.2 Detection ranges for receivers B03-B10. Circles indicate receiver positions and arrows represent maximum detection ranges during low tide.

6.3.2. Tracking of black bream

Individual data on fish size, location and date of release, location and date of last contact, and total period tracked (days since tagged) are provided in Table 6.1. Sex of individual fish was unknown, however, based on size at maturity (see Chapter 5), all tagged fish would have been mature. The VR2 hydrophone receivers recorded a total of 158,181 hits from 34 of the 35 tagged fish, representing 8,215 discrete visit events. Thirty-one fish were tracked for over 120

days and 25 of the tagged fish were last detected within a week of the receivers being removed, indicating that the tags remained functional throughout the study period and that survival was very high. Fish No. 5 was not detected at any VR2 receivers despite being released within the detection range of receiver B04, implying that the tag may have malfunctioned. Fish No. 31, which was released at B04, was captured by a recreational angler on 11th November 2005 in the Little Swanport River (near B02) after more than two months at liberty. The fish was reported to have been in very good condition and the wound site had fully healed.

6.3.3. Movement patterns and habitat use

Receiver B03 recorded the greatest number of detections (92,278 hits), accounting for 34% of the total visit events (Fig. 6.3). As a general trend, the number of visit events decreased between the uppermost (B03) to the lowermost receivers (B10), with a sharp fall occurring at B07, indicating that most of the localised movements occurred within the upper and middle regions of the estuary (Fig. 6.3). The proportion of the combined visit event duration by receiver showed a similar trend to that for visit events, although the average visit duration was clearly greater at B03 than elsewhere as indicated by the proportionally higher (>60%) importance of this receiver. All tagged fish were detected at B03, B05 and B06 during the period of the experiment while only 8 and 6 tagged fish were detected at B09 and B10, respectively (Fig. 6.3).

Table 6. 1 Summary of data for acoustically tagged fish. See Fig. 6.1 for capture and release locations.

Fish ID	Fork length (mm)	Date tagged and released	Capture location	Release location/Last detection	Last date detected	Total days in tracking
1	330	30/07/2005	B04	B04/B08	04/01/2006	159
2	330	30/07/2005	B04	B04/B05	01/02/2006	187
3	280	30/07/2005	B04	B04/B07	31/01/2006	186
4	320	30/07/2005	B04	B04/B05	31/01/2006	186
5	430	30/07/2005	B04	B04	-	0
6	325	30/07/2005	B04	B04/B05	01/02/2006	187
7	311	30/07/2005	B04	B04/B06	31/01/2006	186
8	284	30/07/2005	B05	B04/B06	01/02/2006	187
9	318	30/07/2005	B05	B04/B03	01/02/2006	187
10	327	04/08/2005	B05	B04/B04	01/02/2006	183
11	420	11/08/2005	B01	B01/B03	16/01/2006	159
12	325	17/08/2005	B04	B04/B04	01/02/2006	170
13	318	23/08/2005	B01	B01/B08	28/12/2005	128
14	293	23/08/2005	B01	B01/B04	01/02/2006	163
15	294	23/08/2005	B01	B01/B06	01/02/2006	163
16	330	23/08/2005	B01	B01/B03	03/01/2006	134
17	420	23/08/2005	B01	B01/B03	29/01/2006	160
18	338	23/08/2005	B01	B01/B05	01/02/2006	163
19	285	23/08/2005	B01	B01/B03	01/02/2006	163
20	352	23/08/2005	B01	B01/B04	31/01/2006	162
21	337	23/08/2005	B01	B01/B08	23/11/2005	93
22	356	02/09/2005	B04	B04/B05	01/02/2006	153
23	272	02/09/2005	B04	B04/B06	25/01/2006	146
24	340	02/09/2005	B05	B04/B05	25/01/2006	146
25	311	02/09/2005	B04	B04/B03	01/02/2006	153
26	280	02/09/2005	B04	B04/B09	31/01/2006	152
27	292	02/09/2005	B04	B04/B03	01/02/2006	153
28	297	02/09/2005	B04	B04/B10	14/01/2006	135
29	268	02/09/2005	B04	B04/B04	01/02/2006	153
30	278	05/09/2005	B04	B04/B08	31/01/2006	149
31	327	05/09/2005	B04	B04/B03	07/11/2005	64
32	295	05/09/2005	B04	B04/B05	04/01/2006	122
33	330	05/09/2005	B08	B04/B07	17/11/2005	74
34	342	05/09/2005	B08	B04/B09	01/02/2006	150
35	296	05/09/2005	B08	B04/B10	26/01/2006	144

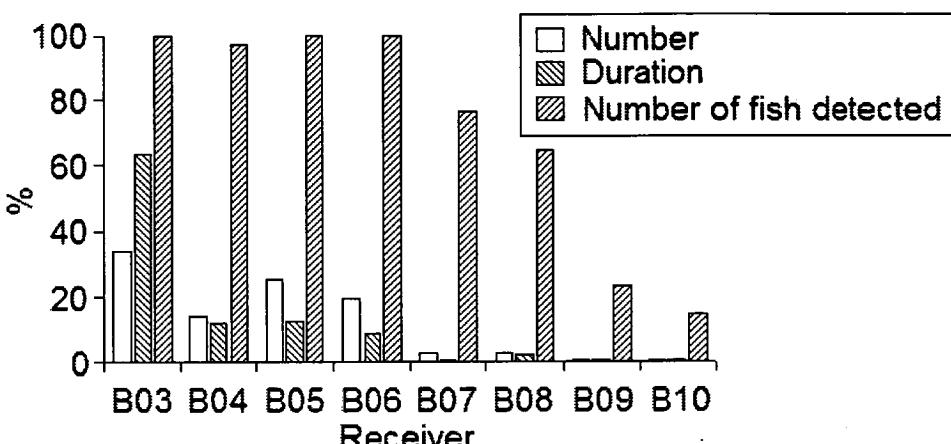


Figure 6.3 Percentage of total visit events and total visit event duration for all tagged fish and number of fish detected recorded by each VR2 receiver during the experimental period.

Considering the average number of visit events per fish (N_F), average total visit duration per fish (ED_F), and number of fish detected in each region by month, it was evident that black bream showed temporal and spatial variability in their utilization of the estuary, with a strong preference for the upper and middle regions of the estuary (Table 6.2 and Fig. 6.4). ANOVA detected significant month and region effects on N_F and ED_F , and there were strong two-way interactions between month, region and fish (Table 6.2). Although the average number of visit events tended to higher in the middle estuary in most months, the average time spent in the upper estuary tended to be greater (Fig. 6.4). Between September and December the average number of visit events to the upper estuary remained relatively constant whereas in the middle estuary there was a marked increase in the visit events in September and October (Fig. 6.4). While the average duration that fish were detected in the upper and middle regions of the estuary was roughly equivalent in September and October there was a strong shift to longer periods of time being spent in the upper reaches in November and December. By January there was an increase in events and time spent in the middle and lower regions of the estuary. In fact the only visit events recorded in the lower estuary occurred in August and January.

Throughout the study period, the proportion of tagged fish detected in the lower middle and lower estuary was consistently lower compared with upper and middle regions (Fig. 6.4c). Over 90% of the successfully tagged fish were detected in the upper and middle estuary in all months apart from August and January. The proportion of the tagged fish detected in the lower middle estuary declined steadily from around 80% to less than 20% between August and December before increasing slightly in January. Comparatively few individuals were detected by receivers in the lower estuary, most detections occurring in January.

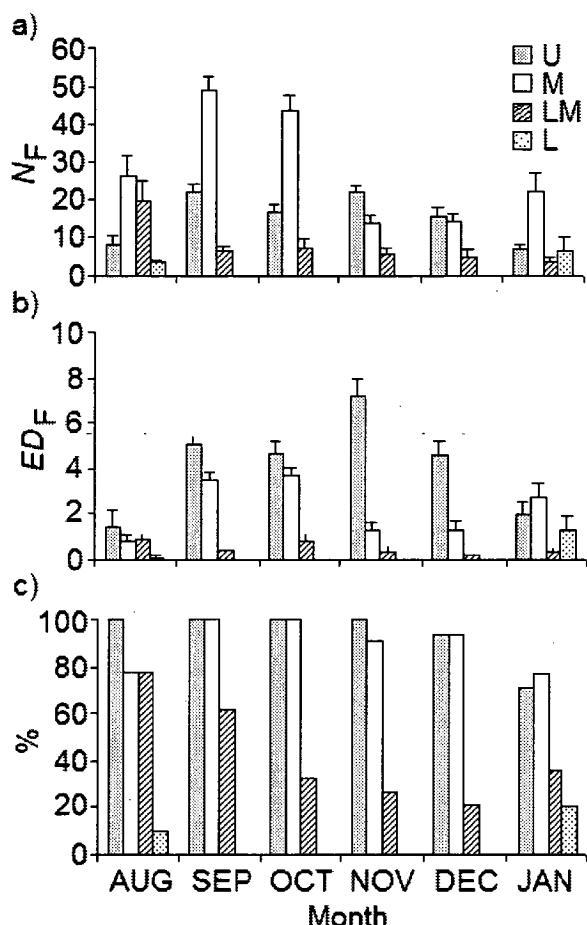


Figure 6.4 a) Average number of visit events per fish (N_F), b) average total visit duration per fish (ED_F) (days) and c) percentage of successfully tagged fish observed in each region by month. U: upper estuary (B03); M: middle estuary (B04-B06); LM: lower middle estuary (B07 and B08); L: Lower estuary (B09 and B10). Note: percentage of fish was calculated by total number of tagged fish observed in each region divided by total number of successfully tagged in the estuary. Total number of successfully tagged for each month was based on fish successfully tagged prior to 5 day of the month. For December and January, following the reported capture of one fish during November, total number of successfully tagged was 33. Error bars are one standard error.

