# Spatio-temporal variability in reproductive ecology of sand flathead, *Platycephalus bassensis*, in three Tasmanian inshore habitats: potential implications for management

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## Summary

Temporal and spatial variability in gonad development, duration of spawning period, and size / age at maturity were investigated in sand flathead, *Platycephalus bassensis*. A 3-year study (2001–2003) revealed that variation in gonad weight with somatic weight was a function of an interaction between season and study location (Coles Bay, Georges Bay, and Tamar River estuary). Highest gonad weight was recorded in Coles Bay in early summer, which in comparison to Georges Bay, was approximately 50% higher and occurred 3 months later. Tamar River mature individuals were reproductively inactive during the spawning season. The proportion of mature individuals at different stages of maturity differed significantly among the three locations across all times. Coles Bay individuals were reproductively active from October to March, while in Georges Bay females with hydrated oocytes were seen in September but were absent from the population by November. Interannual variation in initiation and duration of spawning activity was evident in each location. Apart from male size at maturity, for both sexes the size and age at maturity ($L_{50}$) was higher in Georges Bay compared to Coles Bay. The results emphasize the necessity of temporal and spatial management based on population differences in reproductive ecology.

## Introduction

One of the major challenges in ecology is to understand the processes that shape populations and are responsible for variability in population dynamics. In highly fecund species like fishes, variability in population structure is believed to be in part determined by reproductive potential of that population (Einum et al., 2003), i.e. the ability of a fish population to produce viable offspring that may recruit to the adult population or fishery (Marshall et al., 1999). Spatial and temporal variation in fundamental elements of reproductive characteristics (e.g. size / age at maturity, gonad weight, fecundity, spawning strategy), may be the result of biotic and abiotic conditions (Fowler et al., 2000). Such factors can potentially alter the reproductive potential of a fish population (Marshall et al., 1998), which in turn influences population growth and abundance. Despite the general recognition that reproductive life history characteristics have a significant influence on population dynamics (Trippel et al., 1997; Marshall et al., 1998), little is still known about the magnitude of the influence.

In temperate marine fish species, gonad investment changes seasonally, with extensive gonad growth and investment to reproduction during the spawning season (DeVlaming et al., 1982). However, the length or duration of the spawning season may vary among populations of a species (Brown-Peterson et al., 2001), as well as interannual variability in the start and duration of the spawning season within the population (Yamahira, 2001). In serial spawners, yolked oocytes are repeatedly recruited from unyolked oocytes over the spawning season (DeVlaming, 1983), therefore, a longer spawning period will result in more batches of spawned eggs compared to a shorter spawning period. Additionally, given the positive correlation between fecundity and fish size (Ferriz et al., 2007), a larger fish with greater gonad volume is expected to make a greater contribution to population egg production than its smaller counterpart. The result of such variability in egg production may result in the capacity for variations in population growth.

For animals with indeterminate growth (e.g. reptilians, amphibians, and fish) age and size of first reproduction is a key point in the life history (Charnov and Berrigan, 1991; Roff, 1992). Early maturation may ensure a longer reproductive life, and if larger fish have a greater fishing mortality risk then it guarantees some egg production for population stability (Roff, 1992). However, if early maturation compromises growth, the resulting smaller individuals may be more vulnerable to predation (Rochet, 1998). In contrast, individuals attaining maturity at older / larger age / size are more fecund. However, if large individuals suffered a greater risk of mortality (e.g. fishing), it is possible that individuals that delay maturation would never have the chance to produce eggs (Rochet, 2000). Therefore, estimates of size / age at maturity, together with the size / age composition of population is essential to identifying which parts of the population are involved in egg production (Anastasopoulou et al., 2006). Such knowledge is also beneficial in determination and refinement of size limits in fisheries management.

Sand flathead (*Platycephalus bassensis*) showed temporal and spatial variations in demographic parameters around Tasmanian coastal waters (Bani, 2005). The reproductive biology of this species has also revealed potential for flexibility in reproductive life history characteristics (Bani, 2005). The combination of demographic variability and potential for flexibility can potentially cause spatial and temporal variability

in reproductive output of sand flathead. In spite of the potential of such variability, present fishing regulations for this species are based on similarity in reproductive output and uniformity of population structure for all sand flathead stocks around Tasmania. As demographic variability causes differences in reproductive output (LePage and Cury, 1997; Jennings and Kaiser, 1998), there is concern that under present fishing regulations the sustainability of less productive stocks could be in jeopardy. While sand flathead is the species most heavily targeted by recreational fishers in Tasmania (Lyle, 2005), knowledge about this species' fundamental reproductive traits and their variability in temporal and spatial scales, remain basic (Jordan, 2001).

This study examines the variability in reproduction of sand flathead in order to develop a set of recommendations for recreational fisheries management. Our specific objectives were, (i) to quantify the spatial and temporal variation in reproductive investment to assess the possible influence of egg production on population growth, (ii) to examine the duration of spawning period and its implication in egg production, and (iii) to estimate size/age at maturity to identify the part of the population that contributes in egg production.

## Materials and methods

### Sampling and laboratory processing

Fish were sampled from three inshore coastal locations in the north and east of Tasmania (Fig. 1): Coles Bay (east coast), Georges Bay (north east coast), and Tamar River estuary (north coast). Sand flathead were collected seasonally during 2001/02 and 2002/03 using hook and line. Additionally, to further resolve gonad changes on a monthly basis in the Tamar River, monthly sampling occurred during spring and summer 2001/02, while in Coles Bay monthly sampling was done from October 2002 to May 2003. Fish were also caught in the Tamar River and Georges Bay during early (September) and late (November) spring 2002. To minimize bias in reproductive information, fishing was carried out at 4–5 randomly selected sites at each location. Animals were stored on ice until dissection later on the day of collection.

All fish were sexed (male, female, or immature), measured to the nearest millimetre total length, and weighed to the nearest gram (g). Gonads of each fish were removed and weighed to the nearest 0.1 mg and staged macroscopically and histologically following the criteria described by West (1990). For
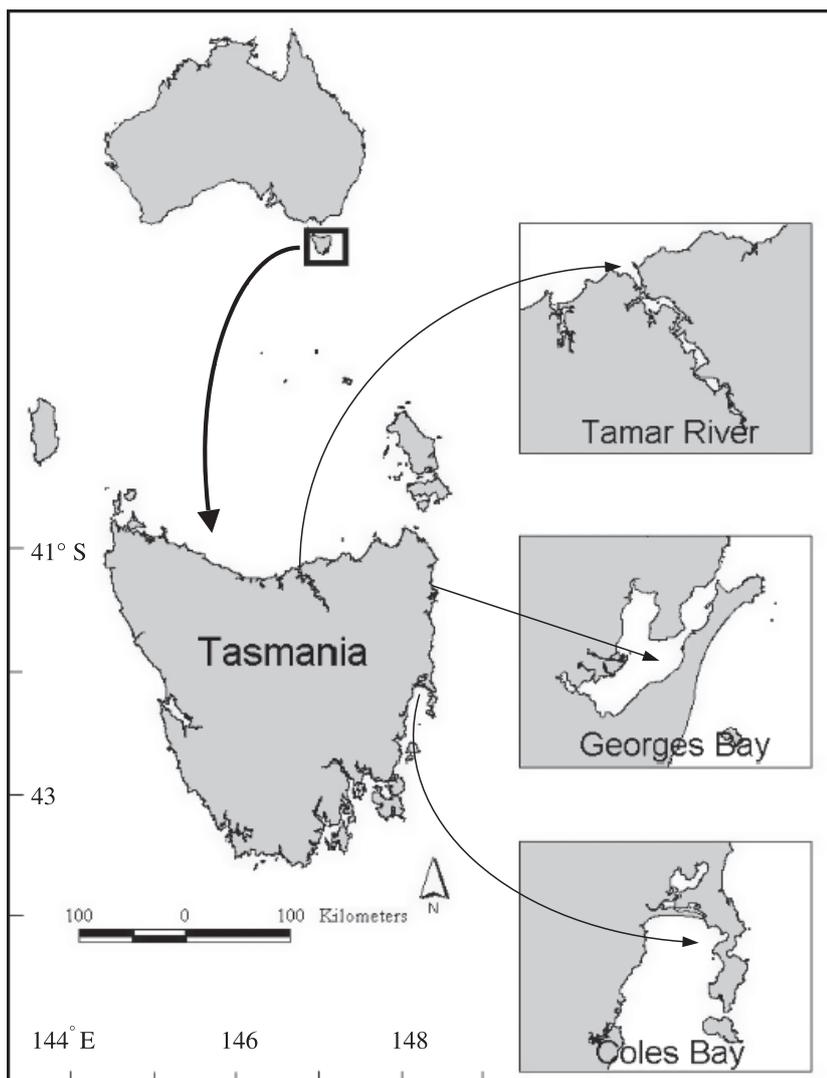


Fig. 1. Map showing sand flathead sampling locations

females, seven stages of gonad maturity were defined as: immature (i), maturing (ii), developing (iii), late developing (iv), ripe (v), running ripe (vi), and spent (vii). Six stages of male gonad maturation were defined as: immature (i), early developing (ii), developing (iii), late developing (iv), ripe (v), and spent (vi).

### Size and age at maturity

Size and age at maturity ($L_{50}$) were estimated as the smallest length or age at which 50% of the fish collected over the spawning season (October to March for Coles Bay and September to November for Georges Bay) were sexually mature. Individuals were considered sexually mature if they were in stage 3 (developing) or higher. To avoid classifying resting (reproductively inactive) or early developing fish as immature, only fish collected at the peak of the spawning season (October to December for Coles Bay and September to November for Georges Bay) were used for this analysis. The proportion of mature fish per 1-cm total length (TL) class and 1-year interval was calculated for males and females separately using a binary logistic regression. Percent maturity was then fitted to age / length class for males and females separately in each location.

### Analysis

Differences in gonad weight were analysed using a 3-way analysis of covariance (ANCOVA) with location, sex, and season as factors of interest and somatic weight (body weight minus visceral weight) as the covariate, followed by a comparison of adjusted means taking the covariate into account (Quinn and Keough, 2002). This provided a size-independence measure of gonad condition. Log-transformed data was used to linearize the relationship. Variations in gonad weight were analysed only for mature fish. Reproductively mature fish were defined by size at maturity for Coles Bay and Georges Bay. In the Tamar River, males >22 cm and females >25 cm were conservatively selected as mature individuals based on the smallest mature size records.

To explore the trends in maturity stages for each location throughout the year and among locations, the frequency of individuals at each maturity stage between the months sampled and in different locations, was analysed using a Chi-square test of independence for males and females separately. Standardized residuals, under normal distribution, were used to determine where observed frequencies differed from expected frequencies.

## Results

### Changes in gonad development

Changes in gonad (both ovary and testis) weight with somatic weight were dependent upon the combination of location and season ($F_{location*season}$ = 72.52, d.f. 6, 713, P < 0.001), with similar patterns seen for both sexes. Thus, a significant three-way interaction between location, season, and sex was not detected. The Coles Bay mature population showed increased gonad weight during spring and summer, which then decreased in autumn (Fig. 2). In Georges Bay, the increase in gonad weight occurred in spring, then declined in summer and remained low (Fig. 2). Interestingly the increase in gonad weight was detected during the winter in the Georges Bay population, but not in the Coles Bay population. However,
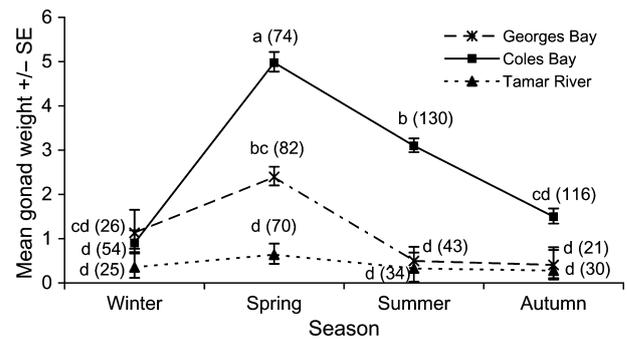


Fig. 2. Mean gonad weight (gr ± SE) adjusted for somatic weight of sand flathead (*Platycephalus bassensis*) at each location and in each season. Means sharing same letter are not significantly different. Asymmetric SEs resulted from back transformation of logarithmic values. Values in parentheses = sample size

Coles Bay individuals had 52 and 84% higher gonad weight than in Georges Bay in spring and summer, respectively. Unlike the two other locations, the adjusted mean weight of gonads in the Tamar River population was consistently <1 g throughout the year.

The proportion of mature females at different stages of maturity (Fig. 3) differed among the three locations across all times ($\chi^2$ = 199.4, d.f. 10, P < 0.001). Additionally, in Coles Bay and Georges Bay, the proportion of mature females in each gonad stage depended upon the month of sampling (CB $\chi^2$ = 349.7, d.f. 50, P < 0.001; GB $\chi^2$ = 134.3, d.f. 26, P < 0.001). This was not the case for the Tamar ($\chi^2$ = 8.2, d.f. 14, P = 0.726), where only two fish had developing ovaries (Fig. 3a) with the remainder reproductively immature.

The appearance of hydrated oocytes in the ovaries was approx. three months earlier in females from Georges Bay compared to females from Coles Bay. In 2001 / 02, Georges Bay females with developing ovaries (stages 3 and 4) first appeared in July 2001; by November 2001, 59% of females were spent (stage 7) (Fig. 3b). During 2002 / 03 females with hydrated oocytes (stage 6) were caught in September, but were absent from the population by November; 25% of females caught in November were spent. From January to July all females in Georges Bay had regressed ovaries.

In Coles Bay, developing (stage 4) and ripe (stage 5) oocytes were present in the ovaries in females caught in October (Fig. 3c). The presence of females with ripe oocytes in October and with hydrated oocytes in the ovary until March suggested an extended spawning activity in Coles Bay. Interannual variation in reproductive activity was seen in Coles Bay. By March in the 2000 / 01 spawning season, 84% of females were either in stage 7 (spent) or stage 2. In contrast, in the 20002 / 03 spawning season, none of the 23 females caught in March were spent; the greatest percentage of spent individuals was seen in May.

The number of mature males at each maturity stage depended on location across all times ($\chi^2$ = 143.8, d.f. 8, P < 0.001). While stage five individuals (ripe) dominated the Coles Bay population, stage 2 fish (immature) were predominant in the Tamar River (Fig. 4). In each location, the proportion of males in each testis stage depended upon the month of sampling (GB $\chi^2$ = 132.7, d.f. 24, P < 0.001; CB $\chi^2$ = 329.2, d.f. 32, P < 0.001; TR $\chi^2$ = 23.7, d.f. 14, P < 0.05). Except for six developing males (stages 3 and 4), no fully spermiated males were found in the Tamar River

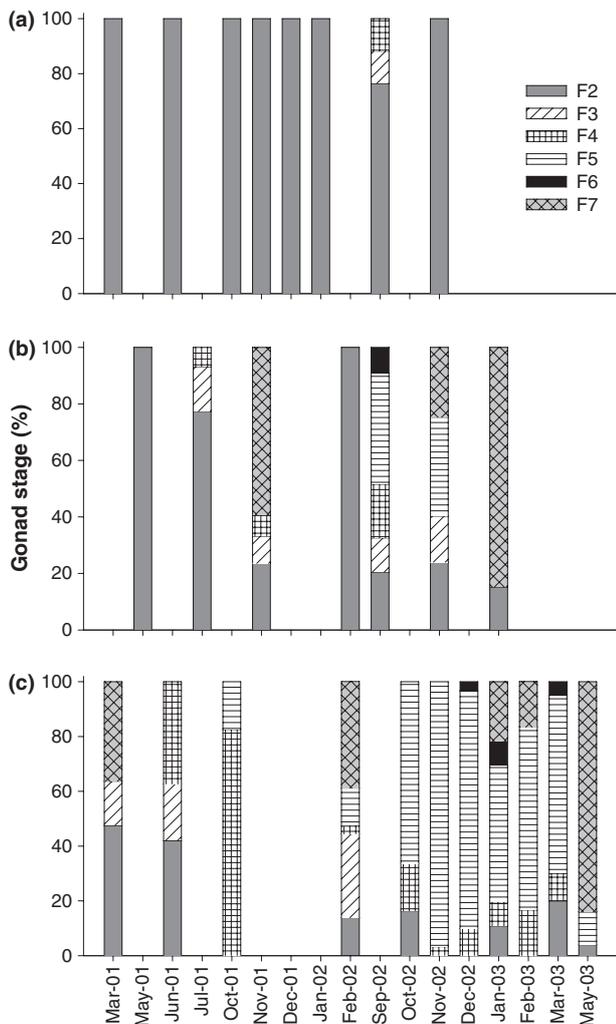Fig. 3. Changes in proportion of mature-size *Platycephalus bassensis* females in each reproductive stage caught in (a) Tamar River (n = 108), (b) Georges Bay (n = 89), and (c) Coles Bay (n = 232) between March 2001 and May 2003


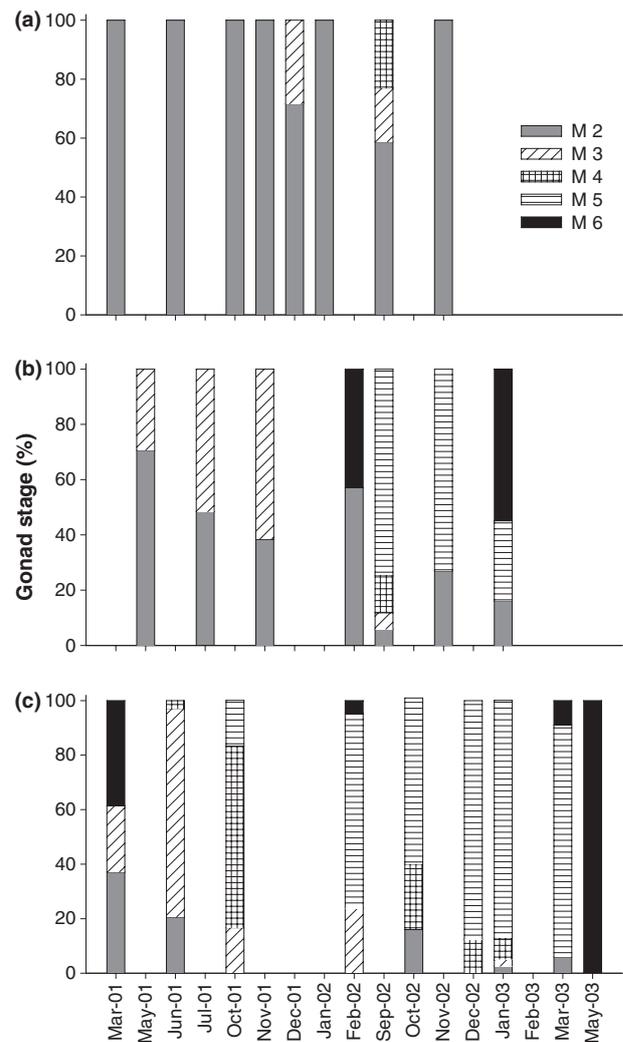
Fig. 4. Changes in proportion of mature-size *Platycephalus bassensis* males in each reproductive stage caught in (a) Tamar River (n = 51), (b) Georges Bay (n = 82), and (c) Coles Bay (n = 142) between March 2001 and May 2003

(Fig. 4a). A considerable proportion of males in Georges Bay were fully spermiated between September and November (Fig. 4b), but by January approx. 72% of males were reproductively inactive. In Coles Bay, regressed (spent) males were first sampled in March; between October 2002 and March 2003, >60% of males were fully spermiated (Fig. 4c).

### Size and age at sexual maturity

$L_{50}$ was not estimated for the Tamar River population because <3% of the individuals sampled were mature. Size and age at maturity were different between males and females at Coles Bay and Georges Bay (Figs 5 and 6). In both locations the size at which 50% of males were mature was 21.7 cm TL (Fig. 5). All males were mature at size 31 cm TL in Coles Bay. In the Georges Bay population, there was no age or size class for either sex where 100% of individuals were sexually mature. $L_{50}$'s for females were 24.7 and 26.3 cm in Coles Bay and Georges Bay, respectively (Fig. 5). Females attained ≥95% sexual maturity at 28 cm in Coles Bay.

The age at which 50% of males were mature was 2.5 and 3.5 years for Coles Bay and Georges Bay, respectively (Fig. 6).

Estimated age of maturity for Georges Bay females (5.2 years) was twice that of Coles Bay (2.6 years). In Coles Bay, all 7-year-old males and 8-year-old females were sexually mature (Fig. 6).

### Discussion

There was evidence of spatial and temporal variability in reproductive investment, duration of spawning activity, and size/age at maturity of sand flathead among the three locations sampled. The Coles Bay population showed consistently better reproductive condition than the other two locations. In contrast, the Tamar River population revealed minimal reproductive effort, while reproductive characteristics of the Georges Bay population were intermediate to these two populations.

Differences in reproductive investment among the locations were evident based on gonad weight, with individuals from Georges Bay and Tamar River having significantly lighter gonads than those from Coles Bay during the spawning season. Gonad weight also showed seasonal changes both in Coles Bay and Georges Bay, whereas the
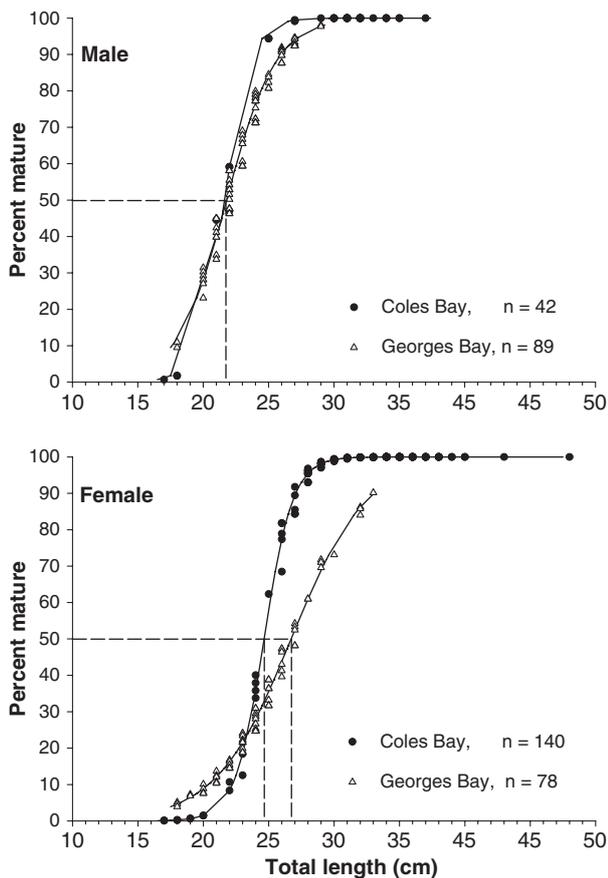
Fig. 5. Percentage of sexually mature male and female sand flathead (*Platycephalus bassensis*) by 1-cm length intervals, with a logistic model fitted to data collected at height of spawning season. $r^2$ for all cases was 0.99. Symbols show probability of fish maturity within 1-cm intervals. Broken line = length at which 50% of individuals were mature
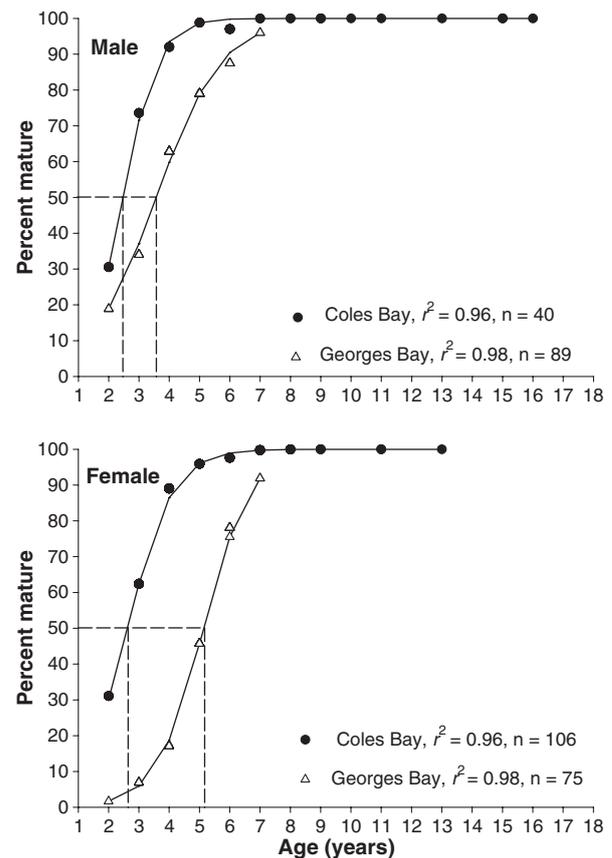
Fig. 6. Percentage of sexually mature male and female sand flathead (*Platycephalus bassensis*) by 1-year age classes, with a logistic model fitted to data collected at height of spawning season. Symbols show probability of fish maturity within 1-year age intervals. Broken line = age at which 50% of individuals were mature

Tamar River population did not exhibit any evidence of seasonal changes in gonad weight. As seasonal changes in gonad weigh are an indicator of reproductive investment (DeVlaming et al., 1982; Tamate and Maekawa, 2000), the lack of seasonal changes in gonad weight in the Tamar River suggests an absence of reproductive activity in the population sampled. In contrast, very high gonad weight in Coles Bay during spring and summer suggests high reproductive investment. As the Coles Bay population consisted predominantly of larger individuals (Bani, 2005), larger body sizes would allow the production of larger gonads since reproductive capacity is strongly influenced by size of individuals (Marteinsdottir and Begg, 2002). In contrast, because of the relatively small size of Georges Bay individuals, gonad weight was less than in Coles Bay due to constrains of body size (Heino and Kaitala, 1999). Therefore a population that mainly consisted of bigger individuals, because of larger gonads, may have greater reproductive potential when compared to populations with smaller individuals.

In many fish species gonad weight together with the proportion of different reproductive stages is considered a reliable method to estimate duration of the reproductive season (Fowler et al., 2000; Brown-Peterson et al., 2001). A single peak in gonad weight during spring and minimal gonad weight in summer in the Georges Bay population suggest a shorter spawning season (~2 months), compared to

the protracted spawning season (~6 months) of the Coles Bay population. Apart from inter-population differences in spawning duration, the spawning season length differed between the two years of spawning, particularly in Coles Bay, which was two months longer in 2002/03 than in 2001/02. For fishes that spawn multiple batches of eggs during a single spawning season the spawning period length of individuals increases with fish sizes (Kjesbu et al., 1996; Trippel et al., 1997). Hence, the presence of larger fish in the Coles Bay population is the most probable explanation for the longer spawning season. In serial spawners a longer reproductive season ensures a greater number of spawning events in each reproductive season (Hunter et al., 1992; Barbieri et al., 1994; Schaefer, 1996). Thus, due to a longer spawning season the Coles Bay population spawn is at least three times more than the Georges Bay population within a single spawning season. Given equal batch fecundity, the population with the longer spawning season (e.g. Coles Bay) would have increased the chance to spawn more batches of eggs and therefore a higher reproductive output is expected when compared to a population with a shorter spawning season (e.g. Georges Bay). Moreover, a shorter spawning period may be disadvantageous for larvae, as it may reduce the larvae hatch probability when environmental conditions favour growth and survival (Trippel et al., 1997).

Spawning in the Georges Bay population occurred in early spring given that the highest gonad weights and greatest

proportion of ripe fish were present in September. In contrast, the greatest gonad weight in Coles Bay occurred three months later, in early summer (December). Temperature and hours of daylight have been proposed as the main environmental factors that can cause differences in the initiation of spawning among populations (Wootton, 1982; Scott and Pankhurst, 1992). Water temperatures increased in Georges Bay 1 month earlier than in Coles Bay (Bani, 2005), possibly explaining the difference in the start of spawning. However, the start of spawning may be affected by other exogenous factors such as plankton productivity (Leggett and Deblois, 1994), and / or endogenous hormones (Stacey, 1984; Bye, 1990) which were not explored in this study. Advancing or delaying spawning may result in larvae missing the peak densities of appropriately sized plankton prey (Leggett and Deblois, 1994; Trippel et al., 1997); however, early spawning may provide a longer growing season for fish and the cumulation of stored energy may prolong survival of larvae when food supplies diminish (Shuter et al., 1980). From a population dynamics point of view, such variability in birth dates, together with plasticity of fish growth, can cause large variations in size-at-age and potentially affect the growth rate of the population.

In comparison to the other two populations, the reproductive output in the Tamar River population was minimal or absent. This may be a function of the low salinity in the Tamar estuary, which was consistently lower than the other two locations and lowest (30–31‰) in September and October (Bani, 2005). Such environmental conditions may not be optimal for spawning of a marine species like sand flathead. The reproductive biology of marine species that normally experience very little variation in the salinity is sensitive to variations in salinity (Bye, 1990). Thus, it is possible that the Tamar estuary may be an unsuitable habitat for spawning by sand flathead.

Estimated male size at maturity in the present study was similar to that found in a previous study (Jordan, 1998). However, our estimates of female size at maturity are slightly larger than previously reported (23.5 cm). This discrepancy may be attributed to: (i) the use of total length in this study compared to fork length for the previous study, and (ii) estimation of size at maturity for each population separately in this study, rather than pooling data from different populations as done in the previous study. The difference between the smallest and largest sand flathead to reach maturity was large for both males (17.8–29.1 cm) and females (18–33 cm). Extreme variation in size at first sexual maturity is a feature common to serial spawners as a consequence of a large range of birth dates (Lowerre-Barbieri et al., 1998).

With the exception of male size at maturity, for both sexes the size and age at which 50% of individuals attained maturity was higher in Georges Bay compared to Coles Bay. Differences in size and age of sexual maturity between these two populations may be attributed to the relatively high growth rate of Coles Bay individuals (Bani, 2005), as a decrease in size / age at maturity of fish species can be the result of higher growth rates (Trippel, 1995). Therefore, slower growth rates of Georges Bay individuals, either due to the fishing effect and / or environmental conditions, may explain a delay in maturity. Furthermore, the larger size at maturity may reflect the movement of the faster growing and maturing individuals out of Georges Bay to other spawning areas. Maturation at a larger size in this population could be problematic as > 60% of the Georges Bay population was smaller and younger than the estimated size and age at maturity (Bani et al., 2007). In many exploited fish stocks a decrease in size / age at maturity is accompanied by the lower population mean size / age (Bowering and Brodie, 1991; Trippel, 1995). However, in this study the smaller size and younger age at maturity (e.g. Coles Bay) were not coincident with a lower population mean size / age. Such a contradiction may result from less-selective recreational fishing effects on the population studied, whereas in almost all previous studies highly selective commercial fishing accounted for changes in size / age at maturity. The effects of recreational fishing on size / age at maturity, and its possible relation to stock structure, need to be explored in the future.

Both spatial and temporal variability in reproductive characteristics of sand flathead as seen in this study indicate that reproductive output and performance of this species vary from year to year and among populations. This is due to either environmental conditions and / or specific size / age structure of stock because of fishing or movement of fish. Apart from causative parameter(s) of reproductive variability in sand flathead, such variability can have a marked impact on conservation of the next generation of each population, as reproduction is the main component of stock restoration. Under the current fishing regulations, spawners are still fished during the spawning season. Removal of spawning individuals could potentially be detrimental for the stability of the populations, in particular for less productive populations, e.g. Georges Bay, as the level of egg production may not be sufficient for survival of the next generation. Approximate spawning time of sand flathead at each location can be helpful for managing fishing activity during the spawning period of heavily fished populations. While the risk of fishing in spawning grounds is higher during spawning periods, overfishing of immature individuals in nursery grounds, e.g. the Tamar estuary, is no less detrimental. Productivity and sustainability of a fishery is dependent on the continued availability of juveniles, which originate from nursery grounds. Hence, special consideration in management seems to be essential for nursery grounds like the Tamar estuary. Neither minimum size limits nor daily bag limits would be sufficient for a sustainable recreational fisheries management, unless temporal and spatial variability in reproductive performance is taken into account.

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