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Variations in sex, length and age compositions of commercial catches of *Platycephalus fuscus* (Pisces : Platycephalidae) in New South Wales, Australia

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Abstract. Commercial landings of dusky flathead (*Platycephalus fuscus*) from four estuaries in New South Wales (NSW), Australia, were sampled for data on sex, length and age composition between February and July each year for 2–3 years between 1995 and 1997. Landings primarily contained female fish, ranging from 55% to 93% by number for different estuaries. Flathead sampled in commercial catches ranged from 30 cm to 96 cm total length (TL), but the majority were 33–50 cm TL. Fish >40 cm TL were primarily female and male fish >45 cm TL were uncommon. The length composition of catches differed between gillnets of different mesh sizes, with the average length of fish being least in the smallest allowed mesh size of 70 mm. Fish were aged by otolith interpretation and the analysis of marginal increments indicated that one opaque and one translucent growth zone was formed each year; the opaque zone being deposited in June–August (winter) and first observed in September–October (spring). Commercial landings included fish aged 2–11+ years, but fish aged 2–4+ years dominated landings in all estuaries. The total mortality of dusky flathead in each estuary was estimated by catch curve analysis and was relatively high, ranging from 0.45 to 1.64. The data indicate that dusky flathead may be heavily exploited in NSW.

Extra keywords: age determination, otolith.

Introduction

The Platycephalidae is primarily distributed throughout the Indo-West Pacific region, with 41 species occurring in Australian waters (Paxton and Hanley 1989). The dusky flathead (*Platycephalus fuscus*) is endemic to Australia, inhabiting estuaries and near-shore coastal waters along the east coast between Cairns in Queensland and the Gippsland Lakes in Victoria, where it is important to commercial and recreational fisheries (Kailola *et al.* 1993). Although some aspects of the reproduction, growth and movements of dusky flathead have been reported for southern Queensland and New South Wales (NSW) (Dredge 1976; Pease *et al.* 1981; West 1993), there is only a rudimentary understanding of its life history. There is also a paucity of information on stock structure and the demographic characteristics of harvested populations in different regions, including their length, sex and age compositions. Consequently, there is little fisheries-related biological data to assess stocks of dusky flathead, the effects of fishing on stocks and thus little information to aid in the management of the species.

In NSW, the reported estuarine commercial production of dusky flathead has been relatively stable over the past 40 years, fluctuating between 150 and 200 tonnes per annum, whereas reported annual landings from coastal waters throughout this period have been less than 2 tonnes (Gray *et al.* 2000). Dusky flathead are predominantly caught using gillnets, although significant quantities are also caught in beach-seine (haul) nets. Dusky flathead are captured throughout the year, but reported commercial landings are generally highest between February and July, with the peak period occurring in June and July (winter), when overnight setting of gillnets in estuaries is permitted (see Gray 2002). Throughout the past 10 years, commercial landings of dusky flathead have been greatest in the large coastal lagoons in central NSW (Gray *et al.* 2000). Although at present there are no state-wide estimates of total recreational catches of dusky flathead, large quantities are taken in some estuaries and, in some locations, this may exceed reported commercial catches (West and Gordon 1994). The fisheries in which dusky flathead are captured are managed by a range of gear restrictions, areal and temporal closures, a minimum legal length and a recreational bag limit.

Accurate information on the length, sex and age compositions of catches and how these vary regionally, temporally and among different gear types is fundamental to the assessment of many fisheries (Megrey 1989; Richards *et al.* 1997). These types of data are gathered most often via sampling of landed catches (Doubleday and Rivard 1983).

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Age determination is best achieved through the interpretation of validated otolith structure (Beamish and McFarlane 1983; Fowler 1995). Considerable research has documented that rates of recruitment and growth of fish can differ substantially over a range of spatial and temporal scales, and that such variations can have important implications for the demography of fish populations (Fogarty *et al.* 1991; Doherty and Fowler 1994). Large regional variations in the demography of fish populations could therefore have significant implications for managing fish stocks and stock assessments.

The aims of the current study were to redress the lack of fisheries-related data on dusky flathead in NSW by assessing spatial and temporal variability in the sex, length and age compositions of commercial catches. This was achieved by sampling catches across four estuaries over a 3-year period and by developing an otolith-based ageing protocol. This information will form the basis of an age-based model for stock assessment analysis. In this paper, we specifically assess for dusky flathead: (*i*) the validity of using thin transverse sections of sagittal otoliths to estimate age; (*ii*) variation in length at age; and (*iii*) spatial, temporal and gear-related variations in the sex, length and age compositions of estuarine commercial catches in NSW. We make recommendations for future research and management strategies concerning the fisheries for dusky flathead in NSW.

Materials and methods

Study locations and sampling of commercial catches

Commercial landings of dusky flathead were sampled for sex, length and age composition on an annual basis between 1995 and 1997 from the Clarence River (29°25´S), Wallis Lake (32°12´S), Lake Macquarie (33°05´S) and St Georges Basin (35°08´S), spanning 600 km along the NSW coast. Sampling was done at the ports of landings (primarily fishing cooperatives) or at the Sydney Fish Market, when it was known that entire ungraded catches from Lake Macquarie and St Georges Basin were available. Whole catches or random subsamples of whole catches landed on each sampling day were measured (total length (TL)) to the nearest 0.5 cm below, and sexed by macroscopic examination of gonads. Because sampling was restricted to commercial landings, no fish below the minimum legal length (MLL) of 33 cm TL were examined in the present study. The gear-type(s) used to capture fish was obtained from fishers at the time the fish were being examined. Catches sampled were taken using gillnets with 80, 83, 95 and 100 mm mesh in the Clarence River, gillnets with 70 mm mesh in Wallis Lake and beach-seine nets with mesh between 30 and 50 mm in the bunts in Lake Macquarie and St Georges Basin.

Sagittal otoliths were collected haphazardly from random subsamples of catches from each port sampled, and the number collected annually from each estuary ranged between 167 and 488. These collections were made in June and July in 1995 and between February and June in 1996 and 1997. Sampling was done during this period because preliminary examinations of sectioned sagittae suggested that they were clearest to interpret because the previous growth zone was furthest from the otolith margin (see Gray *et al.* 2000). Extracted otoliths were cleaned in freshwater, dried and stored in paper envelopes until required for processing in the laboratory. In addition to the annual sampling of fish, 25–70 sagittal otoliths were collected on a monthly basis from landings in the Clarence River between September 1996 and September 1997 to investigate the periodicity of increment formation in that estuary.