Table 6.2 Summary of the analyses of three-factor randomized blocks ANOVA to test difference in the mean number of visit events (N_F), visit event duration per fish (ED_F) among month (August, September, October, November, December and January), region (Upper, middle, middle lower and lower) and fish (blocking factor).

Source	df	N_F		ED_F		P
		MS	P	MS	P	
Month (M)	5	3.92	<0.001	1.63	<0.001	
Region (R)	3	46.176	<0.001	37.32	<0.001	
Fish (F)	33	0.32	0.787	0.16	0.992	
M×R	15	2.22	<0.001	1.36	<0.001	
M×F	151	0.17	<0.001	0.11	<0.001	
R×F	99	0.29	<0.001	0.30	<0.001	

Detections recorded by receivers B03 and B05 were grouped into hourly bins by month to examine periodicity in black bream activity at these sites. In most months there was a clear pattern in detections at B03, with detections increasing progressively during the afternoon to a peak within a few hours of sunset, and then falling sharply around sunrise and remaining at low levels until around midday (Fig. 6.5). During January, however, there was no clear pattern, presumably influenced by the limited data available for the month. Assuming that increased detections reflect limited movement, this does not discount small-scale movements within receiver detection ranges. These data suggest that black bream were more active during daylight hours and less active during the night. The diurnal pattern of detections observed at B05 was less pronounced than that at B03, though there tended to be fewer detections during daylight hours in most months apart from September (Fig. 6.6). In September, there was a clear increase of detections during daylight hours, a trend mainly influenced by detections recorded between 12th and 20th September when the estuary was under the influence of a major flood event (refer below). This apparently anomalous activity pattern may have occurred in response to the flood, with no clear pattern was observed outside of the flood period.

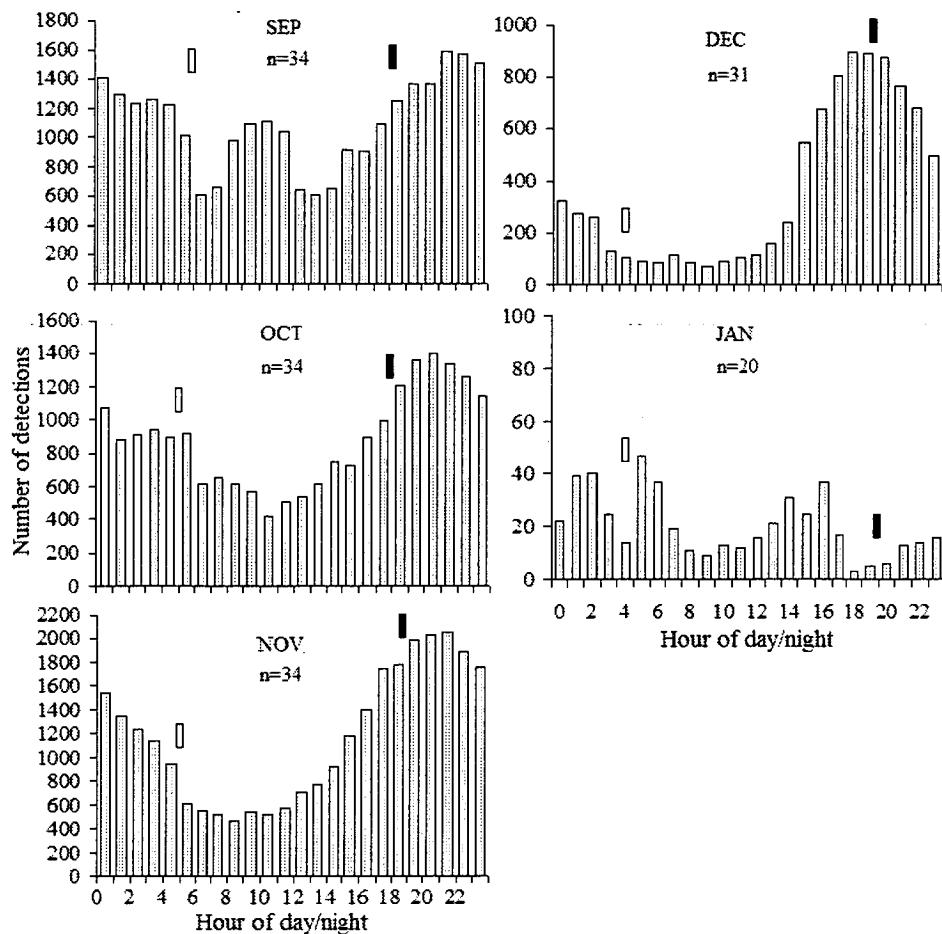


Figure 6.5 Number of detections at B03 deployed at the entrance of the Little Swanport River sorted into hourly categories. n: total number of tagged fish detected in each month. Sunrise and sunset are indicated by white and black squares, respectively.

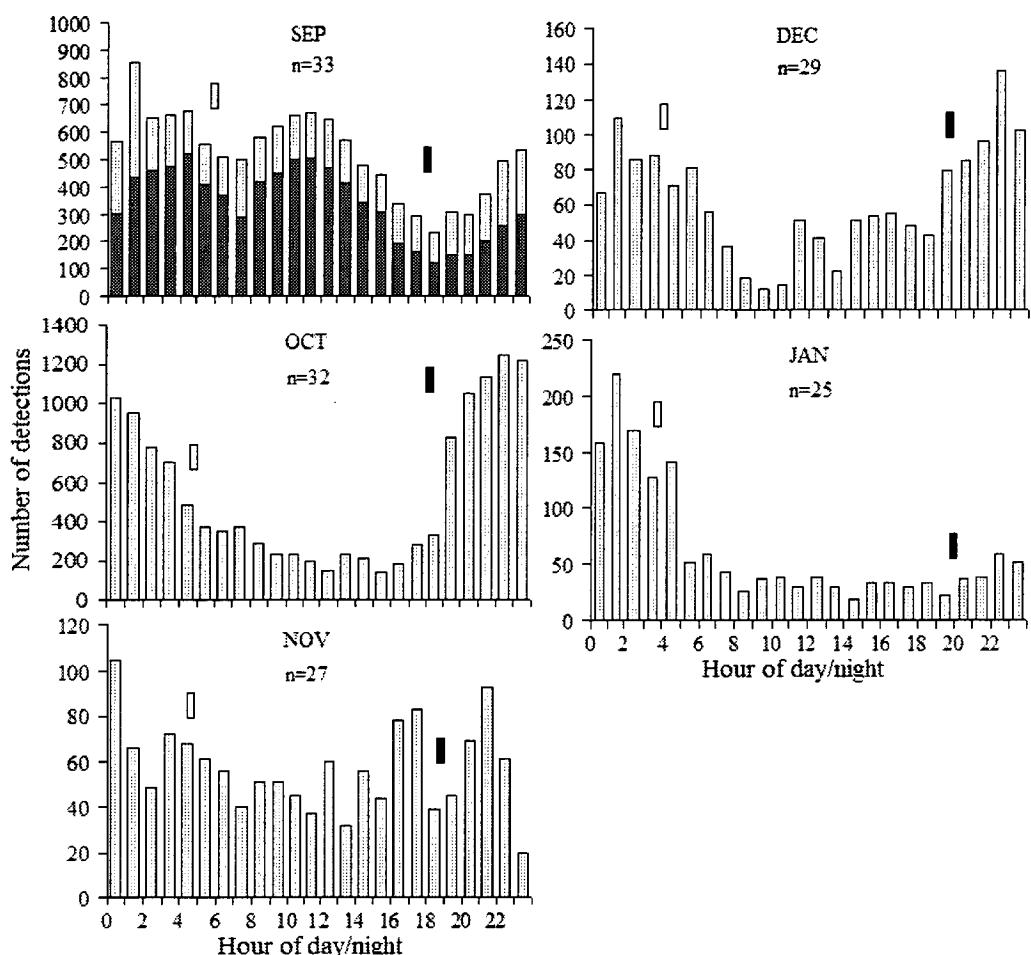


Figure 6.6 Number of detections at B05 deployed in the middle estuary sorted into hourly categories. n: total number of tagged fish detected in each month. Note different scale for y-axes. Sunrise and sunset are indicated by white and black squares, respectively. In September, number of detections during the heavy flood event (12th–20th September) are shown as dark bars.

For most fish, the Fourier analysis revealed two main patterns based on the presence/absence data; a diurnal movement pattern (median 23.8 h) was the most obvious, but a tidal movement pattern (median 12.1 h) was also observed, though less frequently (Table 6.3). There was substantial individual variation in the relative magnitude of the diurnal and tidal behaviour activity peaks (Table 6.3; Fig. 6.7).

Table 6.3 Periodicity of black bream activity based on Fourier analysis. The dashes indicate no peak detectable.

