Reproduction and growth of dusky flathead (*Platycephalus fuscus*) in NSW estuaries

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NON-TECHNICAL SUMMARY

Reproduction and growth of dusky flathead (*Platycephalus fuscus*) in NSW estuaries

OBJECTIVE:

Determine the reproductive cycle, length and age at maturity and the timing and location of spawning of dusky flathead in NSW.

SUMMARY:

Dusky flathead is an important finfish species harvested by recreational and commercial fishers in NSW. Because of concerns over the long-term sustainability of the resource in NSW, the minimum legal length (MLL) of dusky flathead was increased from 33 to 36 cm total length (TL) in July 2001, with further increases (to 40 cm TL) proposed. The initial change in minimum legal length was based on available information concerning the length that dusky flathead spawn. However, detailed information of the reproductive biology of dusky flathead from NSW was lacking. This study was the first step to redress this situation.

Dusky flathead were sampled from various locations throughout NSW between 2001 and 2006 to investigate aspects of their biology. The study identified that female dusky flathead have an extended reproductively active period between November and March while male reproductive activity occurs mainly between September and March. Female dusky flathead in spawning condition were caught only near the entrance of estuaries and in adjacent coastal waters. It was determined that the length at which 50 percent of the population is mature (L_{50}) during periods of peak reproductive activity was 31.72 cm TL for males and 56.75 cm TL for females. The corresponding estimated age at which 50 percent of the population is reproductively mature (A_{50}) during these same periods was 1.22 years for males and 4.55 years for females.

Females grew faster and attained a greater overall maximum TL, weight and age than males. The largest observed female was 98.5cm TL (7.5 kg), and the oldest was estimated to be 16 years, whereas the largest male was 61.5cm TL (weight) and 11 years of age. Although the growth rates and maximum attained lengths varied between sexes, the relationship between length and weight of fish did not differ between sexes.

The current MLL of 36cm TL appears to protect approximately 5 % of the female and 75% of the male spawning population. To provide greater protection to mature females so to allow 50% of females to spawn at least once would require an increase in the MLL to 57cm TL. Such an increase would virtually eliminate males from the fishery. Many other factors, such as the survival rates of released fish from recreational and commercial fishing gears, need to be considered in critiquing future management options, including changes in the MLL, for this species.

1. INTRODUCTION

The dusky flathead (*Platycephalus fuscus*) is endemic to Australia, inhabiting estuaries and nearshore coastal waters along the east coast between Cairns in Queensland and the Gippsland Lakes in Victoria (Kailola *et al.* 1993). Few studies have investigated the life history characteristics of dusky flathead, even though it is a key component of fisheries throughout its distribution, including the estuarine recreational and commercial fisheries in New South Wales (NSW) (Kerby and Brown 1994, Gray *et al.* 2002, 2005, Steffe *et al*. 2005a, b).

Dusky flathead are bottom dwelling ambush predators that normally occur on soft substrates, including mud, sand and seagrass. Tag-release studies show that dusky flathead are capable of moving between estuaries and that they can grow relatively fast (West 1993 and NSW DPI unpublished data). They can potentially attain 18 cm total length (TL) in 1 year, and 40 cm TL in 3 years (Dredge 1976, West 1993, Gray *et al.* 2002); with their maximum reported length being 120 cm TL (approximately 15 kg) (Kailola *et al.* 1993). Reported spawning times of dusky flathead vary between September to March in northern Queensland, November to February in southern Queensland, and January to March in NSW and Victoria (Dredge 1976, SPCC 1981, Russell 1988). There is also conflicting and variable information concerning length at maturity, which has been reported to vary from 46 cm (male) and 56 cm (female) in Queensland to 26 cm (male and female) in southern NSW and Victoria (see Kailola *et al.* 1993). Debate also surrounds whether dusky flathead are protandrous sex reversers (i.e., change sex from male to female) (Dredge 1976, SPCC 1981).

Concerns over the status of populations of dusky flathead in NSW (see Gray *et al.* 2002) led to the minimum legal length (MLL) of dusky flathead increasing from 33 to 36 cm TL in July 2001. Further increases and restrictions in minimum and maximum length at capture have been proposed. At present however, there is not enough information on the reproductive biology of the species in NSW to informatively debate the proposed options. Greater information concerning the reproductive biology of dusky flathead, along with knowledge of their age and growth characteristics, is vital to developing more appropriate management strategies for this species.

This study aimed to redress the current lack of biological information on dusky flathead in NSW by investigating aspects of their reproductive biology, age and growth dynamics.

2. OBJECTIVES

Determine: (1) length and age at sexual maturity; (2) timing and location of spawning; and (3) age and growth characteristics, of dusky flathead in NSW.

3. METHODS

3.1. Sampling

Dusky flathead were sampled in 2001 and 2002 from commercial catches in the Clarence River, Wallis Lake, Tuggerah Lake and Lake Illawarra. Because the majority of samples were restricted to legal sized fish, there was a need to sample a greater length range of fishes, particularly undersized individuals. Further sampling was conducted between 2004 and 2006 in the Clarence River, Lake Macquarie, Tuggerah Lakes, St Georges Basin and the Tuross River (Figure 1.1) to collect undersized and legal sized individuals. A variety of research sampling gears including gillnets, seine nets and angling techniques were employed to sample dusky flathead populations. Additional samples were obtained from the non-retained portion of commercial catches. Samples were also collected from coastal waters adjacent to the Clarence River by chartered commercial prawn trawler operators between November 2005 and March 2007.

The date and location of capture, total length (0.1 cm) and total weight (0.1 g), of each retained dusky flathead was recorded. Fish were then dissected for reproductive investigation and sagittal otoliths were removed, cleaned, dried and stored in labelled paper envelopes before being processed for age determination.

3.2. Reproductive biology

Each retained fish was dissected and its sex determined by macroscopic examination of the gonads (ovaries and testes). When gonads lacked development (i.e., not able to distinguish sex), the fish was classified as juvenile. Macroscopically examined gonads were assigned a reproductive developmental stage based on size, colour and texture, and for females the visibility of oocytes, according to the criteria described in Scott and Pankhurst (1992) (see Table 1.1 and Figure 1.2). The gonads of each fish were then removed and weighed (0.1 g) so that the Gonadosomatic Index (GSI) could be calculated:

$$GSI = (\text{gonad weight} / \text{whole fish weight}) * 100$$

Changes in GSI values throughout time were used to estimate the spawning season; elevated GSI values were interpreted as indicating reproductive activity.

During periods of observed reproductive activity, fish with gonads staged III to VII were considered mature (i.e., capable of spawning during the current reproductive season), whereas individuals staged I and II were considered immature (i.e., not capable of spawning during the current reproductive season). The proportion of fish that were mature within each 1 cm length category and each yearly age class was calculated, and a general least squares modelling approach was used to fit a logistic curve to the data using R statistical programming language. Female maturity calculations were determined from samples pooled across all locations and sampling periods to determine the length (L_{50}) and age (A_{50}) at which 50 % of the sampled population were mature. Maturity calculations for male flathead were pooled across locations and between 2004 and 2006 to determine the length (L_{50}) and age (A_{50}) at which 50 % of the sampled population were mature. The temporal scale analysed was restricted to males sampled between 2004 and 2006 due to potential misclassification of male gonads in the earlier sampling periods.

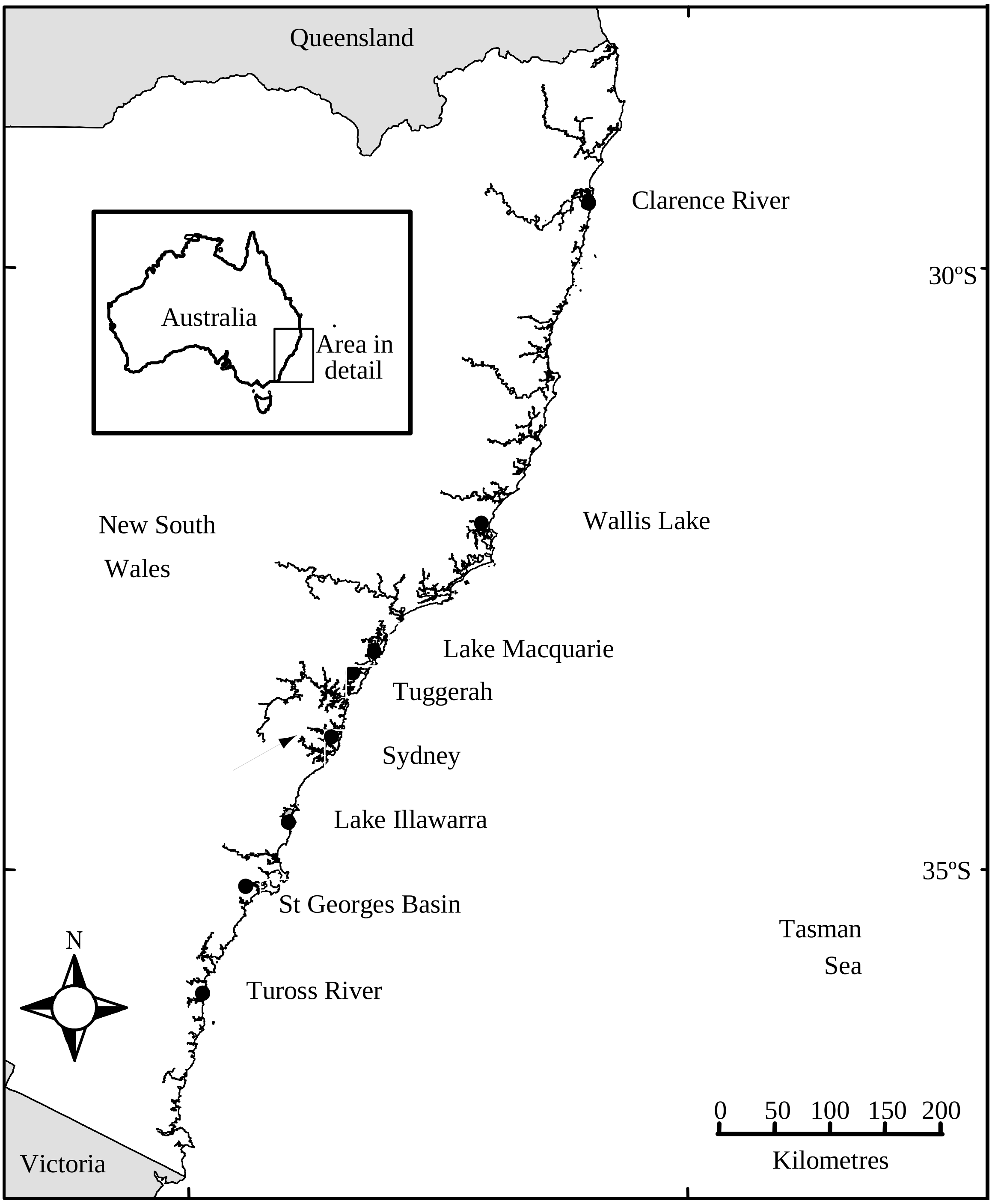


Figure 1.1. Location of estuaries in NSW where dusky flathead were sampled.