Age determination, precision and validation

We used sectioned sagittal otoliths to estimate the age of dusky flathead. Preliminary examinations indicated that whole otoliths were more difficult (and thus less accurate) to interpret than sectioned otoliths. This was particularly the case for older fish owing to the stacking of growth zones near the otolith margin, a feature common to other old-aged platycephalids (Hyndes *et al.* 1992).

One sagittae of each fish was embedded in clear resin and sectioned at approximately 25–30 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× magnification) with reflected light against a black background.

Most otolith sections displayed a clear pattern of narrow opaque (light) and broad translucent (dark) zones. Assignment of age was based on counts of completed opaque zones (i.e. number of opaque zones from the focus to the outer edge, usually along the line of the sulcus). Assignment of age and year class was consistent across years and estuaries because all samples used to determine the age composition of the commercial fishery were collected in the same period (February to July) each year. This was when the previous growth zone was furthest from the otolith margin and, therefore, before a new opaque zone had formed. Two readers examined and assigned ages (counts of completed opaque zones) to all sections, and these readings were considered independent as each reader assigned an age without the knowledge of the length or sex of the fish or of the interpretation of the section by the other reader. When the assigned age of an otolith differed, a third reader viewed the section and, wherever possible, assigned a final age. When discrepancies could not be resolved or when otoliths were not interpretable, they were omitted from further analysis (<0.5% of otolith sections examined).

Inter-reader variability in age estimates was determined by the procedure described by Beamish and Fournier (1981). The results of the two primary readers (4327 sectioned otoliths in total) were compared and an Index of Average Per cent Error (IAPE) calculated as a measure of precision. Separate IAPE values were calculated for each estuary and for the otoliths collected on a monthly basis from the Clarence River.

Marginal increment analysis was used to determine the periodicity of formation of opaque zones. Two readers independently examined sections under a microscope (as described earlier), assigned an age and determined whether the otolith margin was opaque or translucent. A marginal ring was deemed to have formed where an opaque zone appeared on the edge with no translucent zone following. An image processor was used to measure: (*i*) the distance between the otolith focus to the first opaque zone and the otolith edge to the terminal opaque zone when one opaque zone was present; or (*ii*) the distance between the otolith focus to the first opaque zone, otolith edge to the terminal opaque zone and the terminal opaque zone to the terminal less one opaque zone when two or more opaque zones were present. All measurements were made along the dorsal edge of the sulcus to the nearest 0.05 mm. The marginal increment was expressed either as a proportion of the distance between: (*i*) the focus and the outer edge of the opaque zone when only one opaque zone was present; or (*ii*) the outer edge of the two distal opaque zones when two or more opaque zones were present. Mean marginal increments (±1 s.e.) were calculated for separate age groups for each month and values were plotted for the 2-, 3- and 4-year or more age groups and for all age groups combined.

Age compositions of commercial catches

The age compositions of dusky flathead commercial landings were calculated by applying age–length keys to the commercial catch length–frequency data for each estuary in each year. A separate age–length key was used for each estuary and year. The age–length keys were based on length categories of 1 cm for fish 33–55 cm TL, but considered fish >55 cm TL to be from the one length category because of their scarcity in catches.

Total mortality

Estimates of the instantaneous rate of total mortality (Z) of dusky flathead were made for each estuary in each year using the age-based catch curve method described by Beverton and Holt (1957) and Ricker (1975). The natural logarithm of the number of fish in each age class (Nt) was plotted against their corresponding age class (t) and a linear regression was fitted. Z was estimated from the descending slope, b. The 3+ age class was assumed to be fully recruited for each catch curve

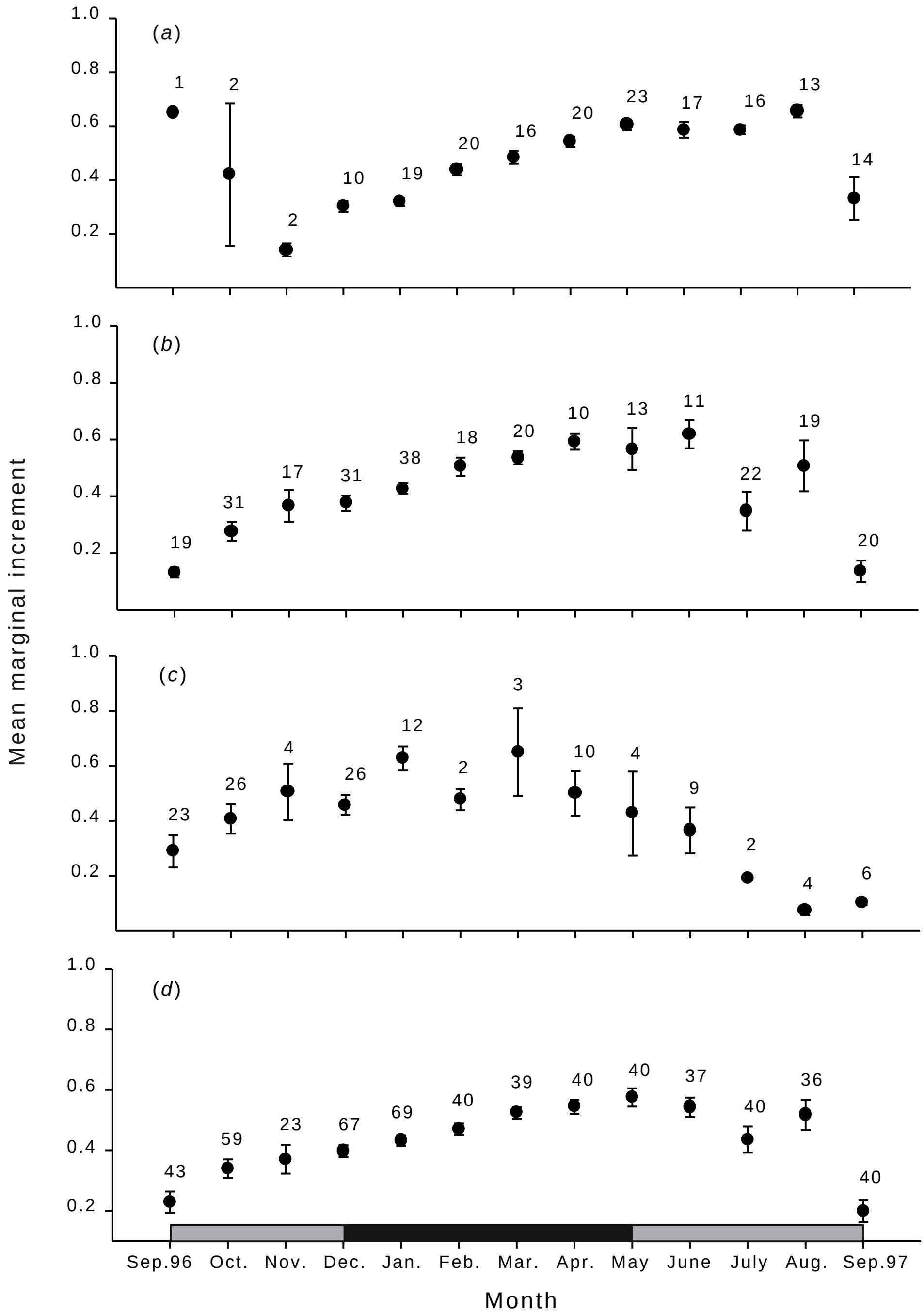

Fig. 1. Monthly changes in mean (± 1 se) marginal increment for sectioned otoliths of dusky flathead and the periods when otoliths displayed translucent edges (black bar) and when otoliths displayed both opaque and translucent edges (grey bar). (*a*) Two opaque zones, (*b*) three opaque zones, (*c*) four or more opaque zones, (*d*) total. *n*, Number of otoliths examined.

analysis. These analyses assumed that recruitment and growth in each estuary was constant across years and that the species displayed asymptotic growth patterns.

Results

Age determination, precision and validation

A total of 4327 dusky flathead otoliths were examined throughout the study. Agreement between the two primary readers in the interpretation of ages from thin-sectioned sagittae was 91.2% for the Clarence River, 92.8% for Wallis Lake, 89.3% for Lake Macquarie and 95.2% for St Georges Basin. The majority of discrepancies in assigning ages were ±1 year. The IAPE value obtained for each estuary was 1.6 for the Clarence River, 1.2 for Wallis Lake, 1.4 for Lake Macquarie and 0.7 for St Georges Basin. The lower IAPE value for St Georges Basin indicated that these otoliths were easier to interpret than elsewhere. The IAPE value obtained for the otoliths collected on a monthly basis from the Clarence River was 7.4. This higher value was probably a result of the added interpretation of the presence or absence of a growth band on the edge of the otolith.

The mean monthly marginal increments in sectioned otoliths for all age groups combined increased from September (0.23) to peak in May (0.57), after which they generally decreased (Fig. 1). The steepest decline in mean marginal increment was evident between August and September. Similar trends were exhibited by the mean marginal increments in otoliths with two and three opaque zones. Although the pattern for fish with four or more opaque zones collectively was less pronounced than in those with two and three zones, the mean marginal increment was least in July, August and September 1997. All otoliths collected between October/November and May had translucent margins. Although not quantified, we observed that some fish collected between June and September had opaque margins, indicating that the opaque zone was formed from mid winter to early spring.

Length at age relationships and growth

Because of the truncation of length data at the 33 cm MLL, no sensible growth curves could be generated for either sex because the data sets resulted in linear fits with no curvature. Relationships between age and total length of dusky flathead above the 33 cm MLL were relatively weak, particularly for males (Fig. 2). The mean length at age of females was generally greater than that of males in all estuaries, suggesting they grew faster (Fig. 2). Females also attained a greater maximum length than males. Mean size of males (data pooled across all estuaries) at ages 2 and 6 years were 36.6 and 40.7 cm TL, respectively, whereas females at the same age were 38.7 and 57.0 cm TL respectively. The largest male and female dusky flathead observed in the present study was 56 and 96 cm TL, respectively, whereas the oldest male and female were 9+ and 11+ years respectively.

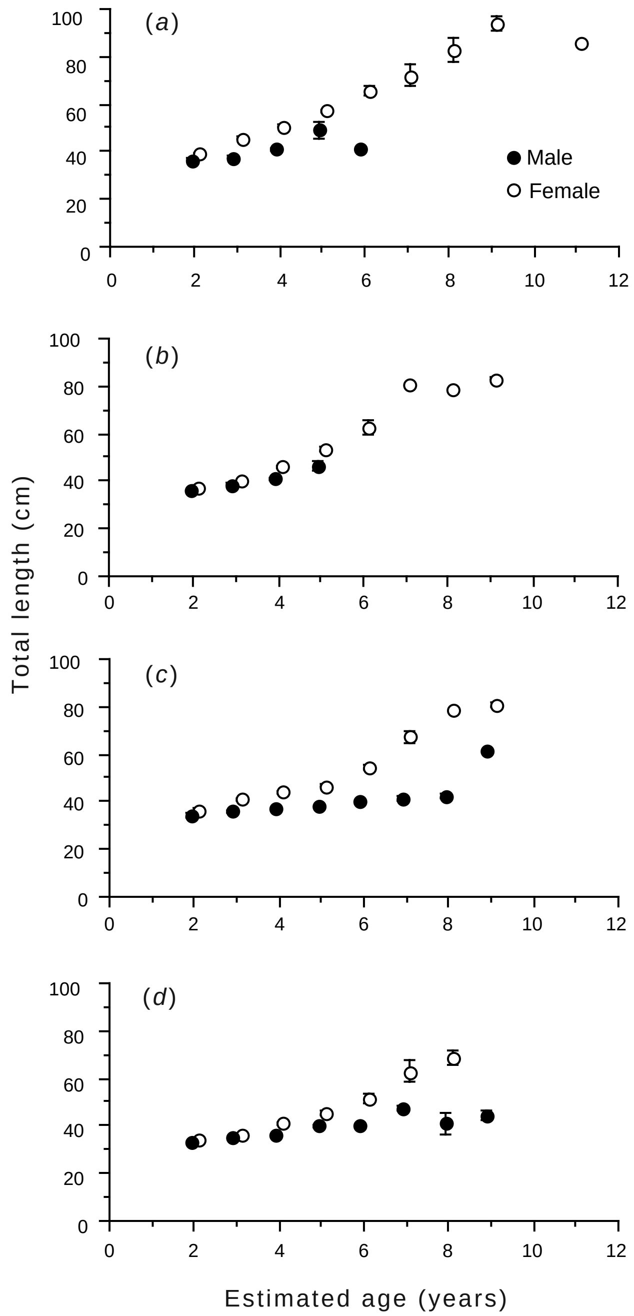

Fig. 2. Mean (± 1 s.e.) length at age of male and female dusky flathead in each estuary pooled across years. (*a*) Clarence River, (*b*) Wallis Lake, (*c*) Lake Macquarie and (*d*) St Georges Basin.

Sex, length and age compositions of commercial catches

Commercial landings of dusky flathead in all estuaries were dominated by females; the overall percentage of females in catches by number was 93% in the Clarence River, 76% in Wallis Lake, 55% in Lake Macquarie and 66% in St Georges Basin. These trends were consistent across seasons and years of sampling (see Gray *et al.* 2000).

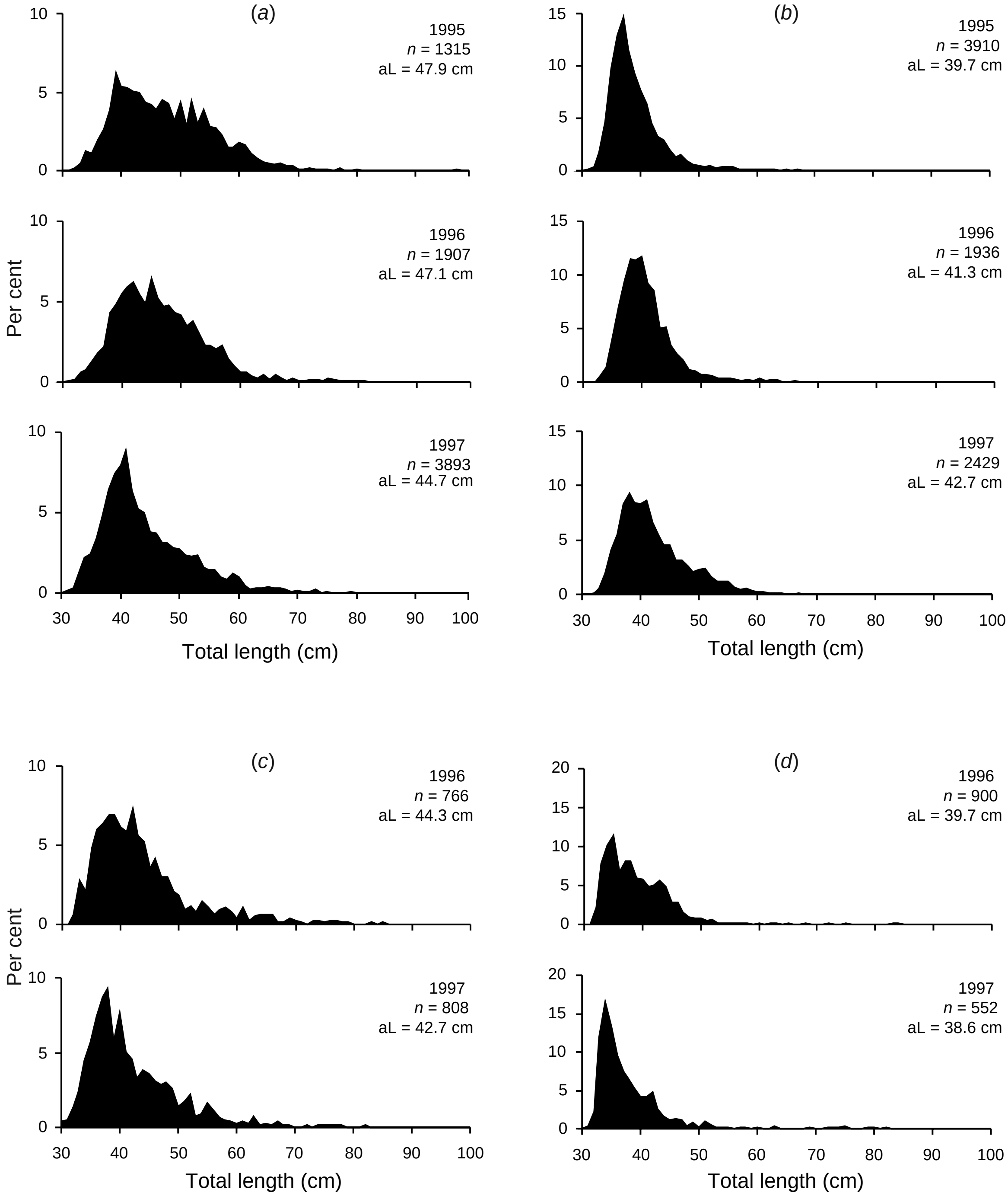

Fig. 3. Length compositions of commercial landings of dusky flathead in each estuary. (*a*) Clarence River, (*b*) Wallis Lake, (*c*) Lake Macquarie and (*d*) St Georges Basin. Catches in the Clarence River and Wallis Lake were from gillnets, whereas those in Lake Macquarie and St Georges Basin were from beach-seine nets. *n*, Number of fish measured; aL, average length of fish in sample.

Dusky flathead between 30 and 96 cm TL were sampled in commercial landings during the present study, although landings, in general, predominantly comprised fish between 35 and 50 cm TL (Fig. 3). A greater percentage of fish >50 cm TL contributed to the fishery in the Clarence River than elsewhere (particularly in 1995 and 1996), and thus the mean length of fish harvested was greatest in this estuary (Fig. 3). Interannual variation in the length compositions of landings and the average length of flathead harvested was evident in each estuary, particularly in the Clarence River. Females contributed a greater length range to the fishery, with few males larger than 45 cm TL being sampled in any estuary

(Fig. 4). The length composition of landings also varied for gillnets of different mesh sizes (Fig. 5), with the average length of fish retained being least in the 70 mm mesh gillnets. Two distinct size classes of fish were taken in the 95 and 100 mm mesh gillnets, and it is most likely that the larger fish were gilled, whereas the smaller fish were probably entangled by the mouth (M. K. Broadhurst, C. A. Gray, D. J. Young and D. D. Johnson, unpublished data). The overall length composition of seine-net catches was most similar to that obtained for the 70 mm mesh gillnets.

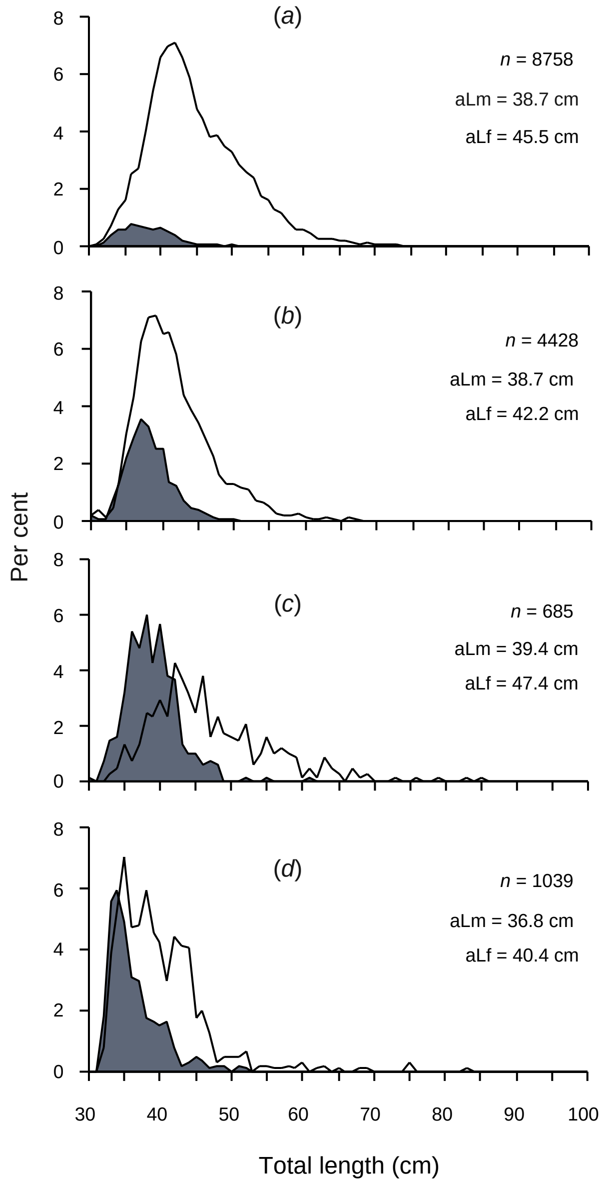

Fig. 4. Length compositions of male (grey area) and female (white area) commercial landings of dusky flathead in each estuary. (*a*) Clarence River, (*b*) Wallis Lake, (*c*) Lake Macquarie and (*d*) St Georges Basin. *n*, Number of fish measured; aLm, average length of males; aLf, average length of females.

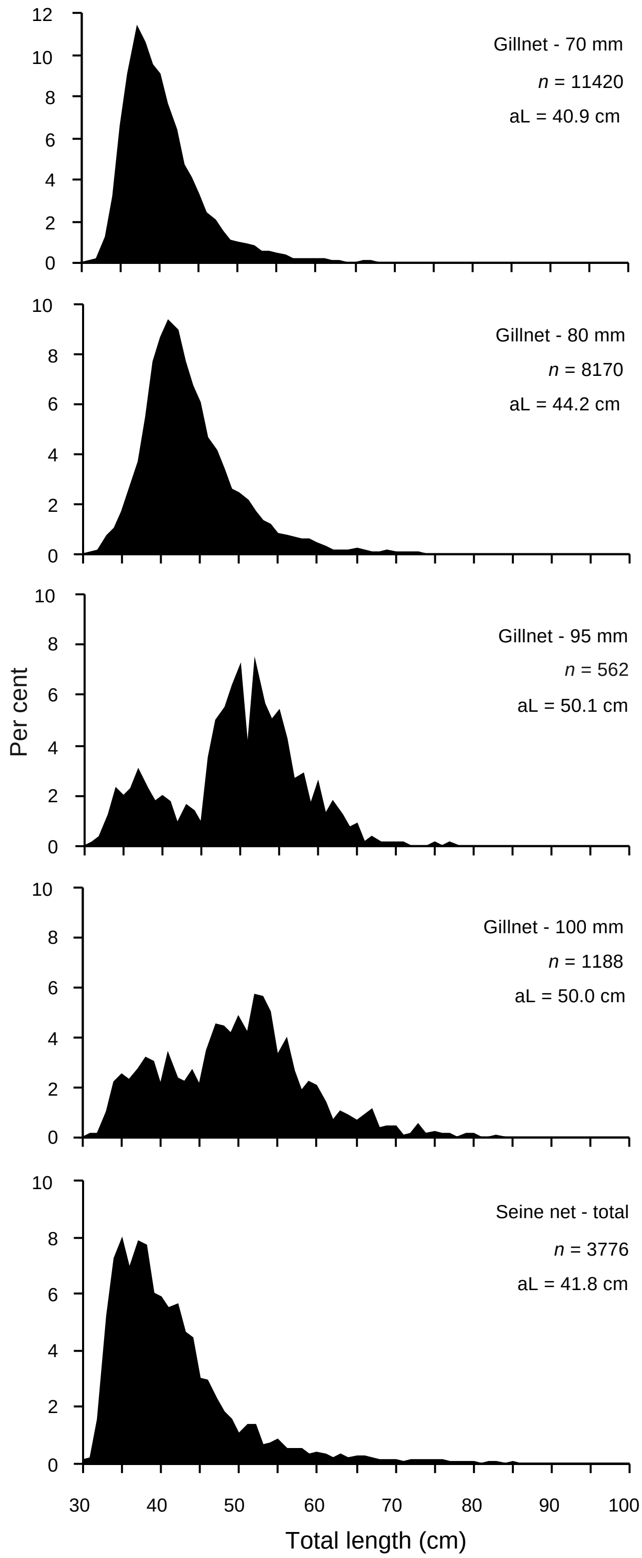

Fig. 5. Length compositions of commercial landings of dusky flathead from gillnets of different mesh sizes and from beach-seine nets pooled across all estuaries. *n*, Number of fish measured; aL, average length of fish in samples. Note that the 70 mm mesh gillnets were sampled in Wallis Lake and the 80, 95 and 100 mm mesh gillnets were primarily sampled in the Clarence River.

Ages of dusky flathead in commercial landings ranged from 2 to 11+ years, although the age compositions varied between estuaries and years (Fig. 6). Fish aged 2–4+ years dominated landings in the Clarence River and Wallis Lake, whereas fish aged 3–4+ years dominated landings in St Georges Basin, and fish aged 3–6+ years predominated in Lake Macquarie. Consequently, the average age of fish retained in commercial catches was greatest in Lake Macquarie. Relatively strong 2+ year classes were evident in landings in Wallis Lake in 1995 and the Clarence River in 1997, and subsequently the average age of harvests was least in these estuaries in these years (Fig. 6). This corresponded with a lower average length of flathead being harvested in Wallis Lake and the Clarence River in 1995 and 1997, respectively (see Fig. 3). Because the fishery in each estuary was based primarily on young fish, the progression of strong or weak year classes was difficult to follow. Nevertheless, the relatively strong 2+ year class in Wallis Lake could be followed to the relatively strong 4+ year class in 1997. Similarly, the relatively strong 3+ and 5+ year classes observed in St Georges Basin and Lake Macquarie in 1996, respectively, could be observed as the relatively strong 4+ and 6+ year classes in the respective estuaries in 1997 (Fig. 6).

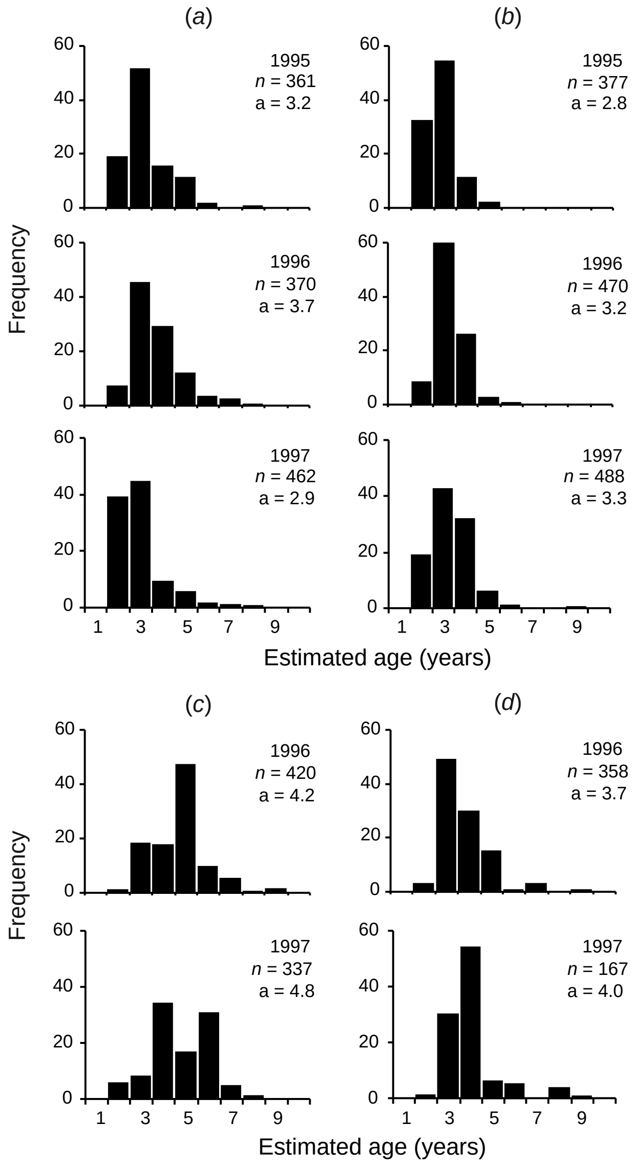

Fig. 6. Estimated age compositions of commercial landings of dusky flathead in each estuary. (*a*) Clarence River, (*b*) Wallis Lake, (*c*) Lake Macquarie, (*d*) St Georges Basin. *n*, Number of otoliths examined; a, average age in years.

Total mortality

Estimates of total mortality (Z) for each year sample are given in Table 1. Estimates of Z ranged from 0.45 (Lake Macquarie 1997) to 1.64 (Wallis Lake 1995). Note, however, that the precision of the Z estimates varied. The regression coefficient calculated for Lake Macquarie in 1997 was low because of the two strongest year classes of fish (4 and 6+) being separated by a weak year class (Fig. 6). The average of all estimates of Z was 0.96.

Table 1. Estimates of annual total mortality (Z) of dusky flathead in each estuary based on catch curve analysis assuming that the 3+ age classes were fully recruited to the fishery

Location	Year	Z ± s.e.	R^2
Clarence River	1995	1.13 ± 0.15	0.93
Clarence River	1996	0.93 ± 0.09	0.96
Clarence River	1997	0.99 ± 0.07	0.98
Wallis Lake	1995	1.64 ± 0.02	0.99
Wallis Lake	1996	1.38 ± 0.16	0.96
Wallis Lake	1997	0.89 ± 0.18	0.90
Lake Macquarie	1996	0.61 ± 0.19	0.67
Lake Macquarie	1997	0.45 ± 0.28	0.39
St Georges Basin	1996	0.97 ± 0.24	0.77
St Georges Basin	1997	0.64 ± 0.14	0.84

Discussion

Ageing

The marginal increment analysis indicated that one opaque and translucent growth zone was formed annually on the otoliths of dusky flathead. Results from a separate field-based mark–recapture study support this conclusion (Ferrell 2000). Several dusky flathead were marked with tetracycline by injection and released into southern NSW estuaries, with the 15 recaptured dusky flathead (aged 2–8 years) each displaying one opaque or translucent growth zone per year of liberty (Ferrell 2000). The marginal increment and mark–recapture studies showed that opaque zones were formed between mid winter and early spring and were completed by early summer, and the translucent zones were formed during the remainder of the year. This pattern of zone formation in otoliths is similar to that observed for several other estuarine and coastal fish species in NSW (Ferrell 2000), but differs slightly to that reported for dusky flathead in southern Queensland for which marginal increments peaked in September and declined in October (Hoyle *et al.* 2000). This latter study was based on interpretations of whole otoliths. Thus, opaque zone formation either occurs later in lower latitudes (i.e. Queensland) or is observed later on whole otoliths. Hyndes *et al.* (1992) reported that marginal increments in whole otoliths of *Platycephalus speculator* were harder to identify than in sectioned otoliths when more than one growth zone was present.

We estimated that the age of fish at the time the first growth increment (opaque zone) was formed was 6–8 months. This was based on the reported spawning of dusky flathead between October and March in southern Queensland/northern NSW (Dredge 1976; West 1993) and on the occurrence of larvae between September and May in waters of central NSW (Miskiewicz 1987; Gray and Miskiewicz 2000). To dusky flathead of southern Queensland, Dredge (1976) arbitrarily assigned a birth date of 1 December, and estimated fish to be 6 months of age when the first annulus on scales was deposited. Despite our assumptions, the age of dusky flathead when the first opaque growth zone is deposited on otoliths needs to be quantified for incorporation into growth models.

It was not possible to determine growth curves for dusky flathead in the present study owing to the limitations of sampling commercial catches. However, the data indicated that females grew faster and attained a greater maximum length than males in all estuaries. This result is in contrast to the findings of Dredge (1976), who reported no sex-related differences in mean lengths at age of dusky flathead. Growth of dusky flathead has been reported to be relatively fast with fish reaching 18 cm TL in 1 year, 30 cm TL in 2 years and 40 cm TL in 3 years (Dredge 1976; West 1993). Dusky flathead is the largest member of the Platycephalidae and has been reported to reach a size of 120 cm TL (Kailola *et al.* 1993), with the maximum age reported being 12+ years (Kerby and Brown 1994). The present study's data show that the fastest growing dusky flathead reach the current NSW MLL of 33 cm TL in 2–3 years. We note, however, that some fish at the 33 cm MLL were 6+ years old. The predominance of fish aged 2+ years in commercial catches was greatest in the Clarence River and Wallis Lake (Fig. 6), suggesting that fish may grow faster in these estuaries. However, the different commercial gear types used in the different estuaries may have confounded this observation. Large disparities between sexes in the maximum length, but not age, were recorded in the present study. Similar disparities have also been recorded for other platycephalids (Hyndes *et al.* 1992).

Several platycephalids are known to exhibit protandrous hermaphroditism (Fujii 1971) and it has been argued that dusky flathead undergo protandrous sex reversal, whereby most fish 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 the present study nor by West (1993). In the absence of any reproductive study, the data presented here indicate it is most likely that dusky flathead do not change sex, but rather male fish do not grow as large as females. This same confusion surrounded another platycephalid, *Platycephalus indicus*, but it now appears that this latter species does not undergo sex reversal (Masuda *et al.* 2000). Microscopic examination of gonad material is probably required to test these alternative hypotheses for *P. fuscus*.

Commercial catch composition

The data show that the estuarine commercial fishery for dusky flathead in NSW is primarily based on young (2–4+ years) female fish. This was particularly the case in the Clarence River, where females contributed 93% of the landings. The reasons for the high proportion of females in the Clarence River catch compared with the other study estuaries are not evident. There is some anecdotal information that male flathead are predominantly caught in near-shore coastal waters adjacent to the Clarence River, suggesting spatial segregation of sexes. Dusky flathead are known to spawn in estuaries, and it has been hypothesized that spawning occurs near river mouths and in near-shore coastal waters (Pease *et al.* 1981; Miskiewicz 1987).

Although no conclusive reproductive studies have been done on dusky flathead in NSW, it appears that a significant proportion of female fish in the commercial catch were below the reported length at first maturity of approximately 38–56 cm TL (Pease *et al.* 1981; West 1993). Given this and the high total mortalities estimated in the present study, there may be a need to provide greater protection to spawning female fish. Thus, there is a need to investigate the impacts of changing the current legal length restrictions on the stock dynamics of dusky flathead in NSW. This should include different strategies that incorporate increases in the MLL and the introduction of a maximum length limit. We note, however, that an increase in the MLL might put more pressure on female fish as males do not appear to grow large and might therefore be excluded from the fishery. The length and age of dusky flathead at first maturity and how this varies throughout NSW needs to be determined to assess the most appropriate legal length limit.

The length compositions of commercial landings generally comprised fish measuring 33–50 cm TL. The notable exception was the Clarence River, where fish >50 cm TL were more prevalent in catches. This was probably a result of the larger mesh gillnets used in this estuary. The length composition of gillnet catches was greatly dependent on mesh size, with the 70 mm mesh gillnets used in Wallis Lake generally harvesting smaller fish than the 80–100 mm mesh gillnets used in the Clarence River. Despite the differences in the length compositions of the gillnet catches between the Clarence River and Wallis Lake, the corresponding age structures of landed fish in each estuary were similarly based on 2 and 3+ year-old fish. As a result, small changes in minimum mesh sizes of nets may have little effect on altering the age compositions of dusky flathead harvested.

The predominance of a few young year classes supporting the dusky flathead fishery combined with the relatively high rates of total mortality ($Z \sim 1$) estimated here suggest that the stock may be prone to over-exploitation, although the long-term stability of the commercial catch suggests otherwise. Similar estimates of total mortality have been reported for other platycephalids (e.g. 0.9 for *P. indicus*; Bawazeer 1989), so this may be a feature common to harvested populations of platycephalids. We note, however, that total mortality is not the ideal indicator of stock status, and that it would be more preferable to have estimates of natural and fishing mortality. Our estimates of total mortality may have been confounded by the selectivity of the commercial fishing gear. Gillnets are highly size-selective (Hamley 1975) and the common mesh sizes used by commercial fishers (70–100 mm mesh) may not select for larger (and generally older) fish, which may effectively escape from the fishery. This would be the case particularly for female fish, which may grow beyond the selectivity of the fishing gear. This, however, should not have affected catches in the beach seine-nets. It is therefore imperative that the selectivity of the fishing gear (particularly gillnets) used by commercial fishers to capture dusky flathead be examined. An alternative explanation is that large dusky flathead may inhabit areas not fished by commercial fishers, and this also needs further examination. Sampling of catches from recreational fishers or undertaking fishery-independent surveys using a variety of sampling gears may provide more insight into this, and may also provide better estimates on total mortality rates of dusky flathead.

Our estimates of total mortality did not appear to be linked to total reported commercial landings of dusky flathead or to total reported commercial fishing effort in each of the study estuaries. Throughout the study period, reported commercial production was greatest in Wallis Lake (29–34 tonnes per annum) and least in St Georges Basin (4–5 tonnes per annum), whereas reported fishing effort (gill-and beach seine-nets combined) was greatest in the Clarence River (average 12434 fisher-days per annum) and least in St Georges Basin (average 989 fisher-days per annum). This reported commercial fishing effort does not necessarily reflect the effort directed solely at dusky flathead, but at a whole range of estuarine fish species (see Pease 1999).

In conclusion, an overview of the commercial fishery for dusky flathead in several NSW estuaries has been presented. The data show that the commercial fishery for dusky flathead is primarily sustained by female fish aged 2–4+ years and the stock appears to be subject to a relatively high total mortality, suggesting the fishery may be prone to over-exploitation (but see cautions discussed earlier). Given that a large proportion of the female catch is below the presumed length at first maturity, it would be advisable that an assessment of altering the current legal length restrictions be made. Because of the weak relationship between length and age of dusky flathead above the MLL, future sampling of catches for stock assessment purposes needs to be based on age. Other cost-effective alternatives to estimate the age of dusky flathead need to be investigated, such as otolith weights and widths (Worthington *et al.* 1995; Fletcher 1996). Further research on dusky flathead is required to assist with stock assessments and management of the species. Current gaps in knowledge of dusky flathead include rates of growth, natural mortality and exploitation, reproductive biology and stock-recruitment dynamics.

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References

Bawazeer, A. S. (1989). The stock and fishery biology of Indian flathead (Wahar) *Platycephalus indicus* (Linnaeus), Family Platycephalidae in Kuwait waters. *Kuwait Bulletin of Marine Science* **10**, 169–78.

Beamish, R. J., and Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences* **38**, 982–83.

Beamish, R. J., and McFarlane, G. A. (1983). The forgotten requirement of age validation in fisheries biology. *Transactions of the American Fisheries Society* **112**, 735–43.

Beverton, R. J. H., and Holt, S. J. (1957). 'On the Dynamics of Exploited Fish Populations.' Fisheries Investigations Series II. (Ministry of Agriculture, Fisheries and Food: London, UK.)

Doherty, P. J., and Fowler, A. J. (1994). An empirical test of recruitment limitation in a coral reef fish. *Science* **263**, 935–9.

Doubleday, W. G., and Rivard, D. (1983). Sampling commercial catches of marine fish and invertebrates. *Canadian Special Publications of the Fisheries and Aquatic Sciences* **66**, 1–290.

Dredge, M. C. L. (1976). 'Aspects of the Ecology of three Estuarine Dwelling Fish in South-east Queensland.' M.Sc. Thesis. (University of Queensland: Brisbane, Australia.)

Ferrell, D. J. (2000). Validation of annual ageing and sources of ageing error in 4 coastal marine finfish from NSW. In 'Sampling Estuarine

Fish Species for Stock Assessment'. (Eds C. A. Gray, B. C., Pease, S. L. Stringfellow, L. P. Raines, B. K. Rankin and T. R. Walford.) pp. 147–54. (NSW Fisheries Final Report Series, No. 18. ISSN 1440-3544.)

Fletcher, W. J. (1996). Application of the otolith weight–age relationship for the pilchard, *Sardinops sagax neopilchardus*. *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 657–64.

Fogarty, M. J., Sissenwine, M. P., and Cohen, E. B. (1991). Recruitment variability and the dynamics of exploited marine populations. *Trends in Ecology and Evolution* **6**, 241–6.

Fowler, A. J. (1995). Annulus formation in otoliths of coral reef fish – a review. In 'Recent Developments in Fish Otolith Research'. (Eds D. H. Secor, J. M. Dean and S. E. Campana.) pp. 45–64. (University of South Carolina Press: Columbia, USA.)

Fujii, T. (1971). Hermaphroditism and sex reversal in fishes of the Platycephalidae. II. *Kumococius detrusus* and *Inegocia japonica*. *Japanese Journal of Ichthyology* **18**, 109–17.

Gray, C. A. (2002). Management implications of discarding in an estuarine multi-species gill net fishery. *Fisheries Research* **56**, 177–92.

Gray, C. A., and Miskiewicz, A. G. (2000). Larval fish assemblages in south-east Australian coastal waters: seasonal and spatial structure. *Estuarine*, *Coastal and Shelf Science* **50**, 549–70.

Gray, C. A., Pease, B. C., Stringfellow, S. L., Raines, L. P., Rankin, B. K., and Walford, T. R. (2000). 'Sampling Estuarine Fish Species for Stock Assessment.' (NSW Fisheries Final Report Series No. 18. ISSN 1440-3544.)

Hamley, J. M. (1975). Review of gillnet selectivity. *Journal of the Fisheries Research Board of Canada* **32**, 1943–69.

Hoyle, S., Brown, I., Dichmont, C., Sellin, M., Cosgrove, M., and McLennan, M. (2000). 'Integrated Fish Stock Assessment and Monitoring Program.' Project report QO99011. (Department of Primary Industries Queensland: Brisbane, Australia.)

Hyndes, G. A., Loneragan, N. R., and Potter, I. C. (1992). Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead *Platycephalus speculator. U. S. Fishery Bulletin* **90**, 276–84.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A., and Grieve, C. (1993). 'Australian Fisheries Resources.' (Bureau of Resource Sciences, Department of Primary Industries and Energy, and FRDC: Canberra, Australia.)

Kerby, B. M., and Brown, I. W. (1994). 'Bream, Whiting and Flathead in South-East Queensland: a Review of the Literature.' Report no. QI94028. (Queensland Department of Primary Industries: Brisbane, Australia.)

Masuda, Y., Ozawa, T., Onoue, O., and Hamada, T. (2000). Age and growth of the flathead, *Platycephalus indicus*, from the coastal waters of west Kyushu, Japan. *Fisheries Research* **46**, 113–21.

Megrey, B. A. (1989). Review and comparison of the age-structured stock assessment models from the theoretical and applied points of view. *American Fisheries Society Symposium* **6**, 8–48.

Miskiewicz, A. G. (1987). 'Taxonomy and Ecology of Fish Larvae in Lake Macquarie and New South Wales Coastal Waters.' Ph.D. Thesis. (University of New South Wales: Sydney, Australia.)

Paxton, J. R., and Hanley, J. E. (1989). Platycephalidae. In 'Zoological Catalogue of Australia, Vol. 7, Pisces. Petromyzontidae to Carangidae'. (Eds D. W. Walton and R. Longmon.) (Australian Biological Resources Study: Canberra, Australia.)

Pease, B. C. (1999). A spatially orientated analysis of estuaries and their associated commercial fisheries in New South Wales, Australia. *Fisheries Research* **42**, 67–86.

Pease, B. C., Bell, J. D., Burchmore, J. J., Middleton, M. J., and Pollard, D. A. (1981). 'The Ecology of Fish in Botany Bay.' SPCC Technical Report BBS23. (State Pollution Control Commission: Sydney, Australia.)

Richards, L. J., Schnute, J. T., and Olsen, N. (1997). Visualizing catch-at-age analysis: a case study. *Canadian Journal of Fisheries and Aquatic Sciences* **54**, 1646–58.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* **191**, 1–382.

West, R. J. (1993). 'The Fisheries Resources of two Southeastern Australian Rivers.' Ph.D. Thesis. (University of New South Wales: Sydney, Australia.)

West, R. J., and Gordon, G. (1994). The commercial and recreational harvest of fish from two Australian coastