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Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munro) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states

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Fish for the future

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Fisheries research in Western Australia

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The primary function of the Fisheries Research Division is to provide scientific advice to government in the formulation of management policies for developing and sustaining Western Australian fisheries.

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Abstract

This synopsis presents a review of the literature and research to April 2001on the biology of black bream, Acanthopagrus butcheri *(Sparidae), particularly in relation to Western Australian populations.* A. butcheri *is a commercially and recreationally important species, and is endemic to the coastal lakes, estuaries, river systems and sheltered coastal waters of southern Australia, including Tasmania. Separate stocks reside within each river/estuarine system in southwestern Australia, and there is considerable variation in feeding, growth rates and age at maturity among stocks. For rivers/estuaries that are seasonally flushed in winter, downstream movement with the flush is followed by the annual upstream spawning run located near the encroaching salt wedge in spring or early summer. Further biological information on habitat, behaviour, mortality, age, maturity, parasites, reproduction, sex ratio and physiology are presented. There is considerable temporal variation in the strength of recruitment, which is reflected by variation in Western Australia's annual total commercial catch: fluctuating between 19 and 104 tonnes in the last 10 years. The history and current status of the fishery, particularly in Western Australia, are discussed. Recent aquaculture developments have led to captive bred and reared* A. butcheri *being released into private farm dams as well as being used for wild stock enhancement for recreational fishers. Biological parameters useful for stock assessment modelling are also presented.*

1.0 Introduction

The black bream, *Acanthopagrus butcheri* (Munro 1949), is a recreationally and commercially important fish species endemic to southern Australia. A truly estuarine species, *A. butcheri* is distributed from Western Australia to New South Wales, including Tasmania. In Western Australia, it is fished both recreationally and commercially in the estuaries and river systems of the lower west and south coastlines. The species has also been introduced into farm dams in southwestern Australia.

Normally, only published information is used as a basis for a synopsis. However, to maximise the amount of information available for the development of future research programs and management of both the commercial and recreational fisheries for *A. butcheri*, all useful and available published and unpublished literature to April 2001 has been cited.

Biological parameters useful for stock assessment modelling have been estimated for various different *A. butcheri* stocks and are presented in Appendix 2. Many parameters remain unknown. It is hoped that ongoing and future research will fill in many of the gaps in our knowledge and be incorporated into future revisions of this report.

This synopsis has been compiled as one of a series on key species which are commercially and recreationally important in Western Australia.

2.0 Taxonomy

Acanthopagrus butcheri is a member of the family Sparidae. Six closely related species of "bream" from this family occur in Australian waters; five (including *A. butcheri*) belong to the genus *Acanthopagrus*, and one to *Rhabdosargus* (Munro 1949). *Acanthopagrus butcheri* was distinguished from *Mylio australis* by Munro (1949) in his early revision of Australian silver breams.

Valid name: *Acanthopagrus butcheri* (Munro 1949)

Common names: *Acanthopagrus butcheri* may be commonly referred to as black bream, Perth bream, grunter, southern black bream, Gippsland bream, southern yellowfin bream, blue-nosed bream, bream (Starling 1988).

Classification:

Class	Teleostomi
Subclass	Actinopterygii
Order	Perciformes
Suborder	Percoidei
Family	Sparidae
Genus	*Acanthopagrus*
Species	*butcheri*

Synonymy:

Mylio australis (Gunther 1859 [as cited by Munro (1949)])
Mylio butcheri (Munro 1949)

Description: Full description given by Munro (1949).

Acanthopagrus butcheri is distinguished from *A. australis* (yellowfin bream) by the dark brown colour of the body and lack of canary yellow colouration on anal and ventral fins (they are usually brown-grey). Fin ray counts are homogenous throughout its range and *A. butcheri* cannot be distinguished from other *Acanthopagrus* spp. on this basis.

Modal formula:- D. XI + 12 ; A. III + 9 ; V. I + 5 ; P. 15.

There are some slight differences in head proportions and lengths of anal fin spines and rays between *A. butcheri* and *A. australis*.

Scales:Lateral line scales 50-62 with mean and mode of 55 (187 specimens), diagnostic as mode greater than in *A. australis* (52) and other *Acanthopagrus* spp. (50).

Five scale rows above lateral line; 13-17 scale rows below lateral line with mean of 15-16, diagnostic as all other *Acanthopagrus* spp. have 13 or fewer rows.

Scales differ from those of *A. australis* in having a wider ctenoid margin containing an additional series of spines.

The double bifurcation of the lateral line tubules distinguish *A. butcheri* from other species except *A. australis*.

Gill-rakers modal formula 7 + 9 = 16. *A. australis* is identical.

Related Species: Other species of bream found in Australian waters are:-

1. *Acanthopagrus latus* (Houttuyn). Commonly called western yellowfin bream, it inhabits coastal rocky shores and reefs from Shark Bay, Western Australia northwards (Allen and Swainston 1988).

2. *Acanthopagrus australis* (Gunther). Commonly called yellowfin bream, eastern black bream, black bream, silver bream, blue-nose bream (Starling 1988), it is distributed from Queensland (Townsville), through N.S.W. to Victoria (Mallacoota) (Hutchins and Swainston 1986). The distribution of *A. butcheri* and *A. australis* can overlap in estuarine systems between Narooma in southern N.S.W. and the Gippsland Lakes, Victoria (Starling 1988). *A. australis* is best distinguished from *A. butcheri* by its yellowish ventral and anal fins (brownish to dusky in *A. butcheri*) (Hutchins and Swainston 1986), but Weng (1971) considered *A. butcheri* and *A. australis* to be one species. Conclusions by Weng (1971) concerning the biology of *A. butcheri* tend to be generally inconsistent with other authors, however, suggesting he may have in fact been studying *A. australis*.

3. *Acanthopagrus berda* (Forskal). Commonly called the pikey bream, bream or black bream, it is a close relative of the yellowfin bream (*A. australis*) and is distributed from Exmouth Gulf in Western Australia around northern Australia to central Queensland. Pikey bream are abundant in tropical mangrove estuaries (Starling 1988).

4. *Acanthopagrus palmaris* (Whitley). Commonly called north west black bream, it inhabits coastal rocky shores and reefs from Shark Bay, Western Australia, northwards (Allen and Swainston 1988).

5. *Rhabdosargus sarba* (Forsskal). Commonly called tarwhine or silver bream, it is

common in coastal waters of eastern and western Australia, often entering estuaries. Occuring in Queensland, New South Wales, and Victoria (to Gippsland Lakes), and Western Australia (Albany to Coral Bay), it is distinguished from *A. australis* and *A. butcheri* by a greater number of scale rows above its lateral line (6-7 versus 4), golden lines along its body, and a third anal spine equal in length to the second (noticeably shorter in *A. australis* and *A. butcheri*). Ventral and anal fins are yellow to yellowish orange, usually fading to a paler colour with age (Hutchins and Swainston 1986).

Hybridization: Rowland (1984) examined the hybridization between *Acanthopagrus butcheri* and *A. australis* from estuaries near Narooma on the south coast of New South Wales. Individuals which displayed morphometric characteristics intermediate to the two species were also heterozygous for alleles that are otherwise fixed and separate between the species, thus establishing their hybrid status. Three individuals were found with allelic characteristics of *A. butcheri* at one locus and *A. australis* at another: evidence that they are backcross hybrids thereby making the F1 hybrid generation reproductively viable. Electrophoretic analysis found a close relationship between the two species (I = 0.91), suggesting a recent speciation. Under normal circumstances the reproduction of *A. butcheri* and *A. australis* is temporally and spatially isolated, but in some landlocked coastal lakes there is a breakdown of these isolating mechanisms. Although hybrids can be caught in some estuaries near Narooma, Rowland (1984) suggests that their specific status be retained, as they appear to only hybridize under the unusual environmental conditions of closed lakes. Farrington *et al.* (2000) also found a close genetic relationship (I = 0.95) but there was no evidence of hybridisation, supporting their recognition as separate species.

3.0 Distribution

3.1 Geographical distribution

A. butcheri is distributed from Myall Lake, New South Wales west to the Murchison River, Western Australia (Rowland 1984), where it is common in estuaries and river mouths (Figure 1). The lack of this type of habitat across the Great Australian Bight suggests the species is rare in this region (Kailola *et al.* 1993). It is also found in the tidal rivers of Tasmania and the southern islands of South Australia such as Flinders Island and Kangaroo Island (Munro 1949; Starling 1988). The Onkaparinga River, and the rivers of Kangaroo Island, South Australia, provide good bream fishing (Scott *et al.* 1974), as do the Gippsland Lakes, Victoria (Ling 1958; Munro 1949). Occasionally it is found in coastal waters.

In Western Australia, *A. butcheri* is common in most river/estuarine systems in the south-west as far east as the Esperance region (Figure 2). These include the Peel-Harvey, Leschenault, Blackwood, Broke, Frankland, Wilson, Nornalup-Walpole, King, Kalgan, Pallinup, Stokes, Barker and Wellstead Rivers/Estuaries and Oyster Harbour (Chubb *et al.* 1979; Cusack and Roennfeldt 1987; Lenanton and Hodgkin 1985; Potter *et al.* 1990; Potter and Hyndes 1994; Sarre 1999). Wild stocks from the Bremer River were introduced to Lake Dumbleyung, and captively bred individuals from Swan River broodstock have been introduced to numerous farm dams (Lenanton *et al.* 1999; Sarre *et al.* 1999) (Figure 1).

Lenanton (1977) sampled the fish and crustacean fauna of the Blackwood River Estuary on a bi-monthly basis from March 1974 to March 1975, and in July 1975. Sampling equipment consisted of seines, set (gill) and plankton nets, and otter trawl. *A. butcheri* were taken in all regions that were sampled, but were most abundant in catches between 8 and 14 km from the mouth, the most upstream region in the study. Nearer the mouth of the estuary, the take was highest in July and September. A total of 758 were taken by seine nets, and 1,025 by set nets with the size range between 12 to 41 cm (total length, TL). Valesini *et al.* (1997), however, caught no *A. butcheri* in the Blackwood River Estuary twenty years later when they used a similar sampling methodology to study the icthyofauna.

Potter *et al.* (1983) sampled the fish fauna of the Peel-Harvey estuary. Fish were sampled at 6-week intervals from August 1979 until August 1980 using beach seines, gill nets, and otter trawls. *A. butcheri* caught by all methods was 0.01% (16 individuals) of the total catch and the fish ranged in size from 149 to 367 mm TL (average = 227 mm).

Loneragan *et al.* (1989) sampled the fish fauna of the permanently open Swan Estuary, Western Australia, between February 1977 and December 1981. *A. butcheri* were caught by beach seines (0.4% of total beach seine catch), gill nets (1.2% of total gill net catch), and otter trawls (0.4% of total otter trawl catch). The length of *A. butcheri* caught by beach seines ranged from 23 to 490 mm TL (mean = 170 mm), by gill nets from 102 to 408 mm TL (mean = 290 mm), and by otter trawl from 86 to 311 mm TL (mean = 143 mm). The number caught increased from the lower estuary to the upper estuary.

Potter *et al.* (1993) sampled the fish fauna of the large, seasonally closed Wilson Inlet/Estuary on the southern coast of Western Australia. Seine and gill nets were used bi-monthly between September 1987 and April 1989 and *A. butcheri* caught in gill nets accounted for 1.1% of the total number of fish caught. Individuals ranged in size from 155 to 459 mm TL, with a mean of 258 mm (N = 66) and were taken from the upper reaches of the system (Hay River), during the dry period.

Potter and Hyndes (1994), in a similar study, took bi-monthly samples using gill and seine nets in the Nornalup-Walpole Estuary, and gill nets in the Wilson Estuary, between October 1989 and August 1990. *A. butcheri* was mainly found in the upper reaches or tributaries of these estuaries. A total of 297 were caught in the Nornalup-Walpole Estuary, ranging in size from 80 to 350 mm in total length but less than 51 were taken from Wilson Inlet.

Chapman (1995) recorded *A. butcheri* in the Fitzgerald, Phillips, Gairdner and Jerdacuttup Rivers. In the Fitzgerald River they were recorded as far upstream as Jonacoonack, about 35 km from the river mouth.

Young *et al.* (1997) used seine nets to sample the ichthyofauna of the upper, middle and lower reaches and mouth of the Moore River Estaury on the lower west coast of Western Australia, sampling monthly between February 1994 and February 1995. A total of 5,705 *A. butcheri* were caught with a combined biomass of 20.07 kg, comprising 5.4% and 14.9% of the number and biomass across all fish species, respectively. There was a positive correlation between *A. butcheri* population density and distance from the estuary mouth.

Sarre (1999) conducted monthly sampling in the upper reaches of the Swan Estuary from September 1993 to April 1995 (see 4.2 Behaviour). Seine and gill net catches combined suggest a downstream movement with winter flushing of the estuary followed by an upstream migration in spring. Between late spring and late autumn *A. butcheri* mainly occupies the upper reaches of the Swan Estuary.

A. butcheri in Western Australia may be considered a true estuarine species as it completes its life cycle within the estuary (Sarre and Potter 1999) (see Figure 3). Although an estuarine species, land locked populations do occur in Western Australia, such as Lake Gore and the Dalyup River (Lenanton 1974), and Lake Clifton (Sarre 1999; Sarre and Potter 2000), as well as in permanently closed estuarine systems in the more easterly regions of southern Western Australia (Lenanton and Hodgkin 1985).

3.2 Habitat requirements

A. butcheri is common in rivers and estuaries of Western Australia and almost never leaves the estuary unless flushed out to the ocean under conditions of extreme flooding (*e.g.* Culham Inlet in 1993) (Lenanton 1977). The preferred habitat includes overhanging banks amongst the branches of dead trees which lie on the bottom of deep, low-salinity pools in most rivers in Western Australia (Sarre, pers. comm.). Deep pools with moderate salinity and high dissolved oxygen are also a preferred habitat in the Hopkins River estuary in southwestern Victoria (Newton 1996) but they will sometimes travel upstream into fresh water (Starling 1988). Sherwood and Backhouse (1982) found that when the salt wedge has been flushed from the Hopkins River, Victoria, many *A. butcheri* leave the estuary and frequent sheltered marine areas such as nearby reefs, where they may be caught by sea anglers, but some may still be caught by estuary anglers even when the river is completely fresh.

In Western Australia, *A. butcheri* can be found in shoreline habitats after excessive flooding of river systems and under these circumstances they prefer sheltered waters such as protected embayments. They can also be found in marinas along the west coast (Lenanton *et al*. 1999).

Zostera, a seagrass, acts as a nursery and cover for young fish, and provides a habitat for shellfish and other food organisms of importance to bream (Butcher 1945a). The almost complete disappearance of formerly extensive *Zostera* beds in the Gippsland Lakes, Victoria, has resulted in a decline in bream stocks (Butcher 1945a). According to Hobday and Moran (1983), the most successful year classes in the Gippsland Lakes are spawned during periods of low river flow. This conclusion contrasts with that of Ramm (unpubl. a) for the same region, and Chapman (1995) for the Hammersley and Culham inlets in southwestern Australia, who claim that high recruitment is associated with increased rainfall. The contrast with the southwestern Australian estuaries can be explained by the fundamentally different physical properties of the estuary systems. The Gippsland Lakes system is relatively large in area and permanently open to the sea. Many southwestern Australian estuaries, by comparison, are normally closed to the sea and have a shallow downstream lagoon that fills only during periods of high river flow (Hodgkin and Clarke 1990; Anderson and Cribb 1994). When full, the lagoons provide a habitat that facilitates the settlement and growth of newly spawned progeny from breeding stocks located upstream in the riverine regions of such systems. However, the future productivity of Culham Inlet may have been reduced by recent physical changes to the sandbar at its mouth (Hodgkin 1997).

A. butcheri appears to be unrestricted by fluctuating salinity or temperature and is well adapted to euryhaline estuarine environments (Holt 1978). In aquaria, they have tolerated salinities ranging from virtually freshwater to 35 ppt (Harbison 1973). In an ecological study of the Blackwood River Estuary, Western Australia, Lenanton (1977) found *A. butcheri* in habitats with salinity, temperature and dissolved oxygen levels ranging from 0.3 to 36.8 ppt, 9.5 to 25.5°C and 5.18 to 8.64 mg/l, respectively. Young *et al.* (1997) observed a negative correlation between population density and salinity when sampling the upper, middle and lower reaches and mouth of the Moore River Estuary on the lower west coast of Western Australia.

3.3 Stock identity

A. butcheri rarely leave an estuary unless flushed out by floodwaters (Starling 1988; Holt 1978), although a tagging program in New South Wales (Dunstan 1965) identified limited coastal movement. Tagging experiments in Gippsland Lakes, Victoria, from 1964 to 1968 suggested that populations on the eastern coast of Victoria and southern New South Wales are a separate stock to those west of Wilsons Promontory (Gorman, unpubl. a).

In April and May 1944, Butcher and Ling (1962) tagged and released 990 *A. butcheri* in and near the Gippsland Lakes, and a further 1460 at various places along the East Gippsland coast. Recaptures numbered 22 (2.2%) and 8 (0.5%), respectively. Migratory behaviour was described as "very local in character", with very little movement out of the Gippsland Lakes. The results tend to suggest that the Gippsland Lakes population is a distinct stock with an abundance that can vary independently of other populations.

Captive bred *A. butcheri* were tagged and released into the Swan Estuary in southwestern Australia in March 1995 (Lenanton *et al.* 1999; Dibden *et al.* 2000). By October 1997, 31 months after release, 97 (12.6%) had been recaptured, all within the same estuary (see 8.2 Stock Enhancement). These results indicate little or no emigration from the Swan, supporting the notion that each river/estuarine system should be managed as a separate stock.

Stock structure may be resolved by surveying genetic variation among populations from a number of estuaries, and using the data to infer migration patterns. Chaplin *et al.* (1998) found a high level of genetic divergence among populations from nine estuaries and a coastal lake in southwestern Australia. Estuary types included those that were permanently open to the sea, seasonally open, intermittently open, and permanently closed. Using allozyme electrophoresis, only three loci were sufficiently polymorphic to be used for analysis. The mean F_{ST} was 0.166 (standardised variance in allele frequency), a high value indicating a very low level of gene flow (migration) between estuaries.

The genetic pattern revealed by Chaplin *et al.* (1998) showed that black bream from geographically closed estuaries tend to be relatively more similar. Although the extent to which estuaries are connected to the ocean could hypothetically influence migration and therefore genetic patterns, no such pattern was detected. Samples from the Murchison and Bowes rivers, which are located in the extreme north of *A. butcheri*'s range, were genetically the most distinct. The authors suggest that the distinctness of these populations may have resulted from only a few individuals founding the population (founder effect) and from local selective forces, *e.g.* climate. A high level of genetic heterogeneity remained among the remaining populations (F_{ST}= 0.091). The Moore River was sampled twice (1994 and 1996) and no significant change was detected over this period.

There has been speculation that *A. butcheri* in Lake Clifton, a permanent coastal lake in southwestern Australia, were recently translocated from another estuary. The lake has a high conservation value, being located inside Yalgorup National Park and having living stromatolites. Allozyme elecrotrophoresis suggested the population was genetically most similar to the Swan Estuary and Collie River populations (Chaplin *et al.* 1998), although other nearby river systems were not sampled. If a population is founded by a small number of individuals that have been translocated, however, it is quite possible that allele frequencies may be unrepresentative of and quite different to the source population. Thus allozyme electrophoresis may show the Lake Clifton stock to appear genetically quite different from a population from which it was recently translocated.

Western Australian *A. butcheri* were compared genetically with two samples of sixty each from Hopkins River and Gippsland Lakes, Victoria (Baudains 1996). The Victorian samples were scored as genetically closer to lower southwestern Australian populations than were the Murchison and Bowes Rivers' samples mentioned above. This may be due to the restriction of having only three polymorphic loci for analysis, however. Farrington *et al.* (2000) did find substantial genetic differences between eastern and southwestern Australian populations. Baudains (1996) found the two Victorian samples were almost genetically identical, despite their being almost 500 km apart. Farrington *et al.* (2000) also reported little genetic differentiation when they sampled six sites in Victoria, but concluded that their data did not allow for the complete rejection of the existence of multiple stocks in that region.

4.0 Biology

4.1 Feeding

A. butcheri is an opportunistic carnivore feeding on shellfish (e.g. mussels and cockles), worms, crustaceans (including crabs and prawns), small fish (gobies) and algae (*Enteromorpha* spp., *Ulva* spp.) (Wallace 1976; Holt 1978; Sarre *et al.* 2000).

Thomson (1957a) examined the stomach contents of *A. butcheri* from Leschenault Inlet, Oyster Harbour and Wonnerup Estuary. He found the major food items to be bivalves (29% by volume), polychaetes (23%), seagrass (*Zostera* spp.) (10%), amphipods (8%), and miscellaneous items such as diatoms and organic debris.

A study by Holt (1978) in the Swan River Estuary, Western Australia, indicated *A. butcheri* fed on polychaetes: mainly *Mercierella enigmatica*, crustaceans: mainly *Halicarinus australis*, molluscs: *Xenostrobus securis* and *Anticorbula amara*, and algae. Wallace (1976) suggested plant material is ingested by *A. butcheri* due to their feeding behaviour rather than as a dietary alternative, since plant material from the stomach and intestine of individuals examined remained undigested.

Ostle (unpubl.) suggests that juvenile fish in the barred river systems of the Hopetoun area of southern Western Australia (Phillips and Steere Rivers, Culham Estuary, Jerdacuttup Lakes) feed on insects, hardyheads (small fish with a high tolerance to salt), tadpoles, other small bream and brine shrimps.

A study by Wallace (1976) in the Blackwood River Estuary, Western Australia, indicated that *A. butcheri* is an opportunistic feeder and ingests the most abundant invertebrate species in the area.

Willis *et al.* (unpubl.) examined the diet of larval and juvenile *A. butcheri* in the Hopkins River Estuary, Western Victoria, to determine ontogenetic differences in diet. Larvae less than 9 mm (TL) fed almost exclusively on calanoid copepod nauplii. Larvae greater than 9 mm consumed mainly calanoid copepodites and unidentified fish larvae. This change in diet coincided with a reduction of larvae in the plankton and an increase in the number of 10-18 mm (TL) *A. butcheri* in weed beds in the upper estuary during December. An icthyoplankton ecology study by Newton (1996) supports the conclusion that copepod nauplii are an important dietary component for larval *A. butcheri* in this estuary. Willis *et al.* (unpubl.) reported that a significant dietary shift occurred at a length of approximately 40 mm (TL). The most important diet items for juveniles less than 40 mm were calanoid copepods, particularly *Gladioferens pectinatus* and *Sulcanus conflictus*, species which tend to be associated with weed beds. As juveniles increased in size, copepods became less important in the diet and were replaced by amphipods, gastropods, polychaetes, brachyurans and fish. Polychaetes were the main food type consumed by juveniles greater than 40 mm in length. The increase in relative importance of littoral invertebrates and detritus in the diet of *A. butcheri* with increasing size, suggested that this dietary shift was associated with a change in feeding locality from planktonic to littoral zones for juveniles above an approximate length of 40 mm (TL).

Heald (1984) opportunistically recorded stomach contents while conducting an amateur net fishing survey of Wellstead Estuary and Beaufort Inlet on the south coast of Western Australia in 1981. "Stomachs contained *Mercierella enigmata*, mudskippers, the southern anchovy and the tiny gastropod *H. brazieri.*" (Heald 1984, page 18).

In southwestern Australia, Sarre *et al.* (2000) determined the dietary compositions for *A. butcheri* from the Swan River, Moore River, Wellstead and Nornalup/Walpole estuaries and Lake Clifton. The dietary compositions of *A. butcheri* in each of the five water bodies were significantly different, which reflected differences in the abundance of different components of the biota in those systems. These differences thus accounted for the relatively larger contributions made to the volume of the stomach contents by the macroalgae *Cladophora* sp. in the Moore River Estuary on the lower west coast, by amphipods and decapods in the Swan River Estuary 85 km south, and by polychaetes in the landlocked Lake Clifton a further 85 km south. The diet of *A. butcheri* in the Nornalup/Walpole Estuary on the south coast contained atypically large volumes of the seagrass *Ruppia megacarpa* and teleosts. In the normally closed Wellstead Estuary, 260 km to the east, stomachs contained relatively large volumes of the macroalgae *Chaetomorpha* sp. and a tube-dwelling amphipod. Sarre *et al.* (2000) suggest that *A. butcheri* prefers to feed on or above the substratum, rather than within the substratum. The dietary composition of *A. butcheri* underwent pronounced ontogenetic changes in each water body, these being progressive in estuaries on the lower west coast and abrupt in those on the south coast. Within the upper Swan Estuary, the dietary composition changed in an upstream direction, reflecting changes in the relative abundance of certain benthic macroinvertebrate prey, but did not undergo conspicuous seasonal changes, which is consistent with the lack of any clear cut seasonal changes in the abundance of their major prey.

4.2 Behaviour

The life-cycle strategy of *A. butcheri* varies depending upon the status of the mouth and associated hydrological conditions of the estuary in which it lives, *i.e.* permanently open estuary, seasonally open estuary, generally closed estuary, or permanently closed estuary or lake (Lenanton and Hodgkin 1985) (Figure 3). There are some remnant populations in Western Australia which inhabit inshore marine waters, but there is no evidence to suggest they successfully reproduce under these conditions (Lenanton *et al.* 1999).

In seasonally open estuaries such as Wilson and Broke in southwestern Australia, *A. butcheri* moves upstream in late spring/early summer spawn. During drought, the population is restricted to the riverine region, but it is unclear whether spawning can occur under these conditions. With the onset of winter rains, the population disperses into the estuary. In both permanently and seasonally open estuaries, a few fish may move or be flushed out to the sea (Figure 3).

Lenanton and Hodgkin (1985) monitored *A. butcheri* in the normally closed Beaufort Inlet both prior to, and following the breaching of the sand bar at the mouth in July, 1978. None were taken in the hypersaline lower estuary prior to the opening, but were taken in the riverine system where salinities were slightly lower. Large *A. butcheri* were caught in the lower estuary soon after the bar had broken, and as salinities increased during the month following sampling, numbers in the lower estuary decreased. There was no recruitment of the small 0+ year class to the lower estuary over this period.

Culham Inlet, in southern Western Australia, is a barred estuarine system that opens very infrequently, and has reportedly broken naturally through the bar to the ocean on only 3 or 4 occasions over the last 150 years, the last break being May 1993. It was broken artificially in about 1920, after 7 years of above average rain (Hodgkin and Clarke 1990). Because most of the estuary bottom is roughly equivalent to about mean sea level, the estuary rapidly empties once the bar has broken, with very little marine water entering the system (Hodgkin and Clarke 1990; Hodgkin 1993). The lagoonal (downstream) section of the estuary is so shallow that it sometimes dries up completely, though it may hold water for several years (Hodgkin and Clarke 1990; Hodgkin 1997). The Phillips River, a tributary, is deeper and always holds water for 7 km from the lagoon (Hodgkin and Clarke 1990), sustaining a population of *A. butcheri* able to recolonise the lagoon when it refills.

In normally closed estuarine systems east of Albany on the south coast of Western Australia, *A. butcheri* do not spawn until fresh water rains promote suitable hydrological conditions within the estuary. All sizes school together during the upstream spawning migration (Ostle, unpubl.).

Young *et al.* (1997) sampled the ichthyofauna in the upper, middle and lower reaches and mouth of the Moore River Estuary on the lower west coast of Western Australia, between February 1994 and February 1995. A total of 5,705 *A. butcheri* were caught, with total lengths ranging from 15 to 335 mm, contributing 5.4% of the total number of fish caught and 14.9% of the biomass. The *A. butcheri* population density was positively and negatively correlated with distance from the estuary mouth and salinity, respectively. There appeared to be a marked tendency for a particular suite of species, including *A. butcheri*, to congregate in the shallows at night.

Sarre (1999) sampled the offshore deep and nearshore shallow waters of the upper Swan

River Estuary between September 1993 and April 1995. During winter, heavy freshwater discharge flushes many *A. butcheri* downstream into the lower reaches of the upper estuary and into the basins that constitute the middle estuary. During the early spring, large numbers of *A. butcheri* migrate upstream when the encroaching salt wedge results in increasing salinities in the upper estuary. Large aggregations of spawning *A. butcheri* were found in the middle region of the upper estuary in late spring and early summer during both years of sampling. During summer and autumn *A. butcheri* were abundant in the upper riverine reaches and remained in this region until being subsequently flushed downstream in winter.

Hatchery bred and reared juvenile *A. butcheri* were tagged and released into the Swan River Estuary for stock enhancement purposes in March 1995 (Dibden *et al.* 2000; Lenanton *et al.* 1999). By the end of October 1997, 31 months after release, 97 fish (12.6%) had been recaptured, all within the Swan Estuary. The diet was similar to that recorded for wild fish in the Swan by Sarre *et al.* (2000), and some of the recaptured fish had mature gonads. Dibden *et al.* (2000) and Lenanton *et al.* (1999) claim that the recapture data suggest tagged fish were more catchable than wild stock. Results of the stock enhancement programme show that hatchery reared juvenile *A. butcheri*, upon release, were able to survive for extended periods, feed naturally, exhibit robust growth, and in all likelihood reproduce successfully (see 9.2 Stock Enhancement).

Tagging experiments in the Gippsland Lakes, Victoria, by Butcher and Ling (1962) demonstrated that migratory behaviour was local in character. Of 990 *A. butcheri* tagged and released, all of the 22 recaptures were inside Gippsland Lakes and juveniles showed more random movement than adults.

A further tagging experiment in the Gippsland Lakes (Gorman 1965; unpubl. a) during 1964-65 involving 2,580 *A. butcheri* yielded a 6% recapture rate (155 individuals) after 1 year at liberty. The majority of the fish (152 individuals) were recaptured in the lakes in which they were tagged, but three individuals had moved out of the lakes to the sea, with one individual migrating 205 nautical miles (Gorman 1965). From 1965-68 a further 286 individuals were recaptured. Emigration of 11 individuals (2.5% of total recoveries) from the Gippsland Lakes to other coastal inlets, eastern Victoria and southern New South Wales occurred during the 4 years at liberty whilst no returns were reported from west of Wilsons Promontory. There is almost certainly some immigration into the Gippsland Lakes (Gorman, unpubl. a; unpubl. b).

Tagging experiments in the Onkaparinga estuary, South Australia, yielded a 3% recovery rate (Harbison 1973). Of the 412 fish tagged, 13 were recovered from the river and one was recovered from the outer harbour after 118 days at liberty. Most recoveries occurred where the salinity was lowest.

4.3 Mortality

In the barred river systems of the Culham Estuary (Phillips and Steere Rivers), Western Australia, high mortality from predatory birds during the upstream spawning run has been reported (Ostle, unpubl.). Further mortality occurs as upstream pools dry up in summer. Those fish remaining in the lower reaches of the river and inlet probably perish as a result of increased salinity from summer evaporation (Ostle, unpubl.). Thus, survival is greatest among fish in riverine pools that do not dry out.

Tagging studies of *A. butcheri* in the Gippsland Lakes, Victoria, during 1964, were used to estimate an annual total mortality of 46% (Z = 0.61 per year) and an annual fishing mortality of 11% (F = 0.10 per year) (Gorman, unpubl. a). Estimates of Z, the total mortality coefficient, for different age cohorts were estimated by Gorman (unpubl. b) and presented in Appendix 2.

Ramm (unpubl. a) concluded that the asynchrony between the peaks in abundance of *A. butcheri* eggs and larvae from the Gippsland Lakes, and differences in spatial distribution, indicated that the rate of larval mortality may vary within the estuary. The survival of larvae is related to density-dependent factors such as competition, cannibalism and predation, and other factors such as nutrients levels, advection and salinity.

Coutin *et al*. (1997) used estimated growth parameters and applied various formulae to present preliminary estimates of natural mortality (M) in the Gippsland Lakes. M ranged from 0.10 to 0.20 yr^{-1}.

An age determination study in the Gippsland Lakes by Morison *et al.* (1998) found *A. butcheri* to have a natural life span of at least 29 years, suggesting a potentially low rate of natural mortality. In comparison, the oldest individuals found by Sarre and Potter (2000) among several southwestern Australian estuaries were in the Nornalup/Walpole Estuary and the Swan River Estuary, where ages of up to 21 years were estimated using otoliths.

4.4 Parasites

Byrnes (1985) studied monogenean flatworms (*Polylabroides* spp.) parasitic on four species of *Acanthopagrus* (*A. butcheri*, *A. australis*, *A. berda, A. latus*) from samples collected throughout Australia. Each of the four *Polylabroides* species in the study showed a preference for one host species with *Polylabroides australis* preferring *A. butcheri*.

Byrnes (1986a) also found *A. butcheri* to host two species of parasitic monogenean flatworms. Forty fish were sampled from the Perth region and from Stokes Inlet on the south coast of Western Australia. *Haliotrema sapriensis*, which infects the gill filaments, was found on 97.5% of fish from Perth and on 10.0% from Stokes Inlet. *Allomurraytrema robustum*, occupying the gill arches and the corner and roof of the mouth, infected 10% of Perth fish and 2.5% of the Stokes Inlet sample. These parasites were geographically widespread around the Australian coastline and were hosted by other *Acanthopagrus* spp.

Acanthopagrus spp. are parasitised by at least three species of bomolochid copepod: *Pseudoeucanthus spinosus*, *Holobomolochus australienis* and *Bomolochus stocki* (Byrnes 1986b). The latter species was located in the nares of a sample of ≥ 40 *A. butcheri* from Eden, southern New South Wales, at a relative density of 0.35 (number of parasites in sample/ number of fish, infected and uninfected, in sample).

Four ergasilid copepod species were found parasitising *Acanthopagrus* spp. from around Australia: *Ergasilus spinipes, Ergasilus lizae, Dermoergasilus acanthopagri* and *Paraergasilus acanthopagri* (Byrnes 1986c). The last three were hosted by *A. butcheri*. *Ergasilus lizae* infected the middle of the gill filaments, and occurred at a prevalence (proportion of individuals infected) and relative density ranging from 10 to 80% and 0.15 to 12.4, respectively. *Dermoergasilus acanthopagri* infected the distal tips of the gill filaments. Prevalence and relative density ranged from 7.5 to 30.0% and 0.18 to 0.63, respectively.

Paraergasilus acanthopagri infected nares and to a lesser extent gill filaments. Prevalence and relative density ranged from 2.5 to 30.0% and 0.28 to 2.7, respectively. Sample sizes for all of the above were at least 40 individual *A. butcheri*.

Byrnes (1988) also studied ectoparasitic copepods (Lernanthropids and Lernaeopodids) on *Acanthopagrus* spp. from around Australia. Of the six parasite species described, four were present on *A. butcheri*, namely: *Lernanthropus atrox, Alella macrotrachelus, Clavellopsis parasargi* and *Neobrachiella lata*.

An opportunistic fungal parasite *Saprolegaria* sp. has been found on *A. butcheri* in low salinity water during grow out trials in fibreglass tanks at Curtin University, Western Australia in 1990 (Craig Lawrence, pers. comm.).

4.5 Growth

Conventional methods for estimating fish age and growth include analysis of growth rings on otoliths and scales, tag and recapture programs, and length/frequency analysis of age classes through time. Robertson and Morison (1999) have developed a system to automate the routine reading of sectioned fish otoliths. Referred to as an artificial neural network, the system had an accuracy approaching that of an expert reader when applied to *A. butcheri*.

A widely used growth model for fish is the von Bertalanffy growth equation:

$$L(t) = L_{\infty} (1 - e^{-K(t - t0)})$$

where: $L(t)$ = length at age t; t_0 = theoretical age at which length = 0; K = rate at which fish reaches its asymptotic length; and L_{∞} = mean asymptotic length. For *A. butcheri*, estimates of these parameters are described below and summarised in Appendix 2. Various length and weight relationships are also listed in Appendix 2.

Gippsland Lakes, Victoria

Butcher (1945a) concluded that “bream” in the Gippsland Lakes, attained a length of 4.75 inches (12 cm TL) by the end of their first year, 8.5 inches (22 cm) by the end of the second year and 13.25 inches (34 cm) by the end of the third year. Thereafter the annual increase in length was smaller than previous years while the increase in body depth was more marked.

Ramm (unpubl. a) found that young-of-the-year *A. butcheri* in the Gippsland Lakes, measuring 10-27 mm LCF first appeared in the littoral zone in January, and grew at an average rate of 17 mm/month during summer, and 2 mm/month during winter. One year old fish ranged from 57 to 100 mm LCF.

Butcher and Ling (1962) reported the results from tagging 1,944 *A. butcheri* in East Gippsland Lakes, but recapture lengths were too variable (including several cases of “shrinkage”) and insufficient for growth estimation.

Concern over the declining commercial catches of *A. butcheri* in the Gippsland Lakes prompted a comprehensive study of the fishery and biology of the species commencing in 1962 (Gorman, unpubl. a; unpubl. b). Examination of scales indicated annulus formation occurred during rapid summer growth from October/November to January (corresponding with the spawning season). Annuli could only be counted on the scales of fish that were

6 years old and younger, as above this age the annuli became crowded together close to the margin, making new annuli very difficult to detect. Data from scale annuli readings as well as a tagging program were used to estimate growth parameters (Appendix 2). Gorman (unpubl. a; unpubl. b) found the growth of tagged fish was inhibited in the first 12 months after tagging, but the study was able to calculate growth parameters from individuals at liberty after the initial 12 month period (165 of the 441 recaptures, from 2,580 tagged).

Hobday and Moran (1983) observed growth rates in the Gippsland Lakes, Victoria to be much slower than earlier studies by Butcher (1945a) (*e.g.* 14-16 cm LCF by the end of their third year, rather than 33.7 cm as reported by Butcher), and to vary from year to year and between year classes. They obtained a good fit by the von Bertalanffy growth curve to mean observed lengths up to age 10 years, using scale annuli (Appendix 2). The fitted curve was, however, well below the mean observed lengths of older (>10 yrs) fish. Estimates of L_∞ by both Gorman (unpubl. a; unpubl. b) and Hobday and Moran (1983) are below the maximum of 41 cm LCF for individuals captured in the Gippsland Lakes by Hobday and Moran (1983).

Morison *et al.* (1998) estimated age with high precision using sectioned otoliths from Gippsland Lakes, sampling between 1993 and 1996. The aging technique was validated by following the annual progression of abundance of age classes over 4 years. The maximum age recorded was 29 years. Estimates of von Bertalanffy parameters are presented in Appendix 2. Growth was found to be slower, and maximum life span longer, than previous estimates by Hobday and Moran (1983). Morison *et al.* (1998) consider age estimates from sectioned otoliths to be more reliable than either length frequency analysis or scale reading for *A. butcheri*.

Western Australia

Holt (1978) found the growth of juveniles in the Swan River Estuary to be extremely rapid: 0+ year old fish increased from approximately 4.8 cm to 6.6 cm TL in a one month period over summer. The growth rate slowed during winter, possibly due to reduced temperatures and the effects of winter flushing. In one year, November to November, 0+ year old fish grew approximately 14 cm TL.

Using sectioned otoliths to estimate age, Sarre and Potter (2000) found considerable variation in von Bertalanffy growth parameters for the Swan River, Moore River, Nornalup/Walpole, Wellstead and Lake Clifton estuaries in southwestern Australia (Figure 4). They demonstrated that although the patterns of growth of female and male *A. butcheri* in the Swan River, Wellstead and Nornalup Walpole estuaries followed the same overall trends, with length increasing rapidly with time initially and then forming an asymptote, estimates of k and L_∞ varied significantly among estuaries. The initial rate of increase in length was greatest in the Swan River Estuary and least in the Nornalup Walpole Estuary. The faster growth rates in the Swan River Estuary and Lake Clifton, located at latitudes of about 32° S on the lower west coast, compared to the Nornalup Walpole and Wellstead estuaries which are further south (about 34° S), may reflect the higher temperatures found in more northern regions (Sarre and Potter 2000).

The pattern of growth in the Moore River Estuary differed from the other sites in that the growth rate was initially slower and the growth curve did not exhibit a marked asymptote (Sarre and Potter 2000). This suggests that some factor or factors were less than optimal for growth during the first few years but that conditions improved later in life. The observation may be related to the exceptionally high densities of juveniles in nearshore, shallow waters, which is their typical habitat (Sarre 1999). Sarre and Potter (2000) estimated the age at legal minimum size (25 cm TL) was 2.5 to 3 yrs in the Swan, and about 6 yrs in the Moore River Estuary.

To validate age estimates, Sarre and Potter (2000) investigated the pattern of marginal growth increments of the opaque zone of sectioned otoliths from *A. butcheri* from the Swan Estuary. The relative size of the mean marginal increment increased for about a year until November, when it declined sharply. This pattern was repeated for two consecutive years, and for otoliths with 2, 3 and 4+ opaque zones. Opaque zones were therefore completed every year and can be regarded as annuli, and sectioned otoliths were regarded as a reliable technique for aging.

Sarre and Potter (2000) compared sectioned otoliths with scales and whole otoliths as a method of aging. Scales resulted in higher age estimates than sectioned otoliths by at least 1 year for most ages. Estimates of 8 to 11 years using sectioned otoliths were 1 or 2 years less than scale ring estimates. A 19 year old (using a sectioned otolith) was estimated to be 26 years old using scales.

Comparing whole and sectioned otoliths, the same age was estimated by both methods for all of 177 fish up to 6 years (Sarre and Potter 2000). For 57% of those estimated to be 7 to 13 years old using sectioned otoliths, the whole otolith estimate was 1 year less. There were underestimates of 1 to 3 years (using whole otoliths) for most fish over 10 years (using sectioned otoliths), and by 5 years for two fish estimated at 19 and 21 years, respectively.

Sarre and Potter (2000) sampled the length/frequency distribution in the Swan Estuary. The 1992 year class was first caught in September 1993 and ranged from 81 to 115 mm (TL) at this time. The length increased to 90 to 125 mm in October and 100 to 152 mm in November 1993. The 1993 year class was first caught in March 1994, with total length ranging from 67 to 101 mm. This increased to 76 to 135 mm in April, but the cohort was then absent until September 1994. The 1991 year class was dominant until November 1994, when it had reached 3 years of age. Not many fish 4 years and older were caught in the study. The oldest female and male taken in the Swan by Sarre and Potter (2000) were 21+ yrs (470 mm, TL) and 15+ yrs (431 mm, TL), respectively. The maximum lengths were 480 mm, TL (15+ yrs) and 475 mm, TL (14+ yrs), respectively.

4.6 Reproduction

Reproductive styles of members of the Sparidae family are diverse. Sex change behaviour such as protandrous, protogynous, simultaneous and rudimentary hermaphroditism have been reported (Buxton and Garratt 1990). For *A. butcheri,* there are conflicting reports on gonad histology and sex change behaviour (see 4.8 Sex Ratio).

Fecundity

A. butcheri is a multiple spawner; spawning more than once in the same spawning season (Sarre and Potter 1999). Fecundity increases considerably with the length of the fish (Coutin *et al.* 1997) and for large females has been estimated to be from 1 to 3 million eggs (Butcher 1945b; Dunstan 1963). Thomson (1957b) suggested fecundity varied from 13,000 to 612,000, with a ripe ova diameter of 0.5 mm. Holt (1978) found a range of 80,642 - 612,000 eggs in seven mature females from the Swan estuary, and a mean egg diameter of 0.59 mm, while Harbison (1973) recorded 235,000 eggs from a fish of 20.6 cm (TL) and 1,874,000 from a 47 cm (TL) fish.

The mean fecundity for the Swan River estuary estimated by Sarre and Potter (1999), based on the combined number of yolk vesicle and yolk granule oocytes found in ovaries just prior to the onset of spawning, was 1,580,000. The maximum fecundity recorded was 7,090,000 for a 470 mm (TL) individual.

Eggs, sperm and larvae

Lenanton (1977) suggested that *A. butcheri* from the Blackwood Estuary, Western Australia, may have eggs adapted to low oxygen levels and higher estuarine salinities. Ovary samples had a distinct orange to red pigmentation (carotenoids) which, it has been suggested, provides an intracellular stock of oxygen, thereby aiding respiration in conditions of low oxygen. Newton (1996) supports the view that oxygen and salinity are strong selective forces affecting egg survival. In the Hopkins River estuary, Victoria, she identified deep pools as important breeding sites, and although their importance "may relate in part to their offering a deep area within which the fish can congregate to spawn... Probably of greater importance... is the prevailing moderate salinity and high dissolved oxygen conditions present at this site (sic) during salt wedge emplacement" (Newton 1996, p. 108).

Studies of *A. butcheri* in the waters of Gippsland Lakes, Victoria, found that eggs were pelagic, being found in the upper 18 inches (46 cm) of water, and in a salinity of 17 ppt (Butcher 1945b). Ramm (unpubl. a) also found that eggs were pelagic, and were neutrally buoyant in salinities of approximately 23-27 ppt at 15 - 25°C. Eggs were found in low abundance in salinities less than 15 ppt. However, this may be due to eggs settling on the substrate (due to negative buoyancy at these salinities) and not able to be taken with the sampling technique being used at the time. Egg distribution observed in the study indicated that spawning occurred over a wide temporal and spatial range, suggesting that *A. butcheri* are ubiquitous extended spawners. The demersal larvae were found in the middle reaches of the estuary. Laboratory cultures indicated that the duration of the embryonic stage is between 40 and 60 hours at temperatures of 17 - 20°C (Ramm unpubl. a).

Newton (1996) studied the ecology of *A. butcheri* eggs and larvae in relation to hydrology in the Hopkins River estuary, Victoria. The peak concentration of eggs occurred in two deep pools in the upper section (subject to seasonal freshwater flushing) in November and December. The eggs were discovered at a depth of 2-4 m but were absent from the surface layer. Salinities and temperatures were 20 to 25 ppt and 15.5°C in one pool and 13 ppt and 17°C in the other during November. In December, salinities were 25 to 28 ppt and 21 to 22 ppt, respectively. These results contrast with those of Butcher (1945b) mentioned above for the Gippsland Lakes, where eggs were found quite close to the surface.

The peak number of *A. butcheri* larvae in the Hopkins River estuary was in November and coincided with the re-establishment of calanoid copepod populations after flooding (Newton 1996). The timing appears optimal for feeding on copepod nauplii, the exclusive food at preflexion larval stage (Willis 1991). The timing also helped to minimise interspecific competition with other numerically dominant larvae (gobies and gudgeons) as peak spawning in these species occurs later. Newton (1996) suggests that such food supply effects are an important part of *A. butcheri*'s spawning strategy. The highly variable level of recruitment from year to year (see section 4.9) may depend to a large extent on food supply and correct timing of the spawning season.

Haddy and Pankhurst (2000a) investigated the effects of salinity on sperm motility, fertilisation and egg survival using sperm and eggs stripped from *A. butcheri* captured in the

Meredith and Swan Rivers at Swansea, Tasmania. Sperm were activated at salinities of 20 and 35 ppt, but not at 5 ppt. Motility was initiated at 6, 7, and 10 ppt for three males tested. Egg fertility was enhanced by salinities of 20 and 35 ppt compared to 5 ppt. Incubation salinity significantly affected egg survival and development. Survival to hatching was highest at salinities from 15 to 35 ppt. Although some eggs survived at 5 and 10 ppt, a high proportion of abnormal larvae were observed (*e.g.* curvature of the spine). No eggs survived when incubated in distilled water.

Spawning

In the Gippsland Lakes, Victoria, spawning is generally in late October and November (Butcher 1945a; Coutin *et al.* 1997), and can be extended as late as March (Ramm, unpubl. a). East of the Lakes spawning is progressively earlier, and westward progressively later. Spawning areas within the Lakes vary with fluctuating salinity, the optimum range being 11-18 ppt (Butcher 1945b). Both the timing of spawning and the spawning location vary from year to year in relation to fluvial discharge.

In the vicinity of Adelaide spawning appears to occur between November and January (Scott *et al.* 1974).

A study by Harbison (1973) in the Onkaparinga Estuary, South Australia, indicated spawning fish were present from August to December with the majority spawning during October. Mature spawning fish move upstream during late winter/early spring to spawn. Harbison (1973) suggested the migration is related to the freshwater flush, where adults utilise the higher oxygen concentration of fresh waters for survival of the eggs.

A study by Sherwood and Backhouse (1982) of the estuaries of the Glenelg and Hopkins Rivers in southwestern Victoria suggested spawning of *A. butcheri* is restricted by the seasonal fluctuation in the fresh water flow rate of the rivers. These estuaries are salt wedge estuaries which show marked seasonal variations in the position and physico-chemical properties of their salt wedges. Sherwood and Backhouse (1982) suggest that *A. butcheri* moves downstream with the winter freshwater flush. In spring and early summer it follows the salt wedge as it advances upstream. When it encounters areas upstream with the correct salinity, dissolved oxygen content and suitable habitat, spawning is stimulated. In mid to late summer months, salinities rise and dissolved oxygen levels drop, coinciding with cessation of spawning and dispersal of fish.

The results for the Hopkins River were confirmed by Newton (1996). She found that *A. butcheri* eggs were restricted to the middle and upper sections during the post-flood period of reformation of the salt wedge, between November and January.

In the Meredith and Swan Rivers at Swansea, Tasmania, annual change in reproductive condition was studied by monitoring the gonadosomatic index (GSI: gonad weight as a percentage of body weight), hepatosomatic index, gonad stage and plasma concentration of sex steroids from April 1996 to May 1997 (Haddy and Pankhurst 1998). Spawning occurred in spring and early summer, commenced earlier in the Meredith than in the Swan River, and was associated with higher salinities and temperatures in the former. Sexually mature fish were caught over a temperature range of 15.5 to 26.2º C, dissolved oxygen concentrations of 4.2 to 13.6 mg L^{-1}, and salinity from 13.9 to 35 ppt. Daily changes in ovary condition indicated ovulation occurred after midday.

In a study of the ecology of the Blackwood River Estuary, Western Australia, Lenanton (1977) undertook a preliminary examination of *A. butcheri* gonads on a bimonthly basis from March 1974 to March 1975, and July 1975. Ripening commenced in late September, and initial records of spent gonads were made in January. The estimated peak spawning time was December.

The timing of the *A. butcheri* spawning season in the Swan River Estuary, Western Australia, has been resolved by monitoring the GSI, the developmental stages of ovaries and the size distribution of oocytes (Sarre and Potter 1999). The GSI was monitored from July 1993 to April 1995. The mean monthly female GSI peaked in October 1993 and 1994 at 5.8 and 8.2, respectively. Between September and December in 1993 and between August and December in 1994, over 70% of females had ovaries classified as "mature", accounting for the relatively high mean GSI's in those months. Ovaries classified as "spawning" and "spent" were most common in November and December in both years. The seasonal trends in GSI and gonad stages for females were mirrored by the males, with the mean GSI peaking in October of both 1993 and 1994 at 7.3 and 6.4, respectively.

Oocyte diameters monitored by Sarre and Potter (1999) showed a consistent and well defined modal class between 20 and 80 µm, represented by perinuclear oocytes. The maximum diameter increased from 100 µm in April to a maximum of 350 µm in November, then declined to 180 µm in February/March. A second modal class, representing large yolk vesicle and yolk granule oocytes from 240 to 340 µm, was present in May, but then absent until August. Thereafter, the prevalence increased to a peak in October and then progressively declined to a minimum in January. Months with low maximum oocyte diameters tended to be associated with ovaries carrying yolk vesicle and yolk granule oocytes that had undergone atresia. Hydrated oocyte diameters ranged from 520 to 810 µm in May and then were absent until October to December, when they were larger: 700 to 950 µm. Sarre and Potter (1999) concluded that in the Swan River Estuary, *A. butcheri* spawns predominantly between the middle of spring to early summer, confirmed by the prevalence of yolk granule and hydrated oocytes and post-ovulatory follicles during this period. Spawning in the Moore River and Nornalup Walpole estuaries was found to be over a similar period, whereas the Wellstead Estuary population started and finished one month earlier.

Sarre and Potter (1999) found many post ovulatory follicles together with yolk granule oocytes in the same ovaries, suggesting that *A. butcheri* is a multiple spawner, spawning more than once in the same season.

Spawning in the Swan River Estuary usually occurs upstream in the narrow reaches (Sarre and Potter 1999). *A. butcheri* movements at this time were in an upstream direction. Temperature and salinity ranges during spawning were: Swan River Estuary 19.7 – 28.6ºC and 3.8 - 25.0 gL^{-1}; Moore River Estuary 23.5 – 28.5ºC and 3.5 - 8.0 gL^{-1}; Nornalup/ Walpole Estuary 18.2 – 23.4ºC and 16.0 - 30.8 gL^{-1}; Wellstead Estuary 17.5 – 20.2ºC and 40.7 - 45.2 gL^{-1}.

4.7 Size/age at maturity

Work by Thomson (1957b) in Leschenault Inlet, Oyster Harbour and Wonnerup Estuary, Western Australia, suggested *A. butcheri* matured at 2+ years of age (16.9 cm LCF males, 15.6 cm LCF females). In the Swan River Estuary, Western Australia, Holt (1978) suggested individuals reach maturity at 2+ years of age with a limited number at late 1+.

Butcher (1945a), considered “bream” in the Gippsland Lakes, Victoria, to become sexually mature at the end of their second year, with an average length of 8.5 inches (21.6 cm). A later study by Scott *et al.* (1974) reported that males spawn for the first time in their third year, and females in their fourth year. Coutin *et al.* (1997) estimated the size at first maturity for female *A. butcheri* in the Gippsland Lakes at 13 cm TL, and 100% maturity at 25 cm TL.

Harbison (1973) found *A. butcheri* in the Onkaparinga Estuary, South Australia, spawn at the end of their third year.

The size and age at reaching sexual maturity in the Swan River Estuary, Western Australia, was estimated by Sarre and Potter (1999). The frequency of mature female *A. butcheri* with a total length of 17.0 cm was 5%, rising to 77% at 22.0 cm and 100% at 30.0 cm. Sexual maturity for males followed a similar pattern. The length at which 50% of females and males were calculated to have reached maturity (L_{50}) was 21.8 and 21.2 cm TL, respectively. This occurred at the end of their second year, and at the end of their third year about 90% of both sexes had matured. L50 and A50 (age at which 50% have reached maturity) estimates for four southwest Australian estuaries are given by Sarre and Potter (1999) and are summarised in Appendix 2.

4.8 Sex ratio

Rowland and Snape (1994) undertook histological examinations of the gonads of *A. butcheri* from three coastal lakes in southeastern Australia. Sample sizes of 19, 38 and 52 were taken from Hoyers and Myall Lakes, New South Wales, and Gippsland Lakes, Victoria, respectively. Seven hermaphrodites (possessing an ovotestis) were detected from Hoyers Lake, ranging from 265 to 290 mm standard length (SL). The overall size range from this sample was 201 to 325 mm, and there was a male:transitional:female sex ratio of 5:7:7. The sex ratio by size category was: 200-249 mm, 0:0:6; 250-299 mm, 1:7:1; 300-349 mm, 4:0:0; where all larger fish were male, and smaller fish tended to be female. Only 3 ovotestes were detected in the Myall Lake sample. The sex ratios for the size ranges given above were: 5:0:12, 5:3:11 and 2:0:0, respectively. Again, there was a female bias among smaller fish, hermaphrodites were found only in the intermediate size range, and there was a male bias in the upper size range. In contrast, no hermaphrodites were found in the Gippsland Lakes, and the sex ratio was close to 1:1 for all size ranges.

Rowland and Snape (1994) have suggested that protogynous hermaphroditism is labile in *A. butcheri*: selective pressures from environmental conditions and/or intense fishing pressure have induced the expression of this condition in Hoyers Lake. These findings are in direct contrast to Sarre (1999), who found no evidence of sex change after examining the gonads of over 800 individuals from several estuaries in southwesten Australia.

Haddy and Pankhurst (1998) examined gonads from Tasmanian *A. butcheri* and found 98% of males to have some ovarian tissue and 13% of females to have residual testis present on the gonad. The sex ratio showed no marked differences with age although 97% were estimated to be over 3 years old. Thus although sex inversion may occur at a younger age, no evidence was detected.

Sarre (1999) estimated the male:female sex ratio in the Swan River Estuary to be 1.19:1. Male bias appeared to be much higher in the spawning season (about 2:1), attributed to spawning aggregations of males. The length and age frequency distributions for each sex were virtually identical. There was no evidence of sex change behaviour. If sex change, such as protogynous hermaphroditism, was occurring at a particular size/age, then one expects the sex ratio to vary in association with size/age. Thus, the observations of Sarre (1999) are fundamentally different to Rowland and Snape (1994) in aspects of sex change behaviour and particularly gonad histology. Recent examination of 40 *A. butcheri* gonads from the Gippsland Lakes, Victoria, by Sarre (unpubl.) identified an ovotestes in all individuals.

4.9 Recruitment

Various studies have indicated that a key feature of *A. butcheri* recruitment is temporal variation. Recruitment to each year class fluctuates within each river/estuarine/lake system. There is little or no recruitment between systems (see 3.3 Stock Identity).

Ramm (unpubl. a) found variation in the relative abundance of year classes in the Gippsland Lakes, Victoria, which he attributed to the rate of larval mortality. This, in turn, was attributed to the abundance of suitable larval prey, the abundance of larval predators, and climatic perturbations. Newton (1996) identified a spring/summer increase in zooplankton abundance (particularly calanoid copepod nauplii) in the Hopkins River estuary, Victoria, which coincided with the *A. butcheri* spawning season. Being an important food item for larval *A. butcheri*, zooplankton abundance may be crucial in determining larval mortality and therefore annual recruitment strength.

Hobday and Moran (1983) also found that year classes showed great variation in abundance in the Gippsland Lakes: 1972, 1973, 1978 and 1980 year classes were dominant, with 1971, 1974, 1975, 1976 and 1979 poorly represented. Weaker year classes tended to coincide with years of high spring river flows and below average temperatures, while dominant year classes resulted from spawning during relatively dry springs.

Morison *et al.* (1998) agreed that annual recruitment in the Gippsland Lakes is highly variable, however they found no evidence of the strong 1978 and 1980 year classes observed by Hobday and Moran (1983). Sampling between 1993 and 1996, Morison *et al.* (1998) found the commercial catch was dominated by just two year classes: 1987 and 1989, with 1990, 1991 and 1992 recruitment found to be poor. Large angler-caught fish were mostly from the strong 1972 and 1973 year classes identified by Hobday and Moran (1983). Walker *et al.* (1998) used this age structure data to develop an environment-recruitment model for Gippsland Lakes, where water temperature and river flow were used to predict relative year class strength.

Chapman (1995) was able to catch large numbers of juvenile (TL < 70 mm) *A. butcheri* upstream of the Culham and Hamersley Inlets, southern Western Australia, during the summer of 1986/87. There had been extensive rain the previous winter, suggesting a positive relationship between rainfall and recruitment for these inlets. In contrast, Sarre and Potter (2000) suggest that heavy freshwater flushing is associated with lack of spawning success in the Wellstead Estuary, southern Western Australia.

4.10 Migration – tagging studies

In April and May 1944, Butcher and Ling (1962) tagged and released 990 *A. butcheri* in and near the Gippsland Lakes, Victoria, and a further 1460 at various places along the East Gippsland coast. Recaptures numbered 22 (2.2%) and 8 (0.5%), respectively. Migratory behaviour was described as "very local in character", with very little movement out of the Gippsland Lakes.

Tagging experiments in the Onkaparinga Estuary, South Australia, yielded a 3% recovery rate (Harbison 1973). Of the 412 fish tagged, 13 were recovered from the river and one was recovered from the outer harbour after 118 days at liberty.

Recreational fishing enhancement was attempted through the release of tagged, hatchery reared *A. butcheri* into the Swan River Estuary in Perth, Western Australia (Jenkins 1995; Lenanton *et al*. 1999; Dibden *et al.* 2000). In March 1995, 767 fourteen month old juveniles were released into the upper reaches of the river. By October 1997, 31 months after release, 97 (12.6%) had been recaptured, all within the same estuary (see 9.2 Stock Enhancement). The longest period at liberty for an individual fish was 945 days. These results indicate little or no emigration from the Swan, supporting the notion that each river/estuarine system should be managed as a separate stock.

4.11 Miscellaneous

Arnold-Reed *et al.* (1996) measured the clearance of lipids from the plasma of *A. butcheri* after injection with radiolabelled lipid emulsions designed to mimic the structure and composition of plasma lipoproteins. A similar pattern to mammalian clearance was detected, although slower. Clearance of triglyceride and cholesteryl ester reached equilibrium after 6.5 hours, with the greatest rate of clearance between 15 minutes and 2.5 hours. The authors did not discuss the relevance of the findings in terms of ecophysiology.

Shand *et al.* (1999) described the development of the photoreceptor mosaic in the retina of *A. butcheri* from hatching to eight weeks of age. During this time a mosaic of rows of single cones reorganised to form a regular square mosaic of single and double cones.

5.0 The fishery

5.1 Fishing methods

The majority of the Western Australian commercial catch of *A. butcheri* is taken using gill (set) nets (approx. 95% of total catch). Other methods include haul nets, seine nets and handlining. Gill net mesh size influences the length range of fish that are caught, but the range is wide and there is considerable overlap in length range between mesh sizes. Sarre and Potter (1999) observed the following mesh sizes (mm) to capture the corresponding length ranges (mm, TL): 38: 50-190, 51: 80-230, 63: 120-260, 76: 150-290, 89: 180-330, 102: 220-370, 115: 260-410, 127: 290-430. Commercial fishers use gill nets with mesh sizes >115 mm, and so the great majority of *A. butcheri* caught would be >260 mm and in excess of the legal minimum length (250 mm) (Sarre and Potter, 1999). Smaller mesh sizes that are used by recreational fishers would catch fish below this limit. In a 1981 survey of amateur net fishing in the Wellstead Estuary and Beaufort Inlet on the south coast of Western Australia, Heald (1984) found 76 mm mesh to be the most popular within the 57 – 114 mm range that was used. Although there is a bag limit for recreational fishers, "the vast majority of fish that are caught in their gill nets are dead or severely damaged by the time those nets are retrieved" (Sarre and Potter 1999, p. 206). Many of the regions where *A. butcheri* is most abundant are legally excluded from netting, however.

In Perth, *A. butcheri* is usually caught by recreational anglers in rocky areas and beside jetties, piles or spit posts using light lines (3-5 kg breaking strain) (Blanksby 1992; Jones 1997). Commonly used baits include prawns and river blood worms but lures can be successful. The state angling record is 2.890 kg caught on 18 August 1991 in the Swan River Estuary (Australian Anglers Association). Due to the species seasonal movement in river/estuary systems, recreational fishing effort is most effective in the upstream region in summer. The first heavy rains of winter can trigger downstream movement, with a consequent geographical shift in effectiveness of recreational effort. More recently, however, hatchery reared juveniles released into the upper reaches of the Swan River Estuary were never recovered below South Perth (Dibden *et al.* 2000).

5.2 State Fisheries – WA and Victoria

Western Australia

The state commercial catch is taken mainly from south-west estuaries, including the Swan-Canning and Peel-Harvey estuaries, the Hardy, Gordon, Beaufort, Stokes, and Culham Inlets, and from embayments such as Oyster Harbour (Figure 2). Smaller quantities may be taken from Oldfield River, Wilson, Irwin and Broke Inlets.

Commercial catches were first taken from estuaries between Albany and Esperance by the late 1920's and early 1930's (Lenanton 1984). Between 1945 and 1948 commercial fishers netted large hauls from the Swan River Estuary. The numbers declined about 1950, but stabilised during the late 1960's and early 1970's. Recreational netters also took quantities of *A. butcheri* in open netting areas. Netting by recreational fishers is no longer permitted in the Swan, where the number of commercial fishers has now been reduced to four licences. The species is increasingly forming the basis of a large recreational rod and line fishery (Holt 1978; Loneragan *et al.* 1987).

Seasonal catches of *A. butcheri* vary from year to year, mainly due to variable recruitment which is dependent primarily on the combined influence of a number of environmental factors (e.g. influx of nutrients and freshwater into estuarine systems). Figure 5 shows the total commercial catch, fishing effort and catch per unit effort in Western Australia from 1975/76 to 1999/2000 (source: Department of Fisheries, Catch and Effort Statistics System). Commercial catch statistics from 1976 to 1984 were analysed by Lenanton and Potter (1987) when the mean annual catch was 26 tonnes (range 4 to 55 tonnes). The catch increased dramatically after 1989/90, reaching a high of 103.9 tonnes in 1992/93. A rapid decline followed, falling back to 1989/90 levels by 1994/95. The total commercial catch for 1998/99 and 1999/2000 was 19.1 and 28.1 tonnes, respectively. The number of commercial fishers targeting *A. butcheri* since 1989/90 has remained relatively constant over the same period (approx. 30-40).

The increased catch in the early 90's was due mainly to increases at Stokes, Gordon and particularly Culham Inlets on the south-coast (Anderson and Cribb 1994). Abundant fresh water in the inlets and consistently high water levels, due to heavy winter rains from 1990 to 1993, generated conditions very suitable for the proliferation of *A. butcheri*. The Culham Inlet catch reported in 1991/92 was 60.7 tonnes, accounting for 69% of the total state catch of 87.9 tonnes; and in 1992/93 was 76.7 tonnes accounting for 74% of the total (103.9 tonnes). In May 1993, however, the Culham Inlet sandbar was broken (the last occurrence was when it was artificially broken about 1920). Commercial fishers continued to achieve high catch rates for a few months after the bar opening, but they declined to nil by November 1993. A proportion of the *A. butcheri* population would have been lost to the ocean. The overall catch has remained low since 1993/94. Repopulation will depend on the time taken for the estuary to fill with water of acceptable salinity (the estuary bottom is roughly equivalent to about mean sea level so it empties once the bar has broken), followed by a successful spawning. However, the record catch from Culham Inlet in the early 90's may never be repeated (Hodgkin 1997). The sandbar has re-established at a lower height since it broke in 1993, reducing the depth of water required to trigger another breach. Moreover, engineering works at the sandbar have been undertaken in an attempt to prevent periodic low level flooding and road closure. A floodway section of roadway was constructed and culverts were embedded in the road embankment, so the inlet will commence to empty to the sea at a more shallow depth than previously. This will cause it to become hypersaline and dry up more often, reducing productivity.

Caputi (1976) carried out a creel census of amateur line fishermen in the Blackwood River Estuary, from May 1974 to April 1975. *A. butcheri* dominated the catch in the upstream section from Molloy Island to Alexandra Bridge where it formed approximately 60% of the catch. Catch rates were higher for boat fishermen compared to shore fishermen, and were lower in downstream sections.

Heald (1984) conducted an amateur net fishing survey of Wellstead Estuary and Beaufort Inlet on the south coast of Western Australia in 1981. *A. butcheri* caught in Wellstead Estuary tended to be below the minimum legal size (25 cm total length), while the length of *A. butcheri* from Beaufort Inlet showed a distinct bimodal distribution with modes at 22 cm and 29 cm total length. After winter rains in 1981, *A. butcheri* comprised a larger proportion of the catch in Wellstead Estuary, where total fish catch rates had significantly increased. This persisted after the bar at the estuary mouth broke to the sea.

A 12 month survey of recreational fishing in the Leschenault Estuary (January to December, 1998) found that *A. butcheri* formed a minor component of the catch (Malseed *et al.* 2000). Although the number kept was not large enough to determine an accurate estimate of the annual catch, 474 were estimated to have been released annually by boat based anglers.

Malseed and Sumner (2001) conducted a 12 month (August 1998 to July 1999) survey of recreational fishing in the Swan-Canning Estuary. The estimated annual catch of *A. butcheri* by boat-based anglers was 900 fish kept (±227 standard error) and 1,449 released (± 242). This was equivalent to about 0.50 tonnes kept. The estimated shore based *A. butcheri* catch was 699 fish (0.31 tonnes) kept (±182) and 927 released (± 158). The authors point out, however, that the *A. butcheri* catch was not representative of the larger Swan-Canning river systems since most of the catch occurs upstream of the estuary basin where the survey was centred. *A. butcheri* was the most commonly caught fish species in autumn by boat based anglers, although more than half of these fish were released. The species was clearly the most dominant caught in winter by boat based anglers, with an estimated catch rate of 0.17 fish kept/boat/hour.

A 12 month survey of recreational fishing in the Peel-Harvey Estuary gaves an estimate of 1,556 (±405 standard error) *A. butcheri* kept and 2,440 (±1,117) released by boat based anglers (Malseed and Sumner 2001). The species was taken predominantly in autumn and winter. There was no record of the species being kept by shore based anglers.

Victoria

The weight and value ($'000) of the commercial catch of *A. butcheri* has varied over the last five years in Victoria: 1995/96: 146 t, $1,110; 1996/97: 104 t, $867; 1997/98: 163 t, $1,239; 1998/99: 198 t, $1,524; 1999/2000: 174 t, $1,152 (Marine and Freshwater Resources Institute 2000). The majority of the catch was from the Gippsland Lakes and Lake Tyers.

The Gippsland Lakes support one of the largest estuarine commercial fisheries in Australia (Hall and MacDonald 1985). They were permanently opened to the sea in 1889 (Hobday and Moran 1983). Statistical records for the commercial bream fishery go back as far as 1903, but are of little value for statistical purposes before 1913 when licensing provisions were changed (Butcher 1945b). Between 1913 and 1918, the annual catch fluctuated between 490,000 lb (222 t) and 750,000 lb (341 t). There was a very large catch of 955,000 lb (434 t) in 1919, followed by a steady decline to about 43,000 lb (20 t) in 1940, a decrease of 95% (Butcher 1945b; Munro 1949). Between 1940 and 1957, the annual catch was relatively stable at about 150,000 lb (68 t) (Ling 1958). It steadily rose until 1973 when there was a record catch of 485 t, representing 44 % of the total (multi species) commercial catch for the Gippsland Lakes in that year (Beinssen 1978). A limited entry management policy was introduced in 1983 (Hobday and Moran 1983). Coutin *et al.* (1997) examined long term trends in the commercial catch and effort in the Gippsland Lakes. They found that catch rates have been lower in the 1990s than they were in the early and mid 1980s, and the proportion of large fish in the catch was lower than previous years.

Recreational fishing in the Gippsland Lakes is a major tourist attraction. Gorman (unpubl. a; unpubl. b) conducted four two-day angler census' in 1963/64 at the Lakes, interviewing 537 anglers. An estimated 64% of the *A. butcheri* catch retained by the anglers was below the legal size limit of 26 cm. Returns from a tagging survey in 1964/65 indicated that the number of *A. butcheri* taken by commercial and recreational fishers was 57% and 43% of the total number taken, respectively. The estimated recreational catch in 1963 was 59 tonnes, which was 40% by weight of the total catch (commercial plus recreational) for that year.

Beinssen (1978) undertook on-site interviews and aerial surveys of anglers at the Gippsland Lakes over a four month period during 1977, and estimated that 55% were targeting *A. butcheri*, with a success rate of 0.39 fish per hour (average 0.257 kg, totalling 6.9 tonnes over four months).

A recreational fishing survey was conducted in the Gippsland Lakes from April 1979 to February 1983 (Hall and MacDonald 1985). Mean annual angling effort was estimated at approximately 1.30 million hours (252,000 angler days). There were seasonal peaks in effort coinciding with school holidays. The all species combined catch rate was estimated at 1.14 fish per angler hour, or 1.47 million fish per year weighing 351 tonnes. *A. butcheri* was the major target species; the estimated annual catch was 1.02 million fish weighing 232 t, representing 69% and 66% of the number and weight of the total multi species angling catch, respectively. This was more than the annual commercial catch for *A. butcheri* in the Gippsland Lakes over the same period.

Coutin *et al.* (1997) presented preliminary results of a survey of recreational angling in Gippsland Lakes, the quality of which appears to have declined in recent years from 0.9 *A. butcheri* retained per angler hour in 1979-82 to 0.5-0.6 in 1995. The size of the catch has also decreased, and discard rates are high, possibly contributing to total fishing mortality.

A further recreational fishing survey was conducted in Mallacoota Inlet (Hall *et al.* 1985). The recreational catch in the inlet was estimated from monthly angler counts and on-site interviews conducted from December 1981 to June 1984. One of the major species caught by anglers was *A. butcheri*, providing 41% of both the number and weight of the estimated mean annual angler catch of 48,000 fish weighing 27 tonnes. It was the most sought after angling species, being specified as the primary target by 37.7% of the anglers interviewed, and was taken throughout the year with peaks in catch during school holidays. Prawns were the principal type of bait used by anglers targeting *A. butcheri* and the reported incidence of undersized *A. butcheri* being retained by anglers was less than 2% of total retained catch for the species. Comparison of recreational and commercial catches (7 licensed commercial fishers) from 1981/82 to 1983/84 indicated that recreational fishers accounted for 44% of the total annual *A. butcheri* catch (recreational plus commercial).

Recreational fishing in Port Phillip Bay, Victoria, was also estimated from monthly angler counts and on-site interviews conducted during the 12 month period from October 1982 to September 1983 (MacDonald and Hall 1987). *A. butcheri* was caught by shore anglers but not by boat anglers, and constituted a small proportion of the catch. It was not a preferred target for at least 94% of anglers.

Studies by Len (1987) and Gorczyca and Len (1985) examined the spoilage of marine fish under simulated tropical conditions. Three species of fish off the Victorian coast were caught and subjected to inadequate icing procedures as would be experienced in tropical fisheries. *A. butcheri* subjected to 29°C at time of capture were spoiled after 13 hours, and partially chilled fish held for 4 days at 10°C then at 29°C, were spoiled after 4 days 13 hours. The microflora on the carcasses were examined and the biochemically active spoilers reported.

6.0 Status of stock

Stock assessment of fish stocks in west and south coast estuaries in Western Australia is usually based on a long term analysis of catch and effort data together with a good understanding of basic biology. The state of all major fish stocks that support fisheries in Western Australia are summarised in the annual State of the Fisheries report produced by the Department of Fisheries. In the most recent report, the breeding stock levels of *A. butcheri* were listed as adequate for both west and south coast estuaries, and the exploitation status was listed as not assessed (Penn 2000). Preliminary eggs-per recruit models were developed for the Swan River and Wellstead estuaries.

Annual recruitment to *A. butcheri* stocks within estuaries is typically varied (see section 4.9 Recruitment). Thus a marked temporal fluctuation in abundance should be expected. The historical commercial catch data for the Leschenault Estuary over the period 1941 to 1974 serves to illustrate this point: 43 kg in 1955, 6,892 kg in 1962, and 1,710 kg in 1974

(Lenanton, unpubl.). Variable annual catches were also a feature of the Gippsland Lakes, Victoria (Hobday and Moran 1983).

By virtue of its location in a large population centre, the Swan River Estuary has been subjected to heavy exploitation by commercial and recreational fishers compared to most other estuaries in Western Australia. Today, *A. butcheri* is less important commercially in this estuary due primarily to reduced levels of access. The species has come under increasing recreational pressure, however (Holt 1978; Loneragan *et al.* 1987). Since 1987, recreational fishing of all kinds in Western Australia has increased from 284,000 to 600,000 people a year, or from 27% to 34% of the population over 4 years old (Penn 2000). Although long term data on recreational catch and effort are unavailable, the species could be considered fully exploited in the Swan Estuary.

Sarre and Potter (2000) showed that the percentage of *A. butcheri* caught at five years of age in the Swan River Estuary (5%) was far lower than in either the Moore River Estuary (30%), approximately 100 km further north on the lower west coast of Australia, or the Nornalup-Walpole Estuary (45%) on the south coast. Sarre and Potter (2000) suggest that the above differences presumably reflect a greater "mortality" of older fish in the Swan River Estuary where the population is exposed to heavy fishing pressure from the recreational sector throughout the year and from commercial fishers during winter and early spring. By comparison, the population in the Moore River Estuary is lightly fished and the Nornalup-Walpole Estuary is not exposed to commercial fishing (Sarre and Potter 1999).

Coutin *et al.* (1997) assessed stocks in the Gippsland Lakes, Victoria, and concluded that adult stocks had recently declined, and predicted recruitment to the fishery was likely to be below average for the next 3 years. Yield per recruit modelling indicated that only a small increase in fishery production could be achieved by increasing the legal minimum length. Alternatively, larger yield per recruit increases could be achieved by reducing total fishing pressure. (See also MacDonald (1997)).

7.0 Regulations

Western Australia

There is a current minimum legal size for *A. butcheri* of 25 cm TL. A minimum length of 8 inches was in place in 1913, which was increased to 9? inches in 1937. There was a metric conversion to 241 mm in 1973, followed by an increase to the current limit of 250 mm in 1975. For recreational fishers, a bag limit of 30 fish per person per day was introduced in 1986, and decreased to the current limit of 20 fish per person per day in 1992 following recommendations by the Recreational Fishing Advisory Committee Western Australia (1990). The recreational bag limit for the Swan River is 8 fish per person per day (introduced in 1999).

From July 1, 1992, a recreational fishing licence for net fishing (gill, haul, or throw) was required. Gear restrictions for recreational fishers as at April 2001 are as follows (Fisheries Western Australia 1998):

Set nets:	ocean:	60 m maximum length 75-114 mm mesh size 25 mesh cells (max.) depth

	inland waters:	60 m maximum length 63-87 mm mesh size 25 mesh cells (max.) depth
Haul nets:	ocean and inland waters:	60 m maximum length, 51-114 mm mesh size; 25 mesh cells (max.) depth
Throw nets:	maximum radius 3 m, maximum mesh size 25 mm.	

There are a number of situations and locations where netting is banned permanently or intermittently for commercial and recreational fishers.

Victoria

The legal minimum length as at November 1997 is 26 cm TL, recently increased from 24 cm TL for the recreational and 25.5 cm TL for the commercial fishery.

Bag limit: 10 per person per day as at November 1997, including all bream species. This applies throughout Victoria, whereas it once applied to only the Sydenham Inlet and Bemm River.

Historical references to regulations in the Gippsland Lakes are provided by Butcher (1945a; 1945b), Gorman (unpubl. b) and Ling (1958).

8.0 Aquaculture

8.1 Captive breeding and ongrowing

Sparid breeding and aquaculture is a common practice world wide. In Western Australia, *A. butcheri* has been one of the most researched finfish species for aquaculture purposes. A manual for hatchery production has been produced by the Fremantle Maritime Centre (Jenkins *et al.* 1999) where the species is also used for aquaculture education purposes. Spawning was originally induced using hormones, but natural spawning without inducement has now been achieved. Larvae are intensively reared in seawater using a diet of live zooplankton. Fingerlings and juveniles are fed pelletised fish food.

The complementary DNA (cDNA) encoding the preprotein growth hormone (pre-GH) of *A. butcheri* has been isolated, cloned, and sequenced (Knibb *et al.* 1991). The sequences were amplified from reverse transcribed total RNA of whole brains using polymerase chain reaction (PCR) and oligonucleotide primers corresponding to the 5’ and 3’ regions of *Pagrus auratus* (red sea bream or snapper). Use of the PCR technique offers a rapid method of isolating fish GH cDNA sequences for commercial and taxonomic applications.

The inhibitory effect of stress from capture and handling on reproductive processes in *A. butcheri* were studied by Haddy and Pankhurst (1999). Confinement stress resulted in significantly elevated plasma cortisol levels and exerted a rapid inhibitory effect on gonadal steroidogenesis. Hobby *et al.* (2000) suggested elevated cortisol may reduce the binding capacity of sex steroid binding protein (SBP), a plasma molecule which protects and aids sex steroids such as estrodiol. They suggest that confinement for 6 hours after capture may therefore displace estrodiol from SBP, resulting in the metabolism of circulating free estrodiol. Haddy and Pankhurst (2000b) advise that capture and handling stress reduce the responsiveness of *A. butcheri* to exogenous hormone treatment, but that best results are obtained if hormonal treatment is administered at the time of capture. They had compared fish that were injected with hormones at capture with those injected 24 hours post capture. The former showed a better ovulatory response and plasma sex steroid levels remained significantly elevated.

8.2 Stock enhancement

A. butcheri have been translocated from North Landing, Bremer River, to Lake Dumbleyung, Western Australia. In November 1983, approximately 400 small fish (85-210 mm TL) were captured and successfully transferred by members of the Dumbleyung Fishing Club in 200 gallon containers by road to the Lake. Then in March 1984 a further 283 fish were caught by seine nets and again transferred by road to Lake Dumbleyung. The first *A. butcheri* to be caught in the lake were two individuals - a female (270 mm TL; 318.1 g) and a male (326 mm TL; 605.3 g) in September 1986.

A two year FRDC (Fisheries Research and Development Corporation) research project involving the Department of Fisheries, Murdoch University and Fremantle Maritime Centre has recently been completed (Sarre *et al.* 1999). This project was designed to evaluate the success of previous *A. butcheri* stockings in private waters in southwestern Australia and determine some of the environmental parameters required for successful stocking. While more information is clearly required the preliminary data collected to date has demonstrated:

- Survival of black bream stocked into water bodies containing fresh or very low salinity water has been low or nil.
- Survival and growth rates have been encouraging in water bodies containing saline water and in several of these black bream have attained sexual maturity.
- Small black bream, in some water bodies, can be highly susceptible to predation by cormorants.
- Naturally occurring feed in some water bodies may not be adequate for larger black bream and supplementary feeding may therefore be necessary to ensure optimal growth.

Recreational fishing enhancement was attempted through the release of hatchery bred and reared *A. butcheri* into the Swan Estuary (Lenanton *et al.* 1999; Dibden *et al*. 2000). Prior to release, problems of compromising genetic diversity and introducing pathogens and disease were resolved, and a programme to assess the outcome of the strategy was established. In March 1995, 767 fourteen month old juveniles reared at the Fremantle Maritime Centre were externally tagged and released into the upper reaches of the river (Jenkins 1995; Dibden *et al*. 2000). They were an F1 generation from Swan Estuary broodstock.

The restocking programme was evaluated by Dibden *et al.* (2000). By the end of October 1997, 31 months after release, 97 fish (12.6%) had been recaptured, all within the Swan Estuary. The longest period at liberty recorded for any recaptured fish stands at 945 days as at October 1997. Their size at age was compared to wild fish and found to be significantly larger, possibly due to choice hatchery conditions prior to release. Also, some of the recaptured fish had mature gonads. The diet of the tagged fish was similar to that recorded for wild fish in the Swan by Sarre and Potter (2000). Dibden *et al.* (2000) and Lenanton *et al.* (1999) claim the tagged fish were more catchable than wild stock.

In conclusion, the stock enhancement programme demonstrated that hatchery reared juvenile *A. butcheri*, upon release, were able to survive for extended periods. They could feed naturally and exhibit robust growth. Importantly, there was every indication that they could successfully reproduce. As a result, a second restocking trial for the Swan River Estuary has been undertaken. In June 1997, 34,000 hatchery reared 4 month old juveniles were marked with otolith staining oxytetracycline dye before release (G. Jenkins, pers. comm.). The oxytetracycline can be used to validate the aging technique using otoliths. A small number of live fish have been kept in captivity for reference purposes.

Although there have been several informal releases of hatchery reared stock into the Swan River Estuary, there are aspects of the restocking process that could be improved (Lenanton *et al.* 1999). The optimum size at release has yet to be determined, and will depend on a balance between hatchery costs and size related survival in the wild. Broodstock should come from the same estuarine system into which the juveniles shall be released. Also, a genetically effective large number of broodstock are necessary to produce a genetically diverse F1 generation for release. These measures help to preserve genetic diversity within and among estuaries.

9.0 Management issues

Some of the general but important issues for managing *A. butcheri* stocks in Western Australia include:

- Determining the sustainable yield from west and south coast estuaries.
- Increased fishing pressure from recreational fishers leading to a greater conflict among commercial and recreational fishers including the allocation of catch shares.
- Habitat disturbance: residential and other development along the edge of waterways has altered riparian vegetation. Enriched agricultural run-off leading to increased nutrient levels has eutrophied many rivers/estuaries in southwestern Australia. A long history of land clearing in catchment areas has altered the salinity profile of many, if not all, river systems, the full effect of which is yet to be felt.
- Management of populations in barred estuaries. Bar breaching, natural or artificially induced, may cause the death of many fish and the marked fluctuation of population sizes.

The Swan River Estuary in Western Australia is bounded by urban development and experiences limited industrial activity. Marks *et al.* (1980) measured heavy metal concentrations (iron, zinc, copper, manganese, cadmium, lead, chromium, cobalt and nickel) in *A. butcheri* from this estuary. The mean (±95% confidence limits) concentration in mg g^{-1} of muscle tissue (wet weight) for individuals weighing more than 50g (i.e. total length >140 mm) was: Fe: 2.3 (0.92), Zn: 5.5 (1.67), Cu: 0.29 (0.13), Mn: 0.36 (0.23), Cd: 0.039 (0.042), Pb: 0.47 (0.098), Cr: 0.14 (0.049), Co: 0.21 (0.085), Ni: 0.19 (0.11). Generally, there was an inverse relationship between heavy metal concentration and fish size. For all individuals weighing >50 g that were examined (n= 41), concentrations were much less than maximum levels stipulated by the National Health and Medical Research Council and WA Drug and Food Regulations.

Butcher (1945a) attributed the steady decline in bream catches in the Gippsland Lakes, Victoria, to overfishing together with ecological changes which began after construction of a permanent entrance to the estuarine system in 1889. Environmental changes listed in the Parliamentary Public Works Committee Report (1952) inquiry were:

1. Disappearance of silt sub-stratum by water movement and submersion by sand.
2. Disappearance of *Zostera* (seagrass) beds resulting in loss of feeding and nursery grounds.
3. Disappearance of marginal flora affected by salt water.
4. Erosion resulting from (2.) and (3.).
5. Influx of plague crab.
6. Loss of agricultural country by erosion and salt effect.
7. Loss of fisheries: Bream, Bass, Luderick, Salmon, Snapper, and Whiting.

Coutin *et al.* (1997) identified several important ecological considerations in the Gippsland Lakes. These include the vulnerability of seagrass habitats to epiphyte smothering as a result of raised nutrient levels from sewage effluent, urban stormwater and agricultural run-off. Algal blooms have also resulted. Also, pesticides and industrial discharges introduce toxicants with the potential to affect *A. butcheri* early life stages. Catchment management and water use has altered run-off and river flows, affecting physical properties of the lakes. Introduced exotic species such as carp (*Cyprinus carpio*) have the potential to change the ecological balance. The abundance of cormorants, predators of *A. butcheri*, appears to have sharply increased in recent years.

Hobday and Moran (1983) drew attention to the dramatic fluctuations in recruitment and catches in the Gippsland Lakes, and were concerned that planned industrial and agricultural development in the region could further decrease the inflow of freshwater into the Lakes, with further detrimental consequences for the fish. They also demonstrated a massive increase in catch rates through improved efficiency following the introduction of echo sounders to locate schools and encircle them with mesh nets.

Sherwood and Backhouse (1982) concluded that 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 *A. butcheri*.

Fabris *et al.* (1999) estimated mercury and organochlorine concentarions in *A. butcheri* from the Gippsland lakes. The mean mercury concentration of 0.22 $\mu g\ g^{-1}$ (wet weight) was below the maximum in fish permitted for human consumption but at least 58% higher compared with fish tested in 1978-79. Possible causes were discussed. Organochlorine insecticides were detected in all fish but the concentrations were less than 10 $ng\ g^{-1}$ (wet weight), one order of magnitude below the maximum for human consumption.

10.0 Current Western Australian research

Research and development for aquaculture of *A. butcheri* is ongoing. Reducing production costs and accelerating growth rates are high priorities with improvements in marketing also desirable (Jenkins 1995). The Fremantle Maritime Centre has produced a hatchery manual (Jenkins *et al*. 1999).

Murdoch University and the Fremantle Maritime Centre are currently undertaking a Fisheries Research and Development Corporation (FRDC) funded project entitled “Factors required for the successful aquaculture of black bream in inland water bodies”. The objective of this study is to determine the suite of conditions required in inland saline water bodies that will enable *A. butcheri* to be grown to a size suitable for angling. This information will also benefit those wishing to produce *A. butcheri* commercially. Aspects of this research will include:

- Effect of caging juveniles on survival and growth.
- Evaluation of currently available commercial fish feeds.
- Effect of introducing various types of protection on predation by birds.
- Elucidation of growth rates from different genetic stocks.

Stock enhancement in the Swan River Estuary has been ongoing. A number of hatchery reared *A. butcheri* have been marked with otolith staining oxytetracycline prior to release in an attempt to evaluate the future benefit to the fishery.

A stock enhancement project for the Blackwood River in the extreme southwest of Western Australia has commenced. This FRDC funded collaborative effort between Murdoch University and the Fremantle Maritime Centre plans to more rigorously evaluate the results of enhancing with *A. butcheri*.

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13.0 Tables and figures

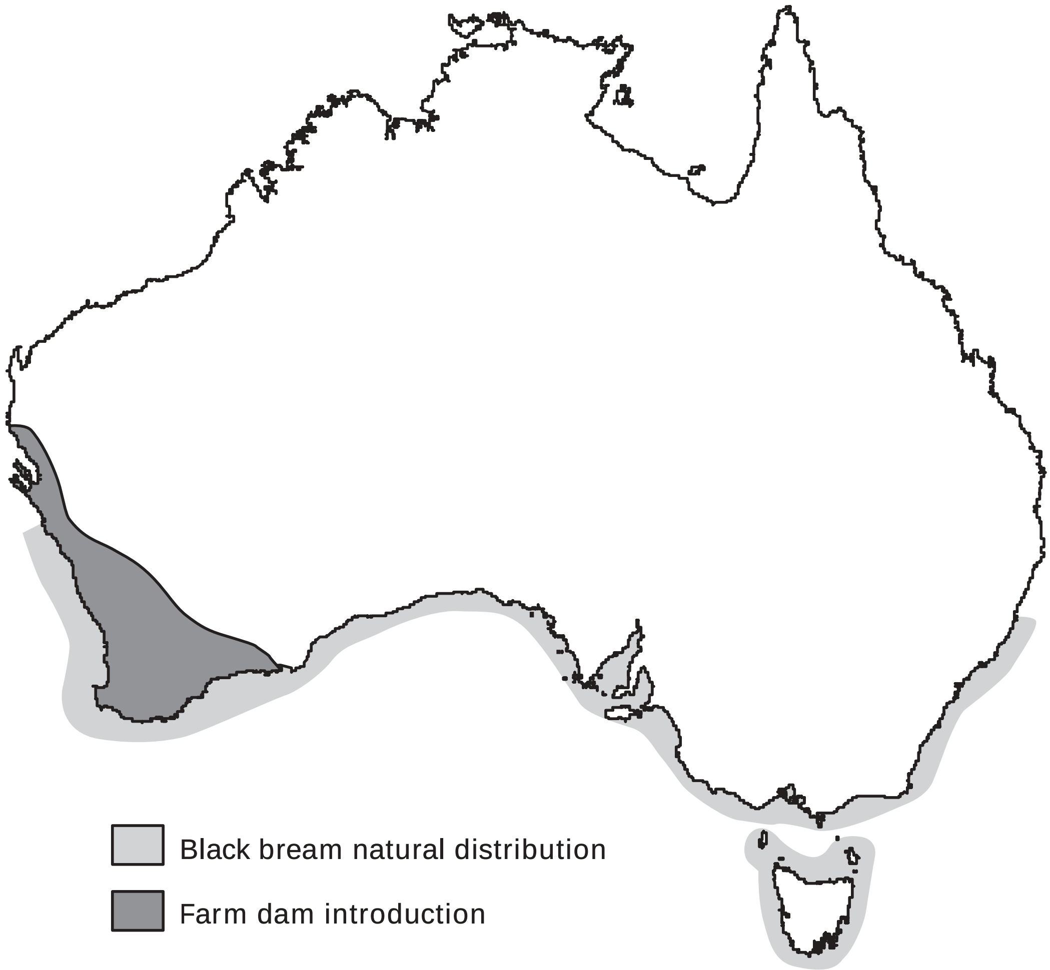

Figure 1. Natural distribution and region of Western Australian farm dam introductions of *A. butcheri.* The natural distribution is mostly in the rivers, estuaries, coastal lakes and sheltered coastal waters along the coastline indicated.

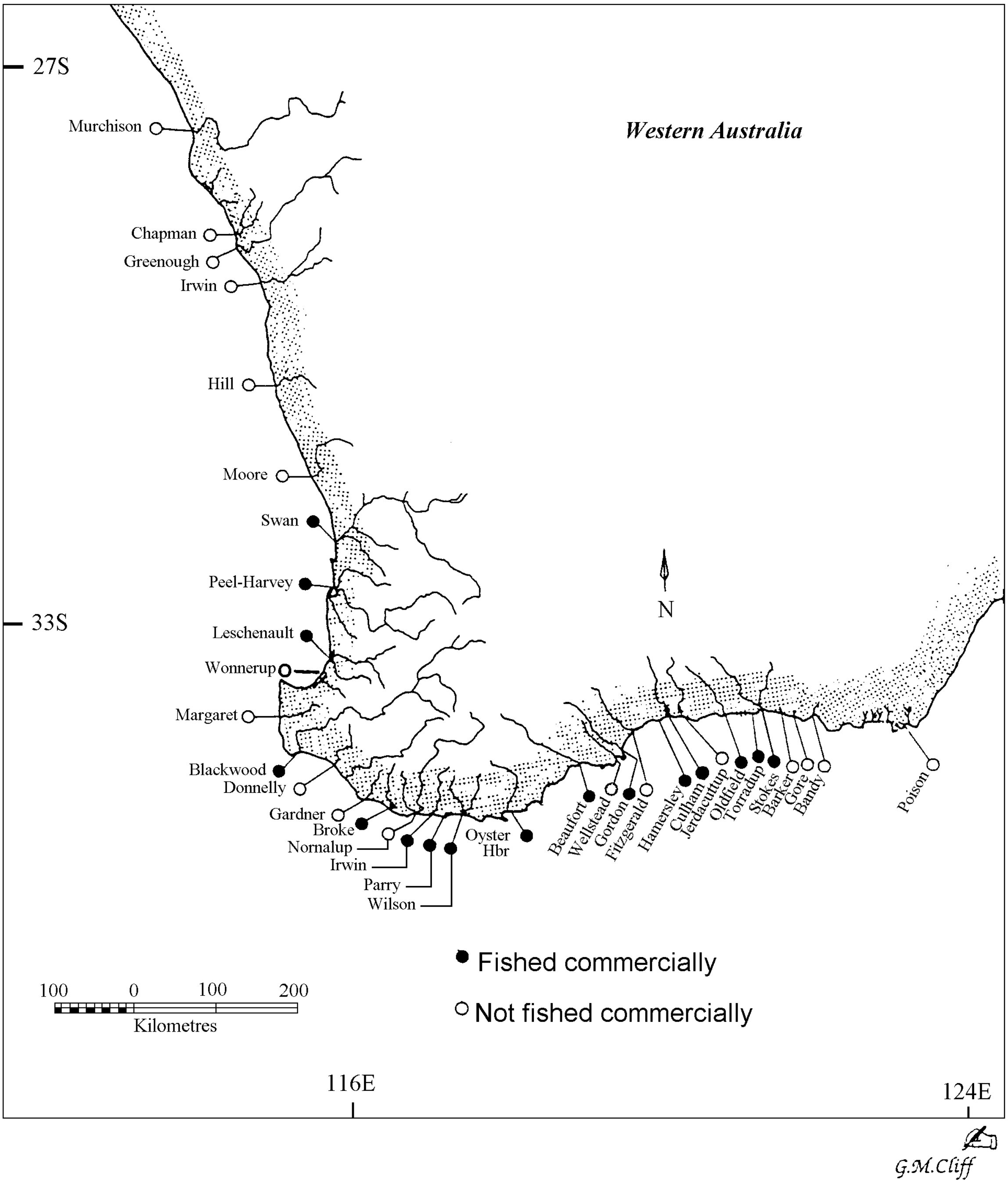

Figure 2. Rivers and estuaries of southern Western Australia where A. butcheri has been reported to occur.

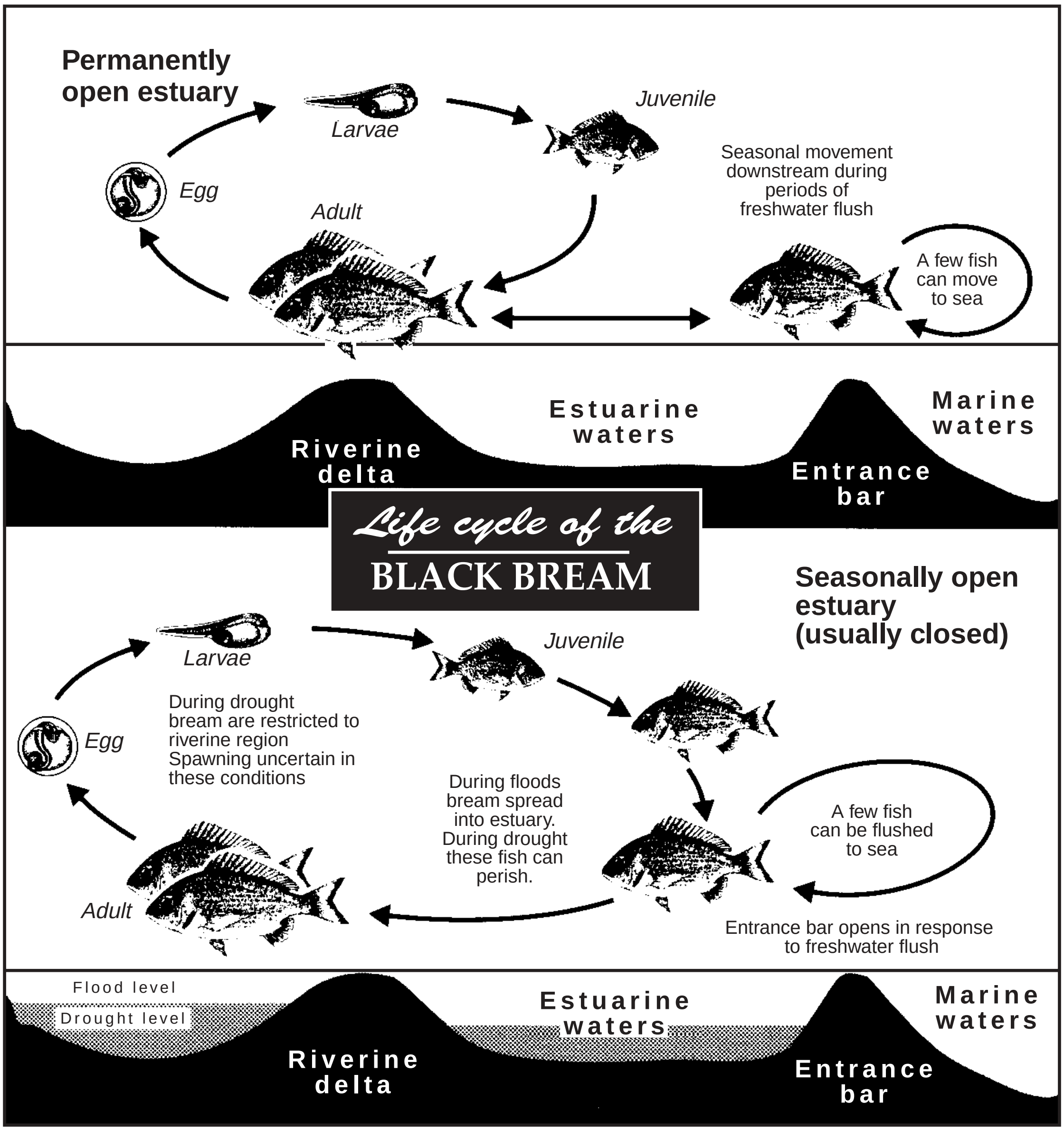

Figure 3. Life cycle of A. butcheri in a permanently open estuary and a seasonally open (usually closed) estuary. Source: Fishing WA leaflet No. 10, 1993, Department of Fisheries.

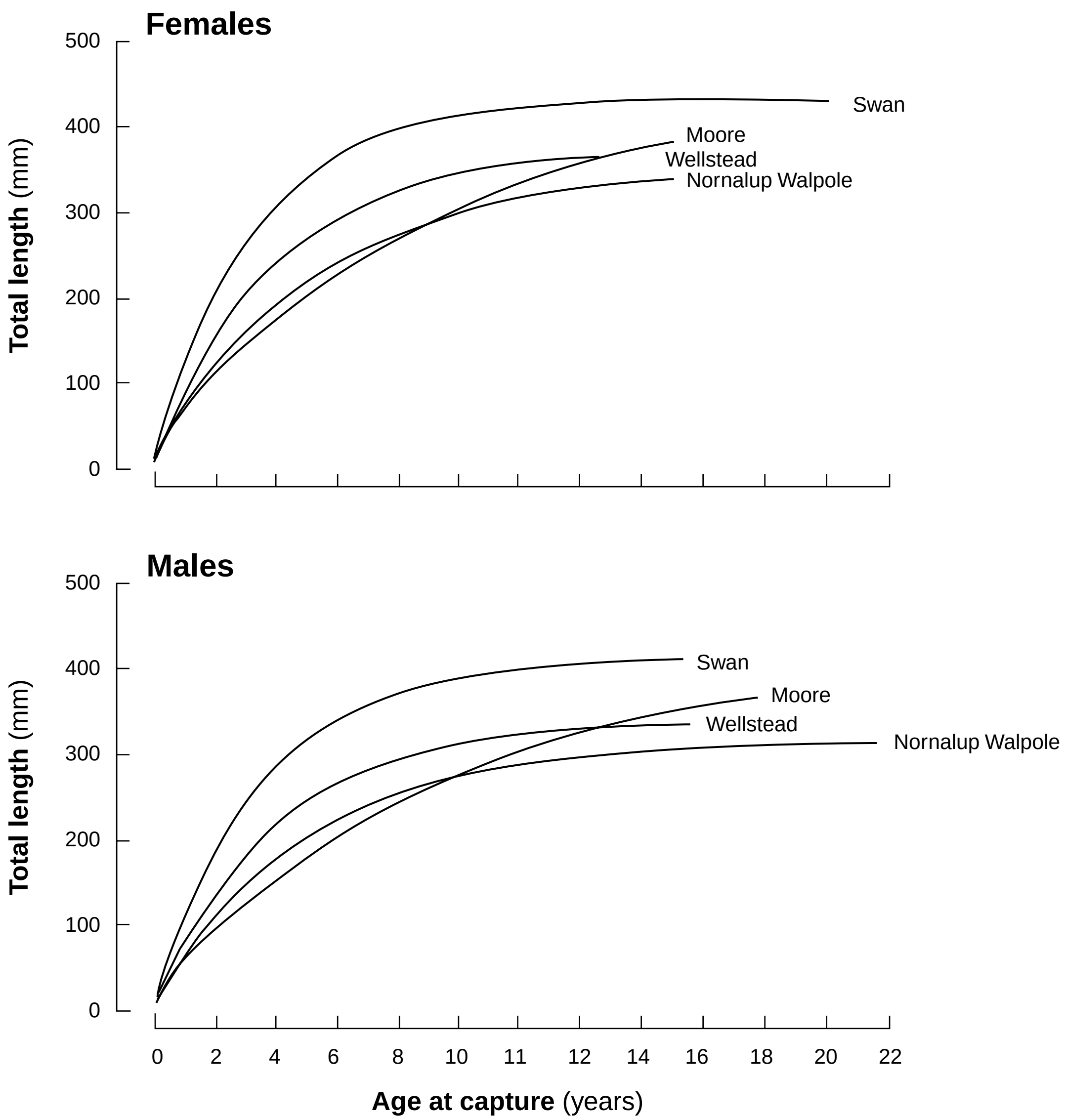

Figure 4. Growth curves derived from von Bertalanffy parameters estimated by Sarre and Potter (2000) for males and females from the Swan River, Moore River, Nornalup/Walpole and Wellstead estuaries, Western Australia.

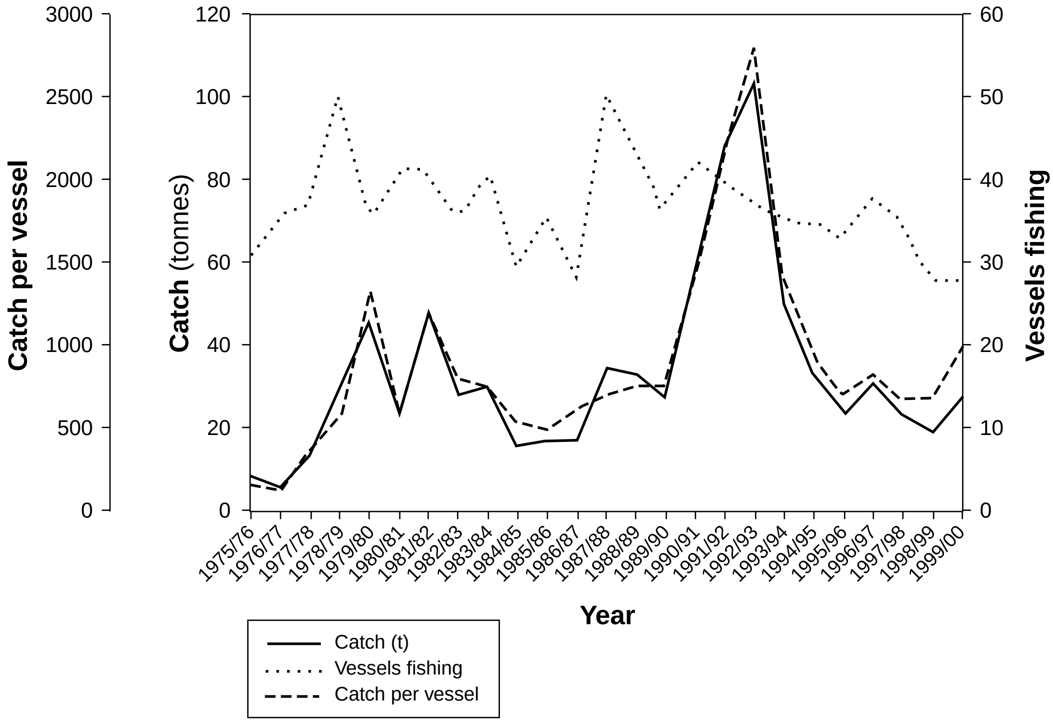

Figure 5. Total reported commercial catch, catch per vessel (kg) and number of commercial vessels fishing for A. butcheri in Western Australia from 1975/76 to 1999/2000 (Source: CAES, Department of Fisheries).

14.0 Appendix

Modelling and biological parameters

A summary of the available values for biological parameters is presented below. Estimates are from various sources and cover different stocks of *A. butcheri*. For further details see text.

Mortality

Gippsland Lakes, Victoria:

(Gorman, unpubl. a): annual total mortality 46% (Z = 0.61 year^{-1}), annual fishing mortality 11% (F = 0.10 year^{-1})

(Gorman, unpubl. b): annual total mortality for different age cohorts

Z = 0.763 year^{-1} for fish 4+ years and above

Z = 0.63 year^{-1} for fish 7+ years and above

Z = 0.7 year^{-1} for fish 4+ to 8+ years

Coutin *et al.* (1997): natural mortality (M) = 0.10 to 0.20 yr^{-1} depending on estimating formulae.

Sex ratio

Hoyers Lake, New South Wales:

Labile protogynous hermaphrodites. Male:transitional:female ratio = 5:7:7 (Rowland and Snape 1994).

Myall Lake, NSW:

Labile protogynous hermaphrodites. Female:transitional:male ratio = 12:3:23 (Rowland and Snape 1994).

Gippsland Lakes, Victoria:

No evidence of hermaphroditism. Ratio essentially 1:1 (Rowland and Snape 1994).

Swan River Estuary, Western Australia:

Male:female ratio 1.19:1, increasing to about 2:1 during spawning (Sarre, 1999). All fish possess ovotestis, but no evidence of sex change.

Age and size at maturity

Western Australia

Leschenault Inlet, Oyster Harbour, Wonnerup Estuary (Thomson 1957b).

Age at maturity: 2+ yrs. Size at maturity: 16.9 cm LCF males; 15.6 cm LCF females.

Swan River (Sarre and Potter, 1999).

Age at 50% maturity (A_{50}): 2.2 yrs females and 2.1 yrs males.

Length at 50% maturity (L_{50}) (mm, TL): females 218, males 212.

Moore River (Sarre and Potter, 1999).

A_{50}: 3.3 yrs females and 2.6 yrs males.

L_{50}: (mm, TL): females 156, males 129.

Wellstead Estuary (Sarre and Potter, 1999).

A_{50}: 1.9 yrs females, 1.8 yrs males.

L_{50}: (mm, TL): females 157, males 145.

Walpole/Nornalup Estuary (Sarre and Potter, 1999).

A_{50}: 4.3 yrs females, 2.8 males.

L_{50}: (mm, TL): females 201, males 158.

Victoria

Gippsland Lakes:

Age at maturity: 2+ yrs (Butcher 1945a).

Age at maturity: 3+ yrs males, 4+ yrs females (Scott *et al.* 1974).

Size at maturity: 21.6 cm LCF (Butcher 1945a).

South Australia

Onkaparinga Estuary

Age at maturity: 3+ yrs (Harbison 1973).

Fecundity

Western Australia

Leschenault Inlet, Oyster Harbour, Wonnerup Estuary

Thomson (1957b): 13,000 to 612,000.

Swan River Estuary

Holt (1978): 80,642 to 612,000.

Sarre and Potter (1999): Mean 1580 x 10^3. Maximum 7090 x 10^3.

Von Bertalanffy Growth Parameters

Western Australia

Sarre and Potter (2000), sectioned otoliths:

Swan River Estuary

Females: t_o = -0.13 years; K = 0.30 year^{-1}; L_∞ = 437.8 mm TL (n= 733, R^2= 0.94)

Males: t_o = -0.15 years; K = 0.31 year^{-1}; L_∞ = 419.3 mm TL (n= 894, R^2= 0.94).

Moore River

Females: t_o = -0.54 years; K = 0.11 year^{-1}; L_∞ = 451.6 mm TL (n= 345, R^2= 0.93).

Males: t_o = -0.61 years; K = 0.11 year^{-1}; L_∞ = 429.2 mm TL (n= 387, R^2= 0.92).

Nornalup Walpole

Females: t_o= -0.60 years; K = 0.16 year^{-1}; L_∞ = 367.0 mm TL (n = 346, R^2 = 0.91)

Males: t_o = -0.31 years; K = 0.21 year^{-1}; L_∞ = 323.0 mm TL (n = 265, R^2 = 0.90)

Wellstead

Females: t_o = –0.17 years; K = 0.25 year^{-1}; L_∞ = 377.8 mm TL (n = 324, R^2 = 0.91)

Males: t_o = -0.18 years; K = 0.27 year^{-1}; L_∞ = 344.6 mm TL (n = 331, R^2 = 0.92)

Lake Clifton

Males: t_o = -0.46 years; K = 0.32 year^{-1}; L_∞ = 441.5 mm TL (n = 85, R^2 = 0.96)

Gippsland Lakes, Victoria

Gorman (unpubl. a; unpubl. b): t_o = 0.5 years; k = 0.22 year^{-1}; L_∞ = 38.5 cm LCF (n= 650).

Scale annuli.

Hobday and Moran (1983): t_o = -0.587, K = 0.28 year^{-1}, L_∞ = 24.9 cm LCF (n= 2577).

Scale annuli. A good fit was observed up to age 10 yrs, length under-estimated thereafter.

Coutin *et al.* (1997): t_o = -3.000, K = 0.09 year^{-1}, L_∞ = 36.0 cm LCF (n= 414). Sectioned otoliths.

Morison *et al.* (1998): Females: t_o = -5.21 years; K = 0.042 year^{-1}; L_∞ = 545 mm LCF.

Males: t_o = -3.70 years; K = 0.077 year^{-1}; L_∞ = 382 mm LCF. Sectioned otoliths.

Lake Tyers, Victoria

Coutin *et al.* (1997): t_o = -8.4613, K = 0.0280 year^{-1}, L_∞ = 71.597 cm LCF (n= 140). Sectioned otoliths.

Length and Weight Relationships

Victoria

Gippsland Lakes:

Gorman (unpubl. a; unpubl. b): $\log_{10} W = -1.8397 + 3.117 \log_{10} L$

n = 654, W = weight (g), L = length LCF (cm)

Gorman (unpubl. a, unpubl. b): TL = 0.2693 + 1.088 LCF (n = 166).

Western Australia

Sarre (1999), W = weight (g) and L = total length (mm):

Swan River Estuary:

Females: $\log_{10} W = -5.09 + 3.14 \log_{10} L$ (R^2= 0.99, N=865)

Males: $\log_{10} W = -5.10 + 3.14 \log_{10} L$ (R^2= 0.99, N=925)

Pooled: $\log_{10} W = -5.07 + 3.14 \log_{10} L$ (R^2= 0.99, N=1790)

Moore River Estuary

Females: $\log_{10} W = -5.10 + 3.13 \log_{10} L$ (R^2 = 0.99, n+ 250)

Males: $\log_{10} W = -5.14 + 3.15 \log_{10} L$ (R^2 = 0.99, n = 287)

Pooled: $\log_{10} W = -5.12 + 3.13 \log_{10} L$ (R^2 = 0.99, N=537)

Nornalup/Walpole Estuary

Females: $\log_{10} W = -4.99 + 3.07 \log_{10} L$ (R^2 = 0.99, n = 302)

Males: $\log_{10} W = -5.05 + 3.09 \log_{10} L$ (R^2 = 0.99, n = 234)

Pooled: $\log_{10} W = -5.00 + 3.08 \log_{10} L$ (R^2= 0.99, N=536)

Wellstead Estuary

Females: $\log_{10} W = -4.84 + 3.01 \log_{10} L$ (R^2 = 0.99, n = 274)

Males: $\log_{10} W = -4.89 + 3.03 \log_{10} L$ (R^2 = 0.99, n = 278)

Pooled: $\log_{10} W = -4.85 + 3.02 \log_{10} L$ (R^2 = 0.99, N=552)

Lake Clifton

Males: $\log_{10} W = -5.12 + 3.14 \log_{10} L$ (R^2 = 0.98, n = 85)

Pooled: $\log_{10} W = -5.10 + 3.13 \log_{10} L$ (R^2 = 0.99, n = 100)

Heald (1984), measurement units not given:

Wellstead Estuary

$W = 3.039 \times 10^{-6} L^{3.3044}$

Beaufort Inlet

$W = 3.383 \times 10^{-6} L^{3.282}$

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Not all have been listed here, a complete list is available online at http://www.wa.gov.au/westfish

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