Table 1.1. The stages of gonad (ovary and teste) development used to macroscopically classify the sexual maturity of dusky flathead (modified from Scott and Pankhurst 1992).

Stage	Classification	Macroscopic characteristics
Female		
I	Juvenile Immature	Small clear threads, macroscopic sexual differentiation not possible.
II	Immature	Small clear lobes, sexual differentiation possible.
III	Vitellogenic	Oocytes visible through ovarian wall. No hydration of oocytes visible.
IV	Hydrated	Ovaries larger, opaque, yellow or orange in colour. Hydrated oocytes visible through epithelium.
V	Ovulating	Hydrated oocytes in oviduct, eggs can be extruded with gentle pressure.
VI	Spent	Ovaries flaccid and bloody. Some yolk granule oocytes still visible through ovarian wall.
VII	Spent/Recovering	Ovaries were small, atretic vitellogenic oocytes present.
Male		
I	Juvenile Immature	Small clear threads, macroscopic sexual differentiation not possible.
II	Immature	Small white threads present, sexual differentiation possible.
III	Partially Spermiated	Testis firm and sperm present with application of pressure.
IV	Fully Spermiated	Testis firm with free flowing sperm in sperm duct.

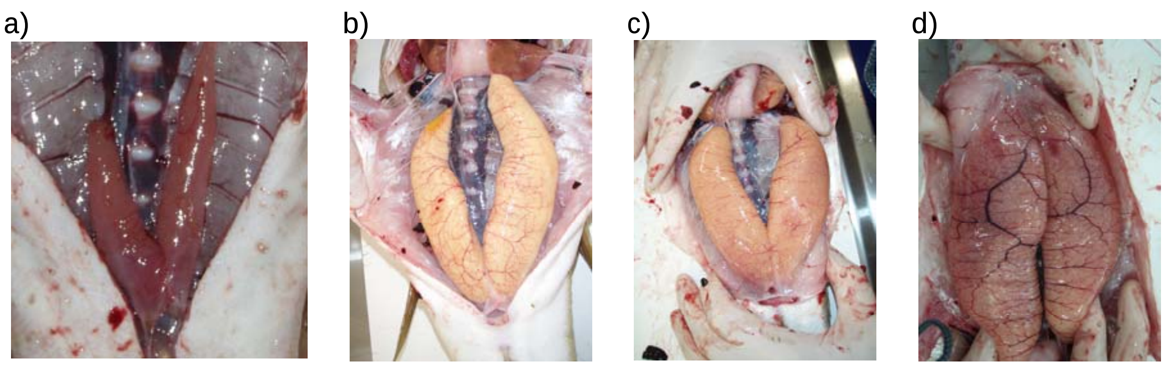


Figure 1.2. Photo showing different staged female gonads. a) Stage II; b) Stage III; c) Stage IV; and d) Stage V.

3.3. Age and growth

Sectioned sagittal otoliths were used to estimate the age of dusky flathead. Previous work (Gray *et al*. 2002) indicated that sectioned otoliths were easier to interpret and produced more accurate estimates of age than whole otoliths. This was particularly the case for older fish due to the stacking of growth zones near the otolith margin, a feature common to other platycephalids (Lewis 1971, Hyndes *et al*. 1992). Gray *et al*. (2002) observed through marginal increment analysis that alternate translucent and opaque bands are formed in the otolith structure annually and can be used to accurately estimate age.

One sagittae of each fish was embedded in clear resin and sectioned at approximately 250 – 300 µm thickness in a transverse plane through the focus using a low speed saw fitted with two diamond blades. Both sides of the resulting thin section were then polished on 9 µm lapping film, after which the section was mounted on a standard glass slide and viewed under a binocular microscope (6 – 25 x magnification) with reflected light against a black background. Most otolith sections displayed clear patterns of narrow opaque (light) and broad translucent (dark) zones (Figure 1.2). Previously, Gray *et al.* (2002) demonstrated through marginal increment analysis that these zones were formed annually, although the exact timing for the formation of the first ring is still unclear.

Assignment of age for each fish was based on independent counts of completed opaque bands (i.e., number of opaque bands from the sulcus to the outer edge, usually along the line of the sulcus) by no less than 2 readers. In cases where the age determination was not unanimous between readers, either consensus was reached or the fish was removed from further age-based analysis (n = 1,273). Similarly, individuals with otoliths that were unable to be sectioned were removed from age based analysis (n = 253). Individuals that were dropped from the aged based analysis ranged in size from 6.5 to 78.5cm TL.

Growth was modelled by fitting the length at age data to the von Bertalanffy growth function (von Bertalanffy 1938):

$$L_t = L_\infty \, [l\text{-}e^{-k(t-t0)}]$$

where L_t is the length at age t; L_∞ is asymptotic length; k is the rate at which the curve approaches the L_∞ and t_0 is the hypothetical age at zero length.

These analyses were done separately for each sex using data combined across all locations. Juvenile fish (not assigned a sex) were assigned to both sexes for each analysis.

The length-weight relationships for both sexes of dusky flathead were calculated using the function:

$$y = ax^b$$

where y = body weight (kg), x = fish length (cm), and a and b are constants.

The model parameters “a” and “b” were calculated by minimising the sums of squares between the observed and expected values using a solver routine in Excel. Juvenile fish (not assigned a sex) were assigned to both sexes for the length weight analysis.

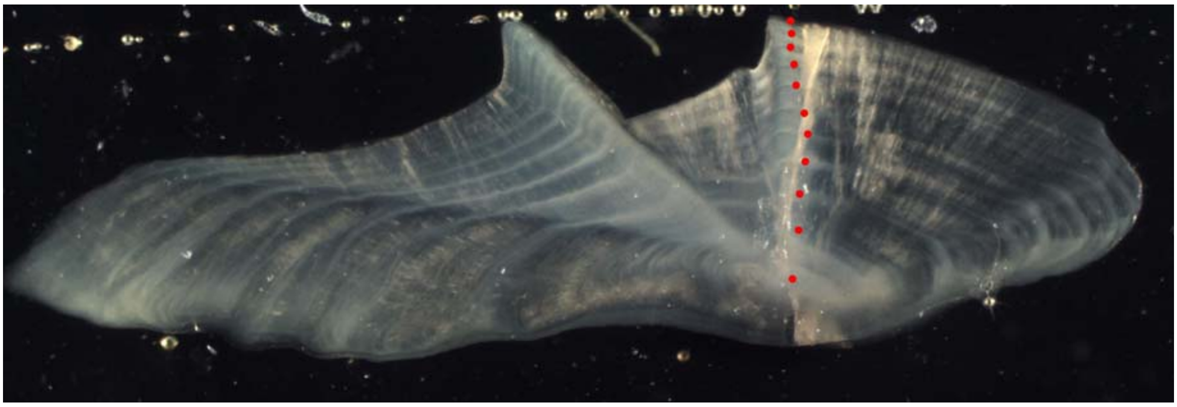


Figure 1.3. Photo of a sectioned otolith showing alternate zones of opaque and translucent material. Marks are placed on the core, opaque zones and the edge. This fish was 9 years old.

4. RESULTS

A total of 77,83 dusky flathead, comprising 394 juveniles, 1,745 males and 5,644 females, ranging from 5.7 to 98.5 cm TL were examined throughout the study.

4.1. Reproduction

Female dusky flathead were reproductively active primarily for 5 months between November and March while males were reproductively active for 7 months between September and March as indicated by an increase in the observed GSI (Figure 1.4). The maximum recorded GSI for males and females was 4.7% and 16.6% respectively. No females and only 3 males were observed in reproductive condition for the 3 months between June and August. Females with hydrated oocytes and ovulating individuals were collected from sites close to the entrance of the Clarence River, Wallis Lake, Tuggerah, Lake Illawarra and Tuross River.

The length at which 50% (L_{50} ± 1 SE) of individuals sampled in estuaries attained sexual maturity during periods of peak reproductive activity was estimated to be 56.75 ± 0.6 cm TL for female and 31.72 ± 1.08 cm TL for male dusky flathead (Figure 1.5,Table 1.2). The estimated age at which 50% (A_{50} ± 1 SE) of individuals attained sexual maturity for females was 4.55 ± 0.13 years and 1.22 ± 0.44 years for males (Figure 1.6,Table 1.3). The smallest observed mature female and male was 22.3 cm and 18.8 cm TL respectively. Less than 5 % of females, but approximately 75 % of males, were classified mature at the current MLL of 36cm TL during the spawning period.

Ovarian and testicular tissue was never observed together in the same gonad throughout extensive macroscopic examination, even though gonad samples were examined from fish with varying lengths, ages, multiple locations and over several years of sampling.

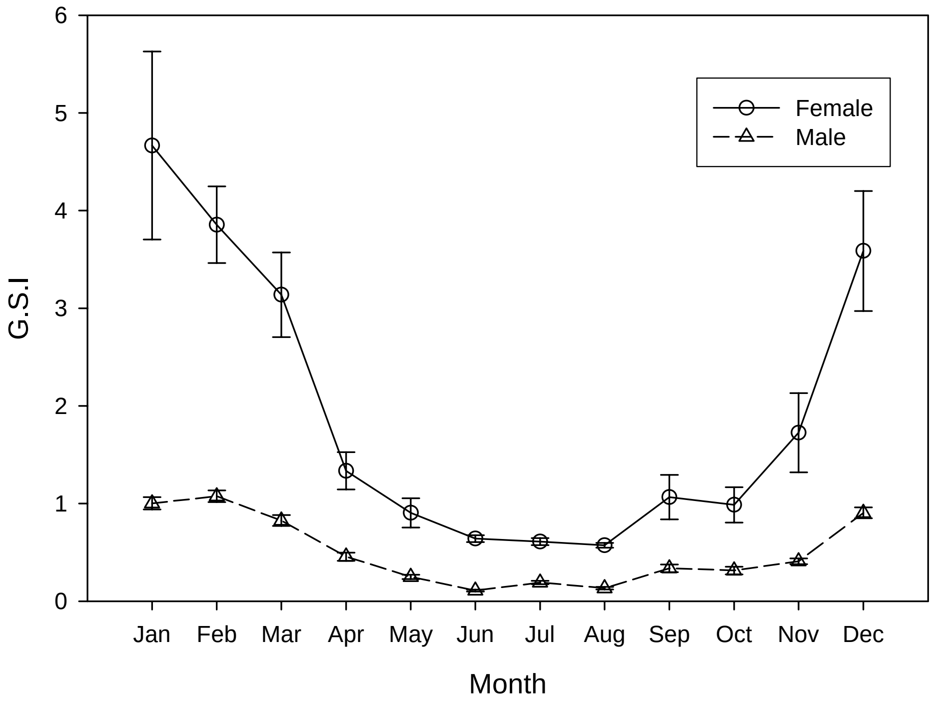


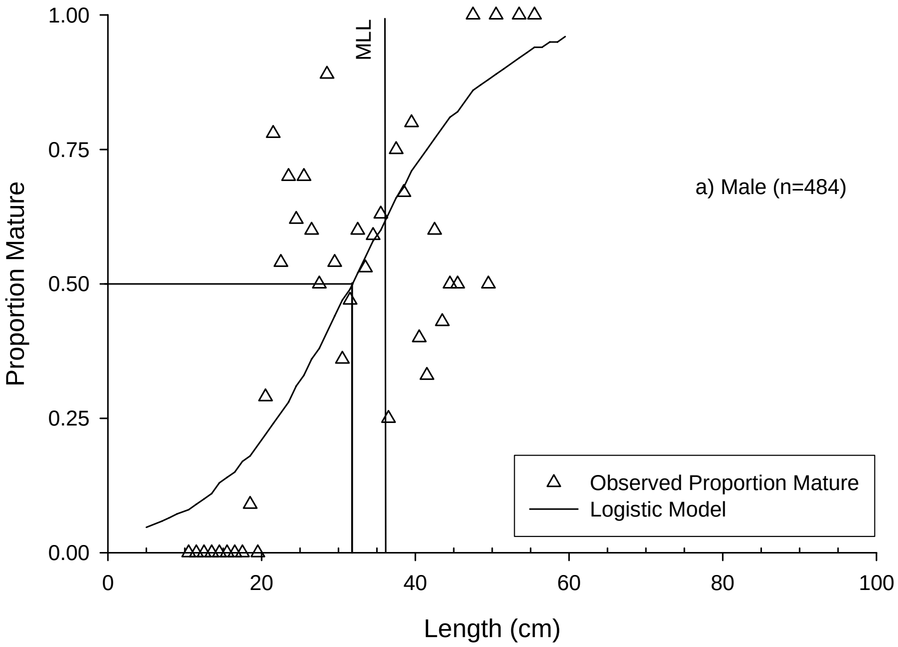
Figure 1.4. Mean monthly gonadosomatic indices (±1 S.E) for male and female dusky flathead equal to or larger than the estimated L_{50}.

Table 1.2. Summary calculations for male and female L_{50} estimates between November and March.

	Male	Female
L_{50} (cm)	31.72	56.75
Standard Error (cm)	1.08	0.6

Table 1.3. Summary calculations for male and female A_{50} estimates between November and March.

	Male	Female
A_{50} (Years)	1.22	4.55
Standard Error (Years)	0.44	0.13



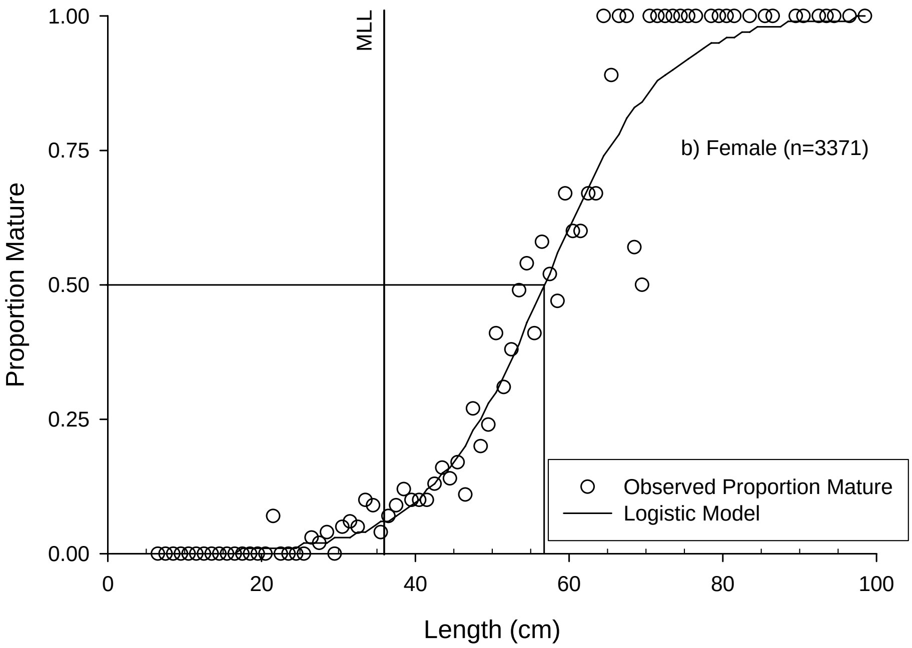


Figure 1.5. Estimated length at maturity (L_{50}) of dusky flathead: a) Male 31.72±1.08 cm (n = 484), b) Female 56.75±0.6 cm (n = 3,371). The current minimum legal limit (MLL) is 36 cm TL.

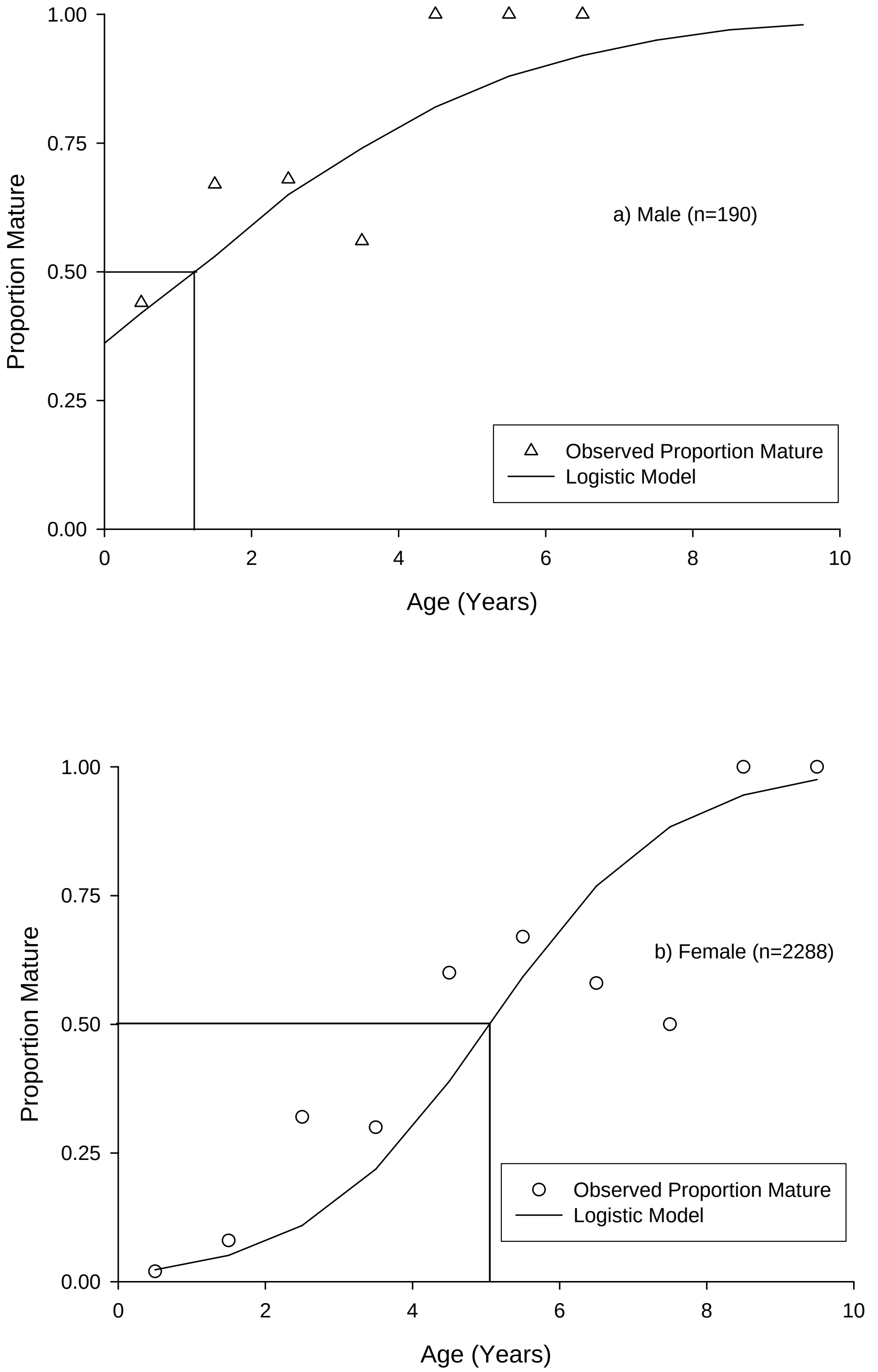


Figure 1.6. Estimated age at maturity (A_{50}) of dusky flathead: a) Male 1.22±0.44 years (n=190), b) Female 4.55±0.13 years (n = 2,288).

4.2. Age and growth

The length-weight relationship between male and female dusky flathead was very similar (Figure 1.7). The length-weight equation for males and females was:

Males: Weight = 2.86 x 10^{-3} * Total Length$^{(3.213)}$;
Females: Weight = 2.09 x 10^{-3} * Total Length$^{(3.283)}$

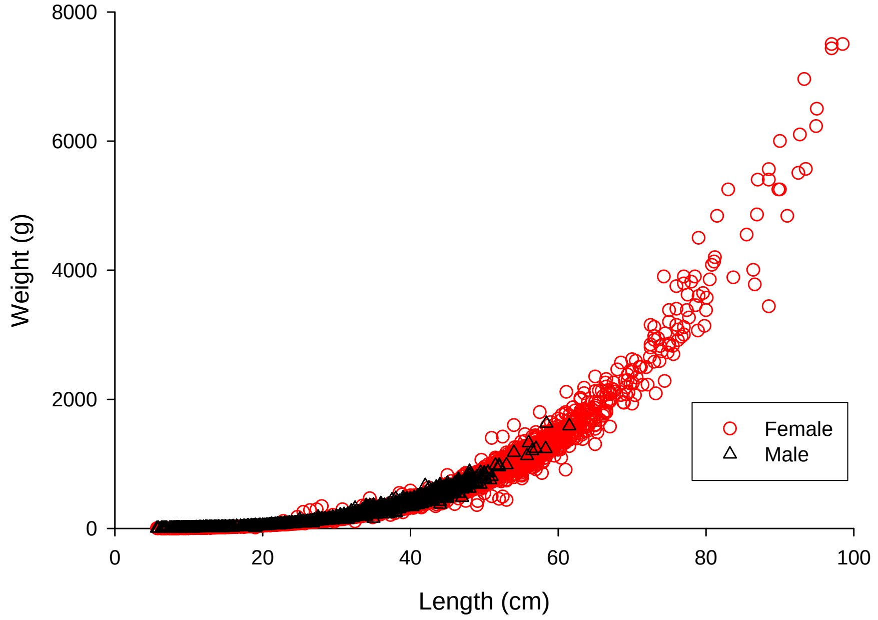


Figure 1.7. Length-weight relationships for male and female dusky flathead.

Female dusky flathead grew faster and attained a greater maximum length and age compared to males (Figure 1.8). The largest female sampled was 98.5 cm TL, weighing 7.5 kilograms and an estimated age of 13 years. The oldest female was estimated to be 16 years (88.5cm TL). The largest male sampled was 61.5 cm TL, weighing 1.58 kg and an estimated age of 11 years.

There was considerable variation in length at age for both sexes (Figure 1.8). The parameter estimates of the von Bertalanffy growth curves differed between sexes. For fish greater than 2 years old, the estimated mean length at age was consistently greater for females than for males.

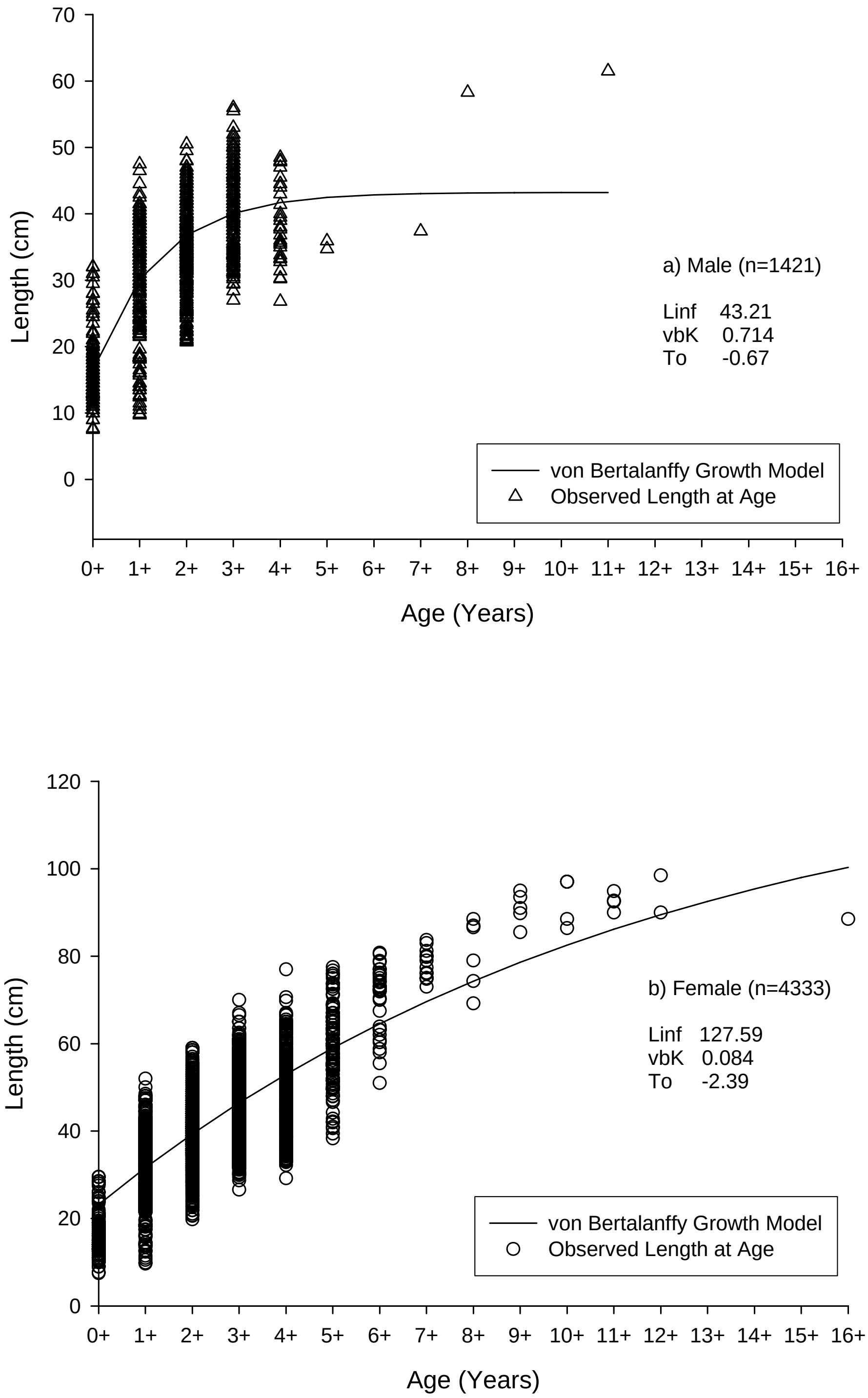


Figure 1.8. Estimated growth of a) male (n = 1,421) and b) female (n = 4,333) dusky flathead.

5. DISCUSSION

5.1. Reproduction

The predominant spawning period we observed for female dusky flathead was between November and March while the observed male spawning period extended from September to March. This general timing of spawning concurs with previous reports from Queensland (September to March in northern Queensland and November to February in southern Queensland). It is however, more extended than that previously reported for NSW (January to March) (Dredge 1976, SPCC 1981, Russell 1988). Larvae of dusky flathead have been captured in estuaries and coastal waters of NSW between September and May (Miskiewicz 1987, Gray & Miskiewicz 2000).

Estimates of fecundity for dusky flathead range from 294,000 to 3,948,000 eggs (Brown *et al*. 1994) however, the mode of spawning is unclear. *P. endrachtensis* and *P. indicus* exhibit an extended spawning period and exhibit bimodal oocyte diameter frequency distributions which lead Lewis (1971) to suggest these species have multiple spawning events throughout the year. Similarly Hyndes *et al.* (1992b) found *P. speculator* to be multiple spawners between December and March. Additional investigation is required to determine the spawning mode of dusky flathead.

Dusky flathead were observed to be in spawning condition in the marine dominated lower reaches of estuaries, ovulating females were sampled from the Clarence River, Wallis Lake, Tuggerah Lake, Lake Illawarra and Tuross River at sites close to the mouth of the estuary. These observations support the general hypothesis that dusky flathead spawn in the lower reaches of estuaries and in nearshore coastal waters (SPCC 1981, Kailola *et al.* 1993). Furthermore, in St Georges Basin and Lake Macquarie where samples were collected upstream of the mouth, only females with vitellogenic oocytes (i.e., not in spawning condition) were observed.

Our estimated L_{50} of 56.75 cm TL for females was similar to the estimate for Queensland of 56cm TL (Russell 1998) but larger than the previously estimated 38cm TL in Botany Bay, New South Wales (SPCC 1981). In contrast however, our estimated 31.72cm TL length at maturity for males was considerably less than that estimated for Queensland (46cm TL), but was similar to that reported by Winstanley (1985) and SPCC (1981) of 26 and 32 cm TL respectively. The estimated L_{50} for male dusky flathead appears to be highly variable. In other teleost species, it has been found that social and behavioural cues, as well as differential hormonal expression influence the timing of male maturation (Oliveira *et al*. 2005, Kuwamura *et al*. 2007). Further investigation is required to determine the roles of these factors in male dusky flathead maturation.

Female dusky flathead reach sexual maturity later and at a larger size than males. On average, males take 1.2 years to reach the L_{50}, females however, take more than 4 years to reach the estimated L_{50} although some females mature at approximately 2 years of age. This pattern is typical of many playcephalid species (Lewis 1971, Jordon 2001) and may be related to an increase in female reproductive potential at larger sizes as seen for many teleost species (Hughes and Stewart 2006, McDermott *et al*. 2007).

Several platycephalids are known to exhibit protandrous hermaphroditism (Fujii 1971) and it has been argued that dusky flathead undergo protandrous sex change, where individuals first function as males for several years before changing sex (Dredge 1976). This has been based on the observed skewed sex ratios in dusky flathead populations with the smaller size classes being dominated by males and the larger size classes by females. No hermaphroditic fish were observed in this study or in previous studies in NSW (Gray *et al.* 2002, West 1993), suggesting that dusky flathead do not change sex, but rather male fish do not grow as large or as fast as females. *P. indicus* (Masuda *et al.* 2000) and *P. bassensis* (Jordon 1998) show the same dimorphic growth pattern between sexes with no evidence of protandrous sex change.

5.2. Age and growth

Dusky flathead grow relatively quickly, with fish estimated to reach a mean length of approximately 30 cm TL in 1 year and 42 and 59 cm TL after 5 years for males and females respectively. It is evident that growth rate is highly variable between individuals. Our estimated rates of growth are consistent with previous growth estimates (Dredge 1976, West 1993, Gray *et al.* 2002). We estimate that most dusky flathead are approximately 2 years old when they reach the current MLL of 36 cm TL.

As with other platycephalids, females grew faster and attained a larger maximum length than males. However, the maximum length (and weight) is considerably greater for dusky flathead than for other Platycephalids such as *P. bassensis* (Jordon 1998), *P. caeruleopunctatus*, *P. speculator* (Brown 1977) and *P. richardsoni* (Cui *et al.* 2005). Our estimate of longevity of dusky flathead of 16 years is comparable to other species of flathead, such as *P. richardsoni* and *P. bassensis*, although these species attain a smaller maximum length than dusky flathead.

The female von Bertalanffy growth model maximum size of 127cm was similar to the largest reported dusky flathead reported (120cm) by Kailola (1993). The largest female dusky flathead sampled within the current study was 98.5cm considerably less than the maximum observed or modelled length. The modelled maximum male length of 44cm was smaller than the 61.5cm largest male observed. The poorer fit of the von Bertalanffy growth model to the male growth may be due to the rarity of larger and older male fishes within the sample. Similarly, larger males may have not been sampled as effectively as smaller individuals due to factors such as habitat association or behavioural characteristics. In general however, larger fishes of both sexes do not appear to be as abundant as smaller individuals nor were they as large as has previously been observed (Kailola 1993) within the habitats and locations that were sampled during this study.

5.3. Management implications

The current MLL of 36 cm TL provides significant protection for mature male dusky flathead, but not for mature females. Approximately 5% of females are estimated to be mature at 36 cm TL. The MLL for many species is set at the female L_{50}; for dusky flathead this would be 57 cm TL. Such an increase in the MLL of dusky flathead would virtually eliminate males from exploitation. At present, there is an additional management regulation of only 1 dusky flathead > 70cm TL to be retained by recreational anglers per day to provide greater protection to large females.

In assessing the implications of the current research on any future changes to the MLL or management intervention, an overall management objective for the population must be formulated. Examples of objectives on which to base management decisions upon may include, but are not limited to, the opportunity to spawn once before recruiting into the fishery, ensuring sufficient reproduction to maintain stocks, maximising value of the resource and maximising yield (Stewart and Hughes 2008). An assessment of dusky flathead stocks, as well as other key species of flathead, needs to be made in order to provide appropriate information on which management objectives can be based and ultimately implemented.

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