Fish ID	Presence/absence		Fish ID	Presence/absence	
	First peak (h)	Second peak (h)		First peak (h)	Second peak (h)
1	-	13.9	19	22.6	12.5
2	24.8	12.1	20	23.9	12.1
3	-	-	21	23.7	12.1
4	23.7	-	22	-	12.4
6	23.7	-	23	23.6	11.9
7	23.7	12.1	24	23.8	11.9
8	23.1	12.2	25	23.8	9.8
9	23.7	-	26	23.6	-
10	23.8	-	27	23.8	11.9
11	23.6	11.5	28	-	16.3
12	23.1	11.4	29	23.6	11.8
13	26.6	-	30	-	-
14	22.7	-	31	27.5	6.2
15	25.4	-	32	23.8	11.4
16	23.8	-	33	20.4	10.8
17	23.9	-	34	24.2	12.9
18	23.9	12.4	35	24.3	-
		Median	23.8		12.1

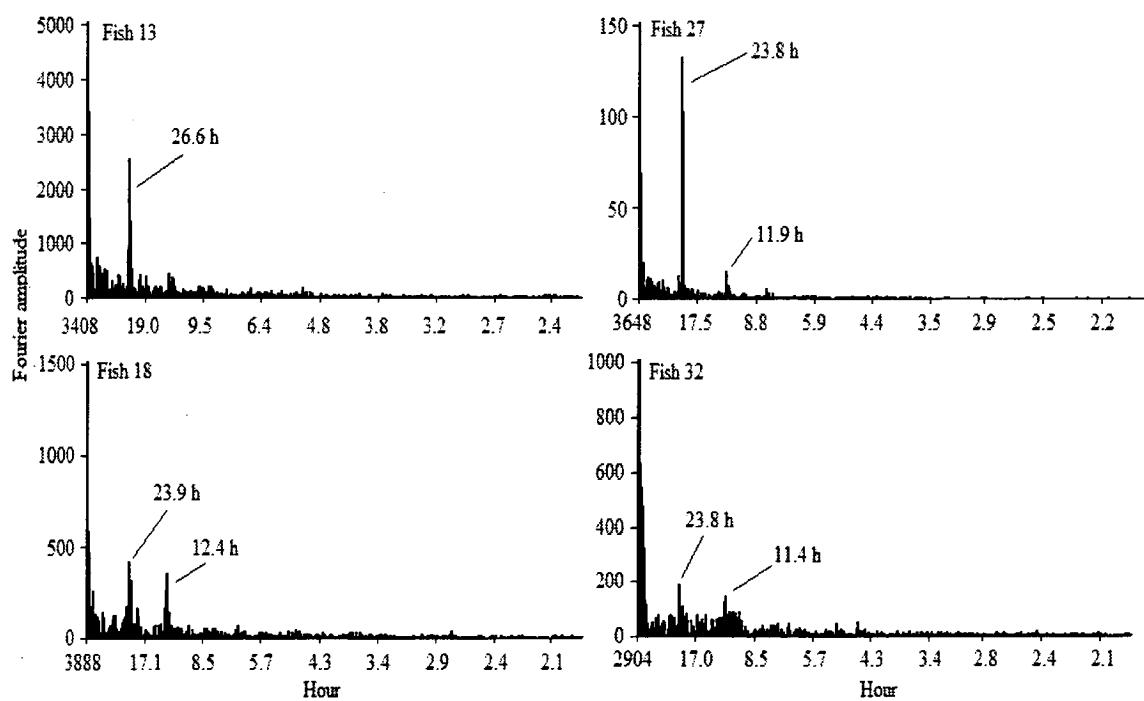


Figure 6.7 Examples of Fourier analysis of presence/absence every hour for four tagged black bream.

6.3.4. Tidal influences on movement

Overall, 82% of all tidal influenced movement (as defined above) during flood tide was upstream, with the most common displacement being one receiver (46%) followed by two receivers upstream (28%). There were a small number of instances involving upstream movements of up to 6 receivers (Fig. 6.8). In a small proportion of instances (8%), tagged fish exhibited downstream movement during a flood tide, the balance (9%) resulted in no net displacement. Conversely, during the ebb tide, around 73% of the tidal influenced movements were downstream, most (37%) by one receiver, followed by two receives (28%), with a small proportion moving downstream by three or more receivers. Upstream movement was rare during the ebb tide (7%) while the proportion of instances resulting in no net movement (20%) was minor but slightly higher than during the flood tide (Fig. 6.8).

Pearson correlation indicated that there was a significant linear relationship between net movements and tidal height differences during flood tide (Pearson correlation: 0.890, $P<0.001$) and ebb tide (Pearson correlation: 0.801, $P<0.001$) (Fig. 6.9). When tidal height differences were large, fish were more likely to move greater distances with tidal forces. Conversely, when fish exhibited movement against tidal movements, tidal height differences were relatively small, particularly less than 0.5 m (Fig. 6.9).

Examples of tidal related movement patterns for individual fish are shown in Fig. 6.10. Fish No. 3 was detected initially by B03, approximately 7 km upstream from the estuary mouth at the beginning of the ebb tide. As the tide fell, the fish moved downstream as far as B08 and then returned upstream to B06 by the following flood tide. This pattern of movement was then repeated during the following days, in one instance with the individual travelling as far as the estuary mouth (B10) on the out-going tide. Generally similar tide-related movements were

observed in Fish No. 7, but there were some differences. This individual was occasionally detected more or less continuously by a single receiver for extended periods, and thus apparently did not always move in relation to the tidal cycle. This was clearly evident between midnight of 7th and midnight of 8th August when the fish was detected more or less continuously at B08 during both ebb and flood cycles.

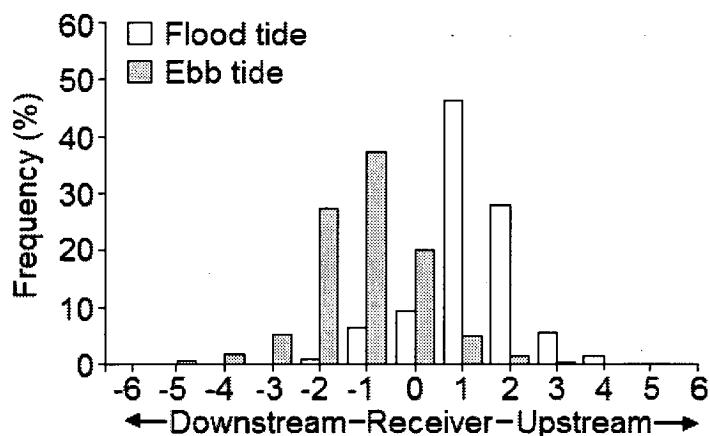


Figure 6.8 Summary of flood tide and ebb tide related movement. The x-axis represents upstream (positive numbers) and downstream (negative numbers) movement during a given tidal phase based on net displacement in terms of the number of receivers visited, 0 indicates no net movement during the tidal phase.

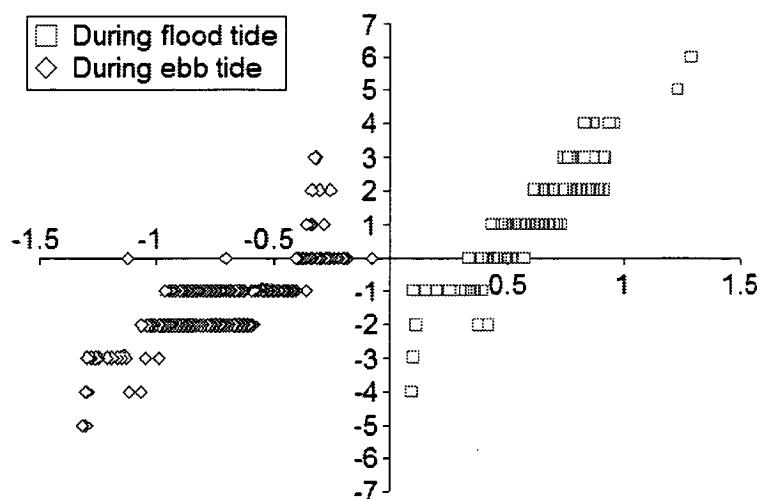


Figure 6.9 Summary of flood tide and ebb tide related movement. Positive and negative numbers on the x-axis is tidal height difference (m) between former and next heights of tidal phases, and the y-axis represents upstream (positive numbers) and downstream (negative numbers) movement during a given tidal phase based on net displacement in terms of the number of receivers visited.

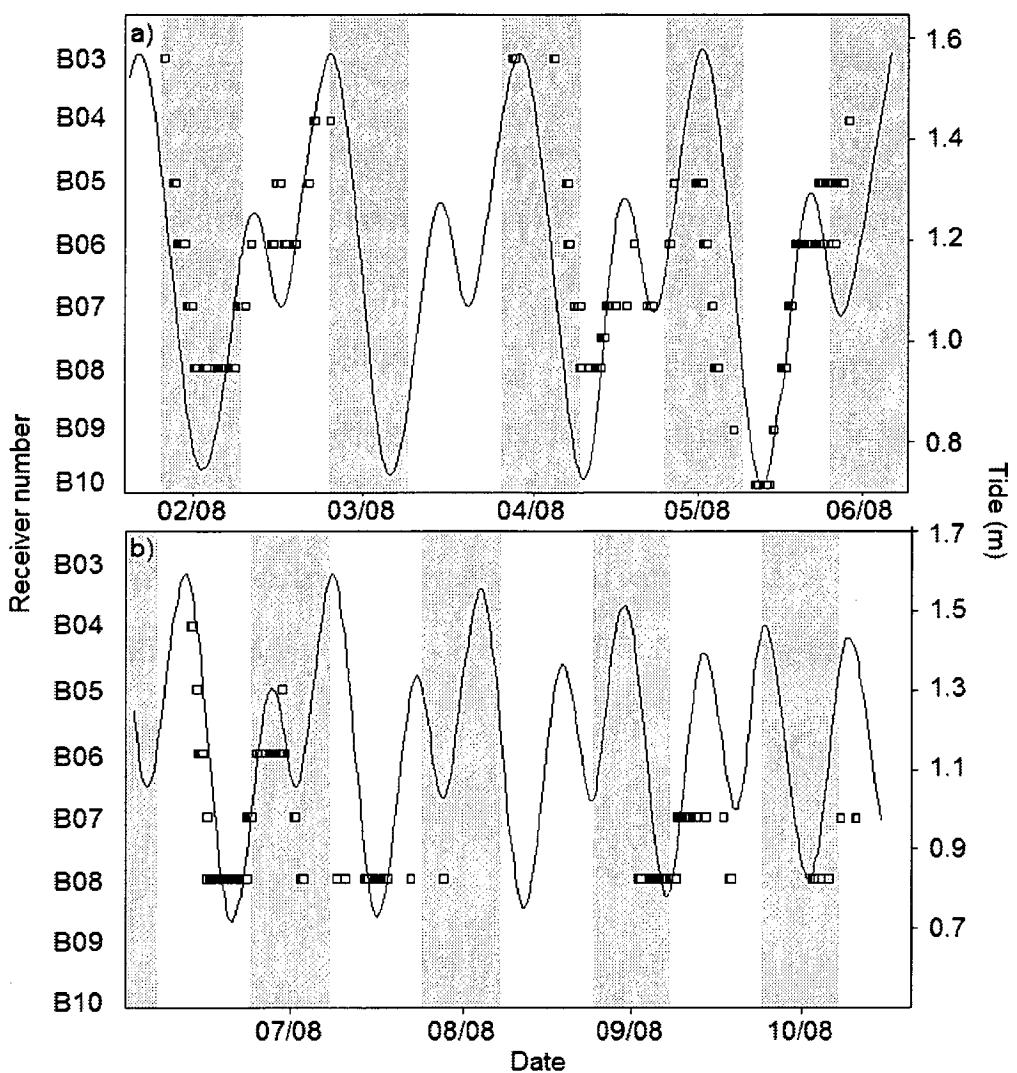


Figure 6.10 Tidal influence on upstream and downstream movements for a) Fish No. 3 and b) Fish No. 7. Open square symbols indicate tag transmissions detected at individual VR-2 receivers. Cyclical variation in tide height is indicated as continuous line and gray bars indicate night time. Note: distance between each neighbouring receivers is approximately 1 km.

6.3.5. Upstream migration

Since tagged fish often exhibited movements linked to tidal cycles, it was assumed that individuals detected at B03 and then redetected within 12 hours at the same receiver, without detection at another receiver, had effectively remained within the upper estuary. Based on this assumption, a total of 1075 visit events were recorded at B03 during the experimental period.

There were significant differences in the average number of visit events per fish between months (ANOVA, $F_{5,160}=6.287$, $P<0.0001$) and in the average time spent in the upper estuary each month (ANOVA, $F_{5,160}=10.093$, $P<0.0001$). *Post hoc* tests (Scheffe's) indicated that the average number of visit events per fish in August and January were significantly lower than those recorded in other months while the average monthly visit duration in January was significantly lower than those recorded in other months, except in August. The average number of visit events per fish was lowest in August and increased steadily to November before declining to levels similar to August by January (Fig. 6.11). Average monthly visit duration at B03 followed essentially the same trend, with individuals spending an average of 8.5 days during November in the upper estuary, compared with less than 2 days per fish in August and January (Fig. 6.11). In addition, throughout the study period it was evident that at various times relatively large numbers of tagged fish were detected concurrently in the upper estuary and conversely, usually corresponding with spikes in freshwater discharge, there were periods where relative few individuals were detected (Fig. 6.12a).

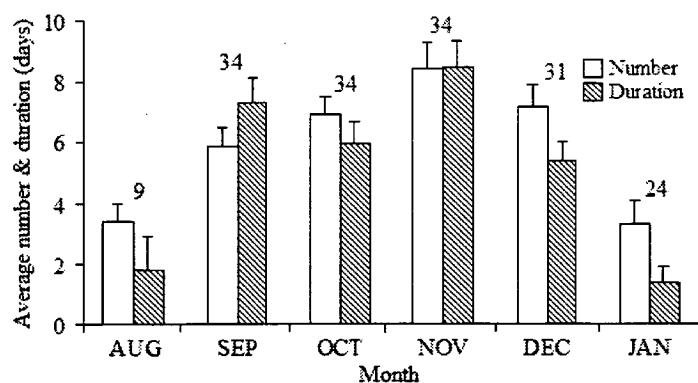


Figure 6.11 Average number and duration of visit events at B03. Error bars represent on standard error and numbers represent number of tagged fish detected.

6.3.6. Movement patterns in relation to freshwater discharges

There was an inverse relationship between the freshwater discharge into the Little Swanport Estuary and the number of fish detected in the upper estuary (Fig. 6.12). Generally, numbers of fish detected in the upper estuary (B03) fell immediately after periods of relatively high daily freshwater discharge (approximately >2000 Ml) (Fig. 6.12a), with most of the tagged fish moving to the middle estuary (B04-B06) region (Fig 6.12b), or to a less extent further downstream to the lower middle estuary (Fig. 6.12c). Fish were typically not redetected in the upper estuary for a couple of days following these periods of heavy discharge. Detections in the lower estuary were not associated with periods of high freshwater discharge (Fig. 6.12d).

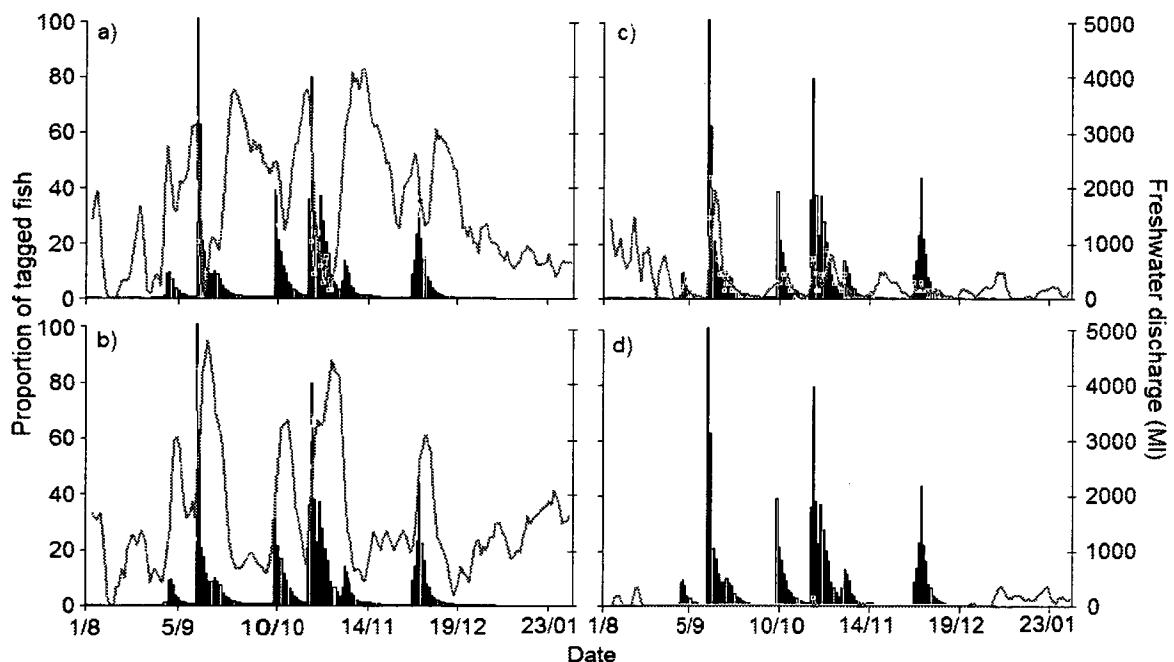


Figure 6.12 Proportion of tagged fish detected in a) the upper, b) middle, c) lower middle and d) lower estuary (a running three point average is represented to smooth the trend line). Vertical bars represent daily freshwater discharge (Ml). Note: on 12th September, daily freshwater discharge of 10233 Ml was recorded, but the bar has been truncated for clarity.

6.3.7. Movements during a major flood event

Heavy rainfall on 12 September 2005 caused the largest flood event in the Little Swanport Estuary during this study (Fig. 6.13a), with water levels in the upper estuary increasing by approximately 3-4 m (Appendix 6.1 & 6.2). The surface waters throughout the estuary became fresh while brackish water (>20) persisted in the deeper water of the middle estuary region (around B05 and B06). Number of tagged fish detected and visit durations over the period prior to, during, and following the flood (1-30 September) were grouped into upper (B03), middle (B04-B06), lower middle (B07 and B08) and lower (B09 and B10) estuary and are shown in Fig. 6.13b and 6.13c. Prior to the flood virtually relatively large number of tagged fish occurred in the upper and middle estuary (Fig. 6.13b), and average visit durations in the upper estuary were relatively high (Fig. 6.13c). However, during the flood average visit durations and number of tagged fish detected in the upper estuary declined dramatically, as fish moved downstream into the middle and lower middle estuary. Most of tagged fish spent most of their time in the middle estuary during the period 12-20 September. Approximately ten days after the flood started, tagged fish moved back to the upper estuary and spent more time in the region, probably corresponding to an increase in salinity in the upper estuary. In addition, during the flood event there was no evidence of any tagged individuals having moved out of the estuary.

Daily average visit durations in the upper estuary over the period of floods showed significant positive correlation with salinities in the region (Pearson correlation: 0.454, $P<0.001$), and conversely, daily average visit durations in the middle estuary correlated negatively with salinities in the region (Pearson correlation: -0.676, $P<0.001$) (Fig. 6.14). These results clearly indicated that tagged fish spent more time in the upper estuary when salinity was high,

probably above approximately 10, but when the salinity in the region dropped to less than 10 due to flood events, they moved down to the middle estuary where higher salinity remained. Decreases in total visit durations in the middle estuary with increasing salinity indicated a general movement of fish back upstream.

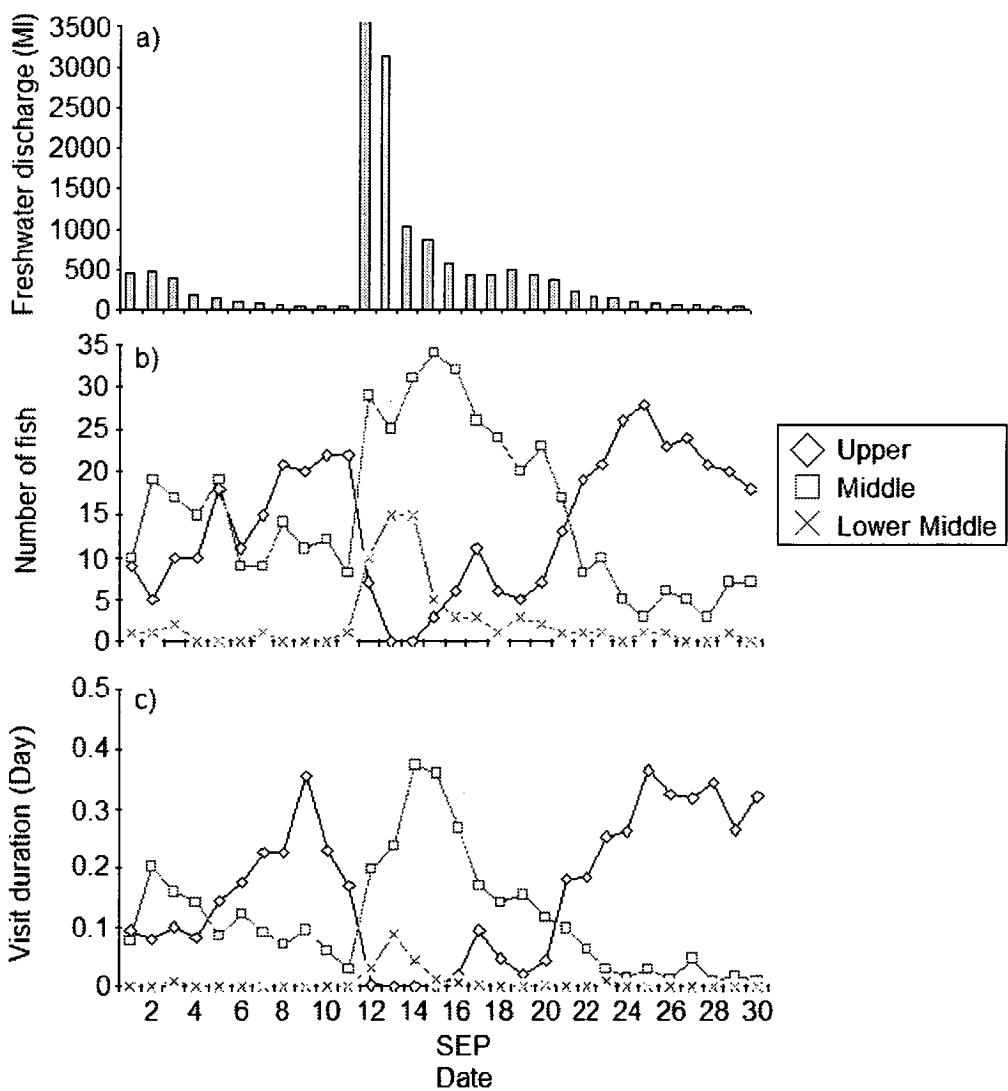


Figure 6.13 a) Daily freshwater discharge (MI), b) number of tagged fish detected and c) average visit duration per fish (34 fish) by day between 1 and 27 September 2005 at Upper (B03), Middle (B04-B06), Lower Middle (B07andB08) and Lower estuary (B09 andB10). Note: on day 43 (12 September 2005), daily freshwater discharge of 10233 MI was recorded, but the bar has been truncated for clarity. None of tagged fish was detected at the lower estuary region during the period.

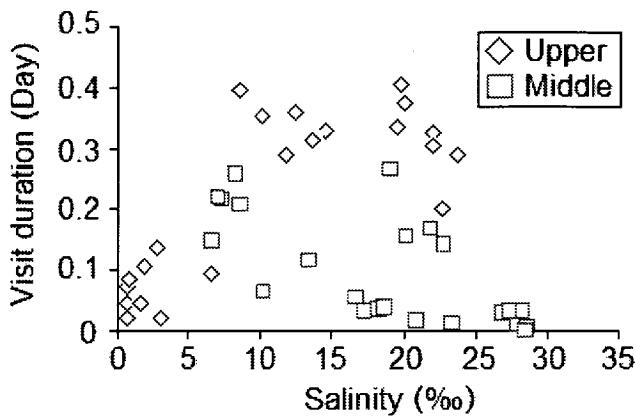


Figure 6.14 Relationships between mean daily salinities and daily average visit durations of tagged fish in the upper and middle estuary.

6.4. DISCUSSION

6.4.1. Movement patterns and habitat utilisation

This study has successfully used acoustic telemetry to described black bream movement patterns within an estuarine environment. Hindell (2007) also found that black bream responded well to surgical implantation of tags and could be successfully tracked over relatively long periods of time.

In the main, black bream undertook localised movements within the Little Swanport Estuary, exhibiting tidally related activity, involving movement at the scale of kilometres within the estuary. This study has clearly established that adult black bream have a preference for the upper and middle regions of the estuary, where typical estuarine environmental conditions occurred, and these findings are generally consistent with previous studies (Loneragan et al., 1989; Hindell et al., 2008). In this region, freshwater inflows caused greater variability in water conditions, especially salinity, than in the lower estuary, where more constant marine conditions persisted. Thus in the context of the entire estuarine system, black bream primarily utilise a narrow range of available habitats, an observation that is consistent with that reported

for the species in the Swan River Estuary, Western Australia (Dibden et al., 2000) and the related *Acanthopagrus berda* in mangrove creeks (Sheaves et al., 1999). Within this relatively narrow habitat range, black bream showed spatial and temporal variation in habitat utilization. Fish spent more time in the upper estuary between September and December than at other times covered by this study, presumably linked to spawning activities in the upper estuary region. Furthermore, fish were rarely detected in the lower middle and lower estuary during the study period, implying that these regions were relatively unimportant for the species. Hindell et al. (2008) also reported that in the much larger Gippsland Lakes system, black bream utilised the upper reaches of the rivers more than the lakes during the spawning season (August-November), but that fish residency time in the downstream lakes areas increased gradually after the spawning season. In this study there was slight increase in visits to the lower middle and lower estuary in January (following spawning) that may be indicative of broader habitat utilization outside of the study period, as report by Hindell et al. (2008).

Black bream appeared to be more active during daylight hours than at night, with more detections recorded during night time at a given receiver, indicating that fish were more likely to remain within the detection range of the receiver at night and thereby implying limited movement. Conversely, Hindell et al. (2008) indicated that there were no clear differences between night and day movement patterns of the Gippsland Lakes black bream. Fewer detections during daytime hours were assumed to reflect movement between habitats, possibly in search of prey. Greater activity during daylight hours was also evident in the feeding periodicity of this species, showing an increase of feeding activity prior to sunset with little evidence of night feeding activities (see Chapter 5). However, during September the diurnal pattern in activity was less distinct with increased detections in the morning (8:00-11:00 a.m.)

at B03 and consistently higher detections during daylight hours at B05. It is unclear why detections at B03 increased during the morning period, but the pattern observed at B05 may be related to the influence of the major flood event between 12th and 20th September 2005. Since this receiver was deployed in a deep channel in the middle estuary where the heavy freshwater inflow presumably had reduced impacts, with brackish conditions persisting, it is possible that the tagged fish remained within the detection range of this receiver throughout long periods of the day to avoid more unfavourable conditions.

This represents the first study to demonstrate the link between tidal cycles and small-scale movements in black bream, as inferred from the Fourier analysis and patterns of movement between receivers. Black bream typically moved actively with the current during both flood tide and ebb tides, and regularly travelled distances of up to several kilometres during a tidal cycle, although most movements were less than about 2 km (2 receivers). Connections between movement and tidal exchange have been demonstrated in another sparid, *Pagrus auratus*, in a New Zealand estuary (Hartill et al., 2003). Tidal movements in that species tended to be more limited, generally in the order of several hundreds of meters upstream and downstream during a given tidal cycle. Another estuarine-dependent species exhibiting tidal movement is the spotted grunter, *Pomadasys commersonii*, which moves extensively between the lower reaches of the Great Fish River (South Africa) during low tide and upstream during high tides (Childs et al., 2008). Utilising tidal forces in this manner enables fish to move between habitats with minimum energy cost (Almeida, 1996), to maintain more stable environmental conditions, particularly salinity, and/or access foraging habitats. Colton & Alevizon (1983) and Humston et al., (2005) reported that bonefish, *Albula vulpes* venture onto tidal flats during periods of high tide and retreat into deep channels during periods of low

tides, suggesting that they respond to the dynamics of tide flow to gain access to very shallow waters for foraging. The thin-lipped grey mullet, *Liza ramada*, inhabiting the middle reaches of the Tagus estuary (Portugal), also uses the tidal cycle to access extensive intertidal mud flats which only become available during periods of high tide inundation (Almeida et al., 1993; Almeida, 2003). Black bream may use the same strategy since there are extensive intertidal mud flats within the Little Swanport Estuary and these areas support many benthic invertebrates, including the gastropod *Zeacumantus diemensis*, which is a preferred prey of black bream (see Chapter 5).

Salinity appears to be a key factor influencing black bream movements and distribution, although other factors such as temperature, dissolved oxygen, food availability and habitat types may also be involved. Salinity has been recognised as one of the most important factors influencing the utilization of estuarine environments by fish fauna (Marshall & Elliott, 1998; Selleslagh & Amara, 2008). Although black bream are able to tolerate a wide range of salinities, ranging from 0-60 (Hoeksema et al., 2006), they have a preference for brackish water (10-25), typically found in the upper and middle reaches of estuaries, and move between regions to seek more favourable conditions. This suggestion is supported by Hindell et al. (2008) who found that the movement of black bream into the river systems of the Gippsland Lakes was associated with salt-wedge formation in the regions where haloclines of 17 and 20 occur. In the Little Swanport Estuary when salinities fell outside of this range as a result of freshwater inflows, fish generally moved further downstream, presumably seeking more favourable water conditions. Following particularly heavy floods, most fish actively moved, or were possibly swept away, from the upper estuary but tended to remain in the middle and lower middle region of the estuary for periods of several days. The deep waters of these

regions presumably provide an area of refuge, with higher salinities and reduced water flows compared with the upper estuary and shallower areas of the estuary. When salinities in the upper estuary returned to around 10, fish then moved back upstream. Although Lenanton et al. (1999) suggested that black bream may be flushed out of estuaries when subjected to heavy flood events, the present study provided no evidence to support this phenomenon for the Little Swanport Estuary.

There was in fact no clear indication that black bream left the Little Swanport Estuary during the present study, though movement out to sea by at least some individuals can not be discounted. With the exception of two individuals that were last detected by the receiver located at the mouth of estuary shortly before the receivers were removed, all other individuals detected in the lower estuary were subsequently re-detected further upstream. A tagging experiment in the Gippsland Lakes (Gorman, 1965) indicated that the majority of the tagged black bream were recaptured within the lakes, very few fish moved out of the lakes into the sea. Thus, although migration between adjacent estuaries is possible, it is unlikely that local estuarine populations are replenished by immigrants (Burridge & Versace, 2007). The sparid, *Pagrus auratus*, also exhibits localised movement patterns, with home ranges of within 20 km (Gilbert & McKenzie, 1999; Sumpton et al., 2003) and, despite their ability to move outside of their home estuary, this species also tends to remain within the system.

6.4.2. Spawning related movement

Previous studies have also indicated that spawning of black bream occurs in the upper estuary (Neira & Potter, 1992, 1994; Newton, 1996; Walker & Neira, 2001). Thus it is likely that some of the movement to B03 during the spawning season was related to spawning behaviour. In the present study, the average number of visit events per fish in the upper estuary was

relatively high between September and December, with average visit duration peaking during November. During the spawning period, individual fish spent up to a couple of weeks in the upper estuary, frequently moving back and forth between that region and the middle estuary. It is feasible that in the absence of significant freshwater discharges during the spawning period, as occurred during the 2004/05 spawning season (see Chapter 4), fish may spend longer periods in the upper estuary and the frequency of movement into and out of the region would have been less. By the end of spawning season in January, there was a sharp fall in the number and duration of visit events to the upper estuary, as fish moved further downstream, in particular to the middle estuary.

6.5. CONCLUSION

The present study has advanced our understanding of how black bream utilise estuarine systems. The tagging techniques used in this study were applied successfully, with high survival rates and relatively long-term tracking times. Movement patterns were very localised within the estuary, with no strong evidence of large-scale movement out of the estuary. This study has also provided an important understanding of the spatial and temporal utilisation of estuarine habitats by black bream, including the influence of tidal cycles. Finally, this study has revealed that freshwater discharge into the estuarine environment has a significant influence on the movement and spawning activities in black bream.

6.6. APPENDIX



Appendix 6. 1 Photograph showing typical water conditions near the position of B02. Water was clear with less than 1 m in depth.



Appendix 6. 2 Photograph of flood conditions encountered on 12th September 2005 at the same location as above. Water level was approximately 3 m higher than normal condition.

CHAPTER 7

GENERAL DISCUSSION

Estuaries represent a challenging environment to inhabit due to their strong temporal and spatial environmental variations. Animals in these ecosystems therefore must have biological and ecological adaptations to cope with such unstable environments. The main objective of this study was to examine the relationships between the estuarine environment, habitats and life-history strategies of black bream. This study has increased our understanding of how the black bream has adapted to life in estuaries and of the interrelationship between the species and its environment. Developing an understanding of these characteristics of a species is also important to achieving effective habitat conservation and sustainable fisheries management.

7.1. KEY CHARACTERISTICS FOR LIVING SUCCESSFULLY IN ESTUARINE ENVIRONMENTS

Most fish found in estuarine environments exhibit one of three distribution patterns; 1) adults are found offshore and only juveniles occur in estuaries, 2) juveniles and adults occur in both offshore and estuarine areas (Blaber, 1991), or 3) both juveniles and adults are restricted to estuaries. There are relatively few species in the third class, probably because only a few species have adapted to the environmental instability of estuaries. Black bream is a species in which both juveniles and adults appear to be confined to estuarine environments, exhibiting various adaptations to life in those systems (Table. 7.1). Black bream, like all estuarine-dependent species, must deal with the environmental variability either by avoiding unfavourable conditions or having wide tolerance. Tolerating a wide range of environmental conditions, especially salinity, is probably the most important adaptation to estuarine life, and many estuarine-dependent species, such as gobies and mullets, can tolerate a wide range of salinities (Potter et al., 1993; Larson & Hoese, 1996; Potter et al., 1997; Hoeksema et al., 2006).

Regarding reproduction, spawning in the upper estuary is advantageous because survival of offspring is likely to be higher, firstly because of reduced predation pressure and secondly because of reduced interspecific competition, as few other fish species inhabit the region. It also reduces the chance of eggs and larvae being flushed out of estuaries. However, this reproductive strategy involves a trade-off against the more unpredictable and unstable environmental conditions found in the upper estuary (Chapter 2) which may cause high mortality of early life stages (Chapter 4). Thus this strategy can result in years of poor recruitment due to unfavourable conditions, resulting for instance from heavy freshwater inflows during the spawning season (Chapter 4). The estuarine silverside, *Odontesthes argentinensis*, displays a similar reproductive strategy with regard to spawning site selection. This species spawns on submerged vegetation in saltmarshes where they are in a protected and calm environment that increases egg survivorship (Beheregaray & Levy, 2000). Black bream has evolved reproductive strategies that minimize such catastrophic recruitment failure by having a protracted spawning season (Chapter 4), providing more than one opportunity to spawn within a season (Sarre, 1999). This increases the number of eggs that can be produced within a spawning season and spreads the risk of spawning all eggs at a time of unfavourable conditions (McEvoy & McEvoy, 1992; Abaunza et al., 2008). Because changes in environmental factors, such as temperature, salinity and dissolved oxygen, are quite normal in estuarine ecosystems and constrain the survival of eggs and/or larvae, a prolonged spawning season is a key adaptation for estuarine-spawning species. Short-lived species in particular, such as *Pomatoschistus* spp., cope with environmental instability by having more than one spawning peak in a single breeding period (Mazzoldi & Rasotto, 2001; Dolbeth et al., 2007). Black bream also spread the risk to the population of recruitment failure over a year-to-year

timescale through a long life span (Chapter 3), thereby increasing the number of spawning seasons of an individual fish and thus providing the population with resilience against long-term recruitment variability. A long life span also means that individual populations are made up of multiple age classes. Several studies have in fact indicated that annual recruitment failures have been experienced in black bream populations (e.g. Coutin et al., 1997; Morison et al, 1998; Coutin, 2000; Sarre & Potter, 2000), yet the existence of many age classes in each population has buffered against population collapse.

Black bream consume a wide variety of food including plant, crustacean and molluscs, and can shift food sources as they inhabit at different regions and estuaries (Chapter 5), indicating that black bream are opportunistic omnivorous with substantial flexibility in the diet, which enables the species to exploit temporal and spatial peaks in prey populations. This feeding flexibility has clearly contributed to the success of this species in estuarine environments, where invertebrate communities may change dramatically in space and time. It is not surprising that estuarine-dependent fish often show such feeding flexibility (Humphries & Potter, 1993; Ley et al., 1994; Pasquaud et al., 2008).

Table 7. 1 Summarizes these adaptations of black bream to the estuarine environment.

Characteristic	Relevant Estuarine Characteristic	Strategy
High mobility within an estuary	Unpredictable environmental changes, such as flood events	Seek more favourable conditions at a large spatial scale
Spawning and juveniles restricted to the upper estuary region	Increased interspecific competitions and predation in downstream regions	Increase survival rates of larvae and juvenile, providing better growth, and reduce interspecific competition and predation
Protracted spawning season	Unpredictable freshwater inflows	Spread risk of spawning failure spread through year
Long life span	Variable environments during the spawning season, resulting in recruitment variability	Spread risk of spawning failure over many seasons
Broad diet and feeding flexibility	Strong seasonal and/or annual fluctuations in the abundance of prey	Switch between food sources as the relative abundance of the prey changes spatially and temporally

7.2. IMPLICATIONS OF LIMITED INTER-ESTUARINE MOVEMENT

Black bream are highly mobile, being capable of moving over great distances (e.g. $>6 \text{ km d}^{-1}$) (Hindell et al., 2008) and are able to tolerate fully marine conditions. However, in this study their distributional range was restricted to within an estuary with no clear indication that individuals moved out of the system (Chapter 6). This study has suggested that it is unlikely that black bream move out of the study estuary, even during heavy flood events (Chapter 6). However, in other estuarine ecosystems, with different topography and bathymetry, flood events similar in magnitude to the flood that occurred during this study may flush the fish, or cause them to move actively, out of the estuary to seek more favourable conditions. In fact, there is evidence that some black bream are flushed out of estuaries into the nearshore water

when subjected to extreme flood events, providing opportunity to move individuals between adjacent estuaries (Chaplin et al., 1998; Lenanton et al., 1999).

This study strongly supports the fact that spawning in black bream mainly occurs in the upper estuary (Neira & Potter, 1994; Haddy & Pankhurst, 1998; Walker & Neira, 2001) (Chapter 2 & 4), and thus such reproductive behaviour limits egg and larval dispersal between estuaries. As no egg or larvae of this species have been recorded at sea, there is no evidence for inter-estuarine dispersal of eggs and larvae (Burridge & Versace, 2007).

Wade & McCauley (1988) suggested that the population structure of many species can be considered as an array of local populations linked by variable degrees of gene flow, and recently scientists have used metapopulation theory to describe the population structures of fish species (e.g. Man et al., 1995; McQuinn, 1997). Chaplin et al. (1998) reported that there was an absence of fixed allelic differences between black bream populations in different estuaries of Western Australia, although there were relatively low levels of allozyme variation. Comparative homogeneity of allele frequencies has been also reported in black bream populations of South Australia (Burridge & Vincent, 2007), suggesting that populations in those regions have been connected by gene flow in the relatively recent past. Considering this, the whole Australian black bream population and Tasmanian sub-population are probably made up of a large number of metapopulations, but with limited exchange between local subpopulations.

7.3. ECOLOGICAL IMPORTANCE OF BLACK BREAM

Although estuaries are relatively sheltered productive environments associated with a variety of habitats, they are subjected to variable environmental conditions, especially salinity,

resulting in a reduced diversity of large predatory fish. Black bream are, however, very abundant predatory species in estuaries, and may play an important role in keeping some invertebrate population in check, because they seem to feed on the most abundant prey items, switching between food sources as the relative abundance of preys changes over time and among different regions and locations. If black bream become less abundant or extinct in a given estuary, the local estuarine ecosystem may be seriously affected due to removal of this predator.

Estuarine systems provide essential nursery grounds for many fish species. Over the past decades, estuarine environments have been increasingly exposed to anthropogenic impacts including land reclamation, pollution, eutrophication and introduction of invasive species (Elliott & Hemimgway, 2002; McLusky & Elliott, 2004). Due both to fishing or to other indirect human effects, there have been changes in biological communities and fish diversity may have become unbalanced (Levin et al., 2006). Since black bream are less likely to leave estuaries, they are reliant on a healthy habitat, a productive food chain and good water conditions to maintain healthy populations within a particular estuary. The black bream is an important ecological indicator to assess environmental quality and support decisions in management and conservation plans.

7.4. EFFECTS OF CHANGES IN FRESHWATER INFLOWS

Freshwater inflow has been recognised as an important factor influencing nutrient input levels (Drinkwater & Frank, 1994), to maintaining salinity gradients (Blaber & Blaber, 1980; Whitfield, 1994b), the biochemical properties of estuarine ecosystems (Whitfield, 1999), and triggering spawning events in some fish species (Strydom et al., 2002). The strong temporal and spatial environmental variability found in estuaries is largely due to the frequency and

magnitude of freshwater discharges into the systems. Variation in the amounts and periodicity of freshwater discharge may be the factor that controls the difference in diversity of estuarine resident fish species between regions. In south-western Australian estuaries, there are several estuarine residents; e.g. seven species including *Acanthopagrus butcheri*, *Leptatherina wallacei* and *Pseudogobius olorum* have been recorded in Normalup-Walpole Estuary (Potter & Hyndes, 1994) and six species have been recorded in the Swan River Estuary (Potter & Hyndes, 1999). By contrast, in southern African and Tasmanian estuaries there are relatively few estuarine residents (Crawford et al., 2005; Elliott et al., 2007); e.g. three species namely *Hyporhamphus capensis*, *Gilchristella aestuaria* and *Syngnathus watermeyeri* were recorded in the East Kleinemonde Estuary (James et al., 2008a) and one species, namely *Acanthopagrus butcheri* has been recorded in the Little Swanport Estuary (Crawford et al., 2005). In south-western Australia, there is a strong seasonality in rainfall and thus restricted freshwater discharge; heavy freshwater discharges are largely confined to winter and spring (Sarre, 1999). Although rainfall in Tasmania is seasonal, occasional unpredictable flood events may occur throughout the year (Edgar et al., 1999). An unpredictable environment can increase mortality of eggs, larvae and adults, and may make Tasmanian and southern African estuaries difficult to inhabit for such species.

The increasing rate of global climate change has significantly impacted the coastal and marine environment (Arnell, 1999; Mirza, 2003). Sea temperature has increased steadily, resulting in an increase in species richness in temperate regions due to increasing occurrence of tropical and sub-tropical species (Cabral et al., 2001; Mbande et al., 2005). Climate change predictions for south-eastern Australia, including Tasmania, indicate a reduction in rainfall and an increase in temperature (CSIRO, 2007). In fact, rainfall in south-eastern Australia has been

declining continuously for a decade (CSIRO, 2007), resulting in a reduction of freshwater discharges into the estuarine ecosystem. However, climate change is also predicted to increase the frequency and magnitude of extreme weather events such as droughts and floods (Short & Neckles, 1999; Hughes, 2003; Warren et al., 2006), increasing the variability in the amount of freshwater inflows (Pittock, 2003a; Pittock, 2003b).

Alterations to freshwater inflow to estuaries will have serious implications for estuarine environment (Fig. 7.1), influencing overall estuarine health, and the resilience of estuarine habitats to human impacts. Water quality (flow, chlorination, temperature, dissolved oxygen, pH and suspended solids) is affected by drought, and freshwater flows can be important in diluting pollutants and maintaining oxygen levels. Reduced freshwater inputs can enhance eutrophication in polluted estuaries due to decreased flushing potential of the estuary, and the interaction of flow-induced changes in the nutrient environment, elevated nutrient levels due to anthropogenic pollution, and alterations in phytoplankton composition. Decreasing freshwater inflows will allow the incursion of saline waters further upstream into regions previously influenced largely by freshwater (Attrill et al., 1996). Increased intrusion of seawater is likely to affect marine plant distributions by changing conditions at specific locations, causing relocations, decline and/or loss of some plant species (Short & Neckles, 1999). Vegetated habitats are particularly important for juvenile fish providing food (Bell & Pollard, 1989), protection from environmental disturbance (Edgar, 1990) and shelter against predation (Orth, 1992; Hindell et al., 2000; 2002). Specifically, in the upper regions of the studied estuaries *Ruppia megacarpa* seagrass beds are important in providing shelter and habitats for epifauna, which is an important food resource for juveniles, and seagrass and algae are important components of the diet of adults (Chapter 5). Decreased freshwater inflows will

also influence the estuarine fish community directly (Elliott, 2002; Kimmerer, 2002; Whitfield & Harrison, 2003) since many estuarine-dependent species are sensitive to freshwater inflows (Meynecke et al., 2006; James et al., 2008b). Marine fish species will potentially become more abundant, whereas the abundance of estuary-dependent fish species will decline (e.g. Mbande et al., 2005; Meynecke et al., 2006; James et al., 2008b). For example, catch rates of estuarine-dependent species such as mullet, *Mugil cephalus*, and barramundi, *Lates calcarifer*, have already shown reductions during dry years associated with El Niño (Meynecke et al., 2006). Moreover, Martinho et al. (2007) recorded a strong negative correlation between freshwater inflows and marine adventitious species and a decrease in abundance of the estuarine resident species such as gobies during the driest period in the Mondego River Estuary, on the western coast of Portugal. As most estuarine resident fish are small, predation on those species could increase due to an increase in the abundance of larger marine species. Loss of brackish water habitat in the upper and middle estuary due to the incursion of seawater will become a critical problem, resulting in loss of important nursery grounds and estuarine habitats (Faria et al., 2006). Additionally, hypersalinity in the upper estuary may cause mortality of some fish and moving into the further upper estuary (Young & Potter, 2002).

Since black bream are highly adapted to unstable conditions, they are unlikely to become extinct and will potentially cope with changed/ altered environment conditions. However, reduced inflows combined with seawater incursion can cause hypersaline and hypoxic water in estuarine ecosystems (Nicholson et al., 2008), especially in the upper estuary region, and may result in increased predation pressure due to the invasion of marine species, thus potentially affecting the spawning success of black bream. A long term reduction of inflows may cause modifications to spawning behaviour. For example, black bream may seek to migrate further

upstream into areas where brackish water still occurs. However, there are often natural physical barriers, such as shallow waters in river systems, which may prevent fish from migrating further upstream, resulting in loss of spawning habitat and/or spawning failure. Loss of brackish water habitat in the upper and middle estuary is particularly critical and may result in a distributional shift of black bream.

Extreme flood events can cause habitat alteration (James et al., 2008b) and rapid change in environmental factors such as salinity and temperature, resulting in changes in the distribution and abundance of fish species. They may also cause large-scale mortalities of fauna (Whitfield & Paterson, 1995; Steffe et al., 2007) and habitat degradation due to deoxygenated waters caused by decomposition of vegetation, and increased hydrogen sulphide produced by anaerobic bacteria after flood events (Steffe et al., 2007). Furthermore, sudden increases in river flow may cause mortality or advection of fish eggs and larvae out of the system (Faria et al., 2006), resulting in recruitment failures. As indicated in the present study, heavy freshwater discharge during the spawning season negatively influenced reproduction (Chapter 4) and disturbed upstream spawning behaviours in black bream (Chapter 6).

In estuarine areas especially, anthropogenic pressures, including residential and industrial developments, recreational activities, aquaculture and harvesting can impact both the biotic (i.e. fish abundance) and abiotic components (i.e. freshwater inflows) of the system (Whitfield & Elliott, 2002), and produce environmental degradation leading to the decline and/or the loss of habitats in the ecosystem (Griffiths, 2001). Over past decades, increasing numbers of dams have been built on coastal rivers for use in flood control, energy supply, water supply and recreation. However, such artificial structures modify downstream freshwater inflow, and generate hydrological changes in estuarine ecosystems which can result in changes of

associated fauna and flora. In fact, many Australian river systems, as well as estuarine systems, have been degraded through changes in freshwater inflows via dams and weirs principally for irrigated agriculture (Norris et al., 2001; Pittock, 2003b). Hydrological conditions such as the extent, timing and duration of floodplain inundation have been significantly modified, resulting in increases in nutrient and suspended sediment loads, and loss of aquatic fauna and flora in relation to habitat degradation (Norris et al., 2001). Construction of dams alters how rivers function and causes significant ecological degradation in downstream regions (Edgar et al., 1999; Norris et al., 2001) and interference with the normal hydrological regime of salt wedge estuaries by practices such as damming, desnagging and rivermouth alterations could have serious implications for the successful spawning of estuary spawners such as black bream. It has already been reported that environmental water flow conditions modified by dams and weirs have resulted in significant declines of estuarine-dependent fish, such as barramundi (*Lates calcarifer*) (Walker, 1985). It is essential that natural flows in estuarine environments are protected in order to maintain the diversity of estuarine habitats, fauna and flora and protect these ecosystems against future climate change.

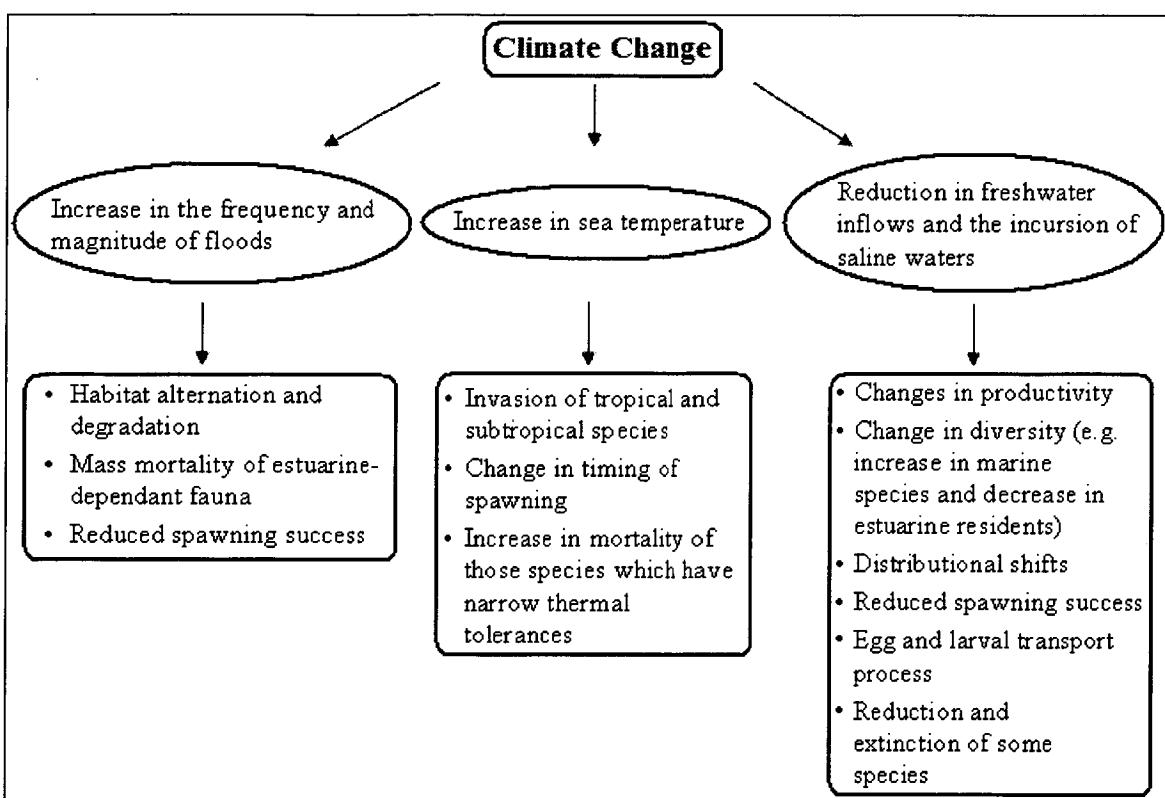


Figure 7. 1 Summarizes the effects of climate change on the biotic communities in temperate estuaries.

7.5. IMPORTANCE OF ECOLOGICAL AND BIOLOGICAL DATA FOR MANAGEMENT

An understanding of the physical and ecological characteristics of the environment and their effects on the biology and ecology of fish is essential for their proper use and management. For instance, while catch rates from surveys conducted at regular intervals can be used to determine how distribution and abundance change, information on fish stocks is essential to set bag limits, in order to prevent over-fishing and to inform other management options required to ensure sustainability. Understanding movement dynamics is informative in determining whether neighbouring populations can be considered to be either a single or separate stocks (King, 1995). An understanding of habitat utilization is also important and of particular ecological interest in identifying which habitats are required for spawning, early-life

stages, and feeding, and how different physical environmental conditions influence the distribution and behaviour of fish. These ecological data are particularly crucial for species such as black bream which form aggregations and heavily exploited by fishers.

Information on reproductive dynamics is particularly important for fishery management. Knowledge of size at first maturity is important in setting effective minimum legal lengths to ensure that individuals are allowed to spawn at least once (Hancock, 1992). The decline of many fisheries has been a consequence of reduced recruitment caused by low levels of spawning populations (King, 1995). To prevent overexploitation of spawning stocks, there is a need for detailed information on spawning, including timing, location and duration. This can provide information on environmental requirements for spawning, such as habitat types and water quality. Based on these data, various management measures such as seasonal and/or spatial closures can be applied. In the following section specific recommendations for the management of black bream populations in Tasmania will be made, based on the findings of this study.

7.6. RECREATIONAL FISHERY MANAGEMENT ISSUES

This study has provided new data and insights that can be applied to the management of black bream in Tasmania. The size at 50% maturity for female black bream in the two east coast estuaries is 219-227 mm fork length (FL), which is equivalent to between 240-250 mm total length (TL), while males mature at smaller sizes; 181-185 mm FL or 199-203 mm TL. The current minimum size limit in Tasmania is 250 mm TL (approximately 225 mm FL), which is very close to the estimated size at 50% maturity for females (Chapter 4). As the current minimum size limit does not provide for spawning in most females, a more appropriate size

limit would perhaps be 300 mm TL, which would enable virtually all females to spawn at least once.

This study suggests that there is little or no mixing of black bream populations between estuaries (at least east coast estuaries with a structure similar to the Little Swanport Estuary), it is unlikely that local populations would be replenished by immigrants and thus each population will be largely dependent on its own recruitment. Furthermore, aggregating behaviour during the spawning season has the potential to attract increased fishing activity, placing further pressure on the stocks. Further protection of spawning fish may be required to maximize the potential of each estuarine population to be self sustaining, especially if, as expected, fishing pressure is likely to increase on the species (Lyle, 2005). Since black bream are more vulnerable to capture during spawning, as a consequence of aggregation behaviour, closures of critical spawning grounds (the upper estuary) during times of heightened reproductive activity (September to January) will increase spawning potential. Alternatively, consideration would be given to the closure of the recreational fishery during the spawning season, particularly during the peak of spawning period (November and December), providing protection for the spawning fish.

7.7. FUTURE RESEARCH NEEDS

This study has provided information on the main biological and ecological characteristics of black bream and has substantially improved our understanding of the species in Tasmanian estuaries. However, there are several key areas where further study is required.

Data on the distribution, reproductive biology and movements of black bream have identified the importance of the upper estuary region. Mature fish migrate upstream and utilize this

region, particularly during the spawning season, while juveniles depend on the region throughout the year. Identifying more specifically the types of habitats which adults require for spawning and those in which juveniles settle would provide further important information on aspects of the early life history of this species. Such data would be particularly valuable to facilitate the protection of such habitats from potential environmental disturbance and in suggesting in-stream works that could enhance the habitat (e.g. Hindell, 2007), and also important in predicting impacts of climate change or changes in freshwater inflows.

The present study, as the previous dietary studies (e.g. Willis et al., 1999; Sarre et al., 2000; Benjamin et al., 2007), have indicated that plant material is a significant component of the gut contents of this species. However, it is still unclear how plant material contributes to energy uptake. Further work is required to understand the role of plant material in the diet of black bream, and techniques such as stable isotope analysis could be used to identify the proportion of energy obtained by this species from plant materials (e.g. Rayner, 2006).

Time and logistic constraints during the two years of this study have restricted data on population size and age structure. Since previous studies have indicated that black bream show significant recruitment variability between years (e.g. Coutin et al., 1997; Morison et al., 1998; Coutin, 2000; Sarre & Potter, 2000), further long-term work is required to gain a better understanding of year to year variability in age structure, and to identify factors that impact recruitment success. Furthermore, studies from a greater geographical range of estuaries would produce more general results for management of the species State-wide.

A further study on movement patterns of black bream is required to better understand behaviour during the spawning season. This study has provided information on local

movement patterns of this species and improved understanding of reproductive dynamics in terms of timing and location of the spawning activity (Chapter 6). However, during the present acoustic telemetry study, the freshwater discharges were relatively large compared with past years, possibly resulting in abnormal reproductive behaviours, such as more frequent movement in and out of the upper estuary. Identifying how black bream behave during years when there is a more normal discharge pattern throughout the spawning season, and comparing such data with the present study, will improve our understanding of reproductive behaviours of this species. Furthermore, a better understanding of migratory movement between estuaries is also important. Such study, carried out using genetic markers, would provide information on the appropriate spatial scale for management and the potential risks of localised overexploitation. An investigation of movement during flood events in estuarine systems larger and smaller than the Little Swanport Estuary would also confirm the generality of the patterns observed here.

To understand ecological importance of black bream, it would be interesting to investigate how absence of black bream affects other estuarine fauna by conducting some field experiments. The field experiments could involve excluding black bream from areas of an estuary and identifying how the rest of the fauna responds.

Since fish species and communities are sensitive to environmental changes in estuarine environments (Whitfield & Elliott, 2002), they have been used to indicate changes in the estuarine environments (Whitfield, 1997; James et al., 2008b). Long-term studies of black bream populations, their habitat usage in response to environmental changes, including temperature, freshwater flows and habitat alteration, will help to illustrate the effects of on-

going environmental changes on estuarine fish communities, and also help to define habitat health in a given estuary.

7.8. CONCLUSION

This study has considerably broadened our understanding of black bream biology and ecology. The ecology, especially in terms of reproduction of black bream appears to be closely linked to environmental conditions in estuaries. Although they are well adapted to estuarine environments, environmental shift could cause significant decline of this species. Further investigations of the kind outlined above will improve our understanding of the complex relationships between black bream and the estuarine environment, and the impacts of climate and habitat variability on this ecologically and recreationally important species.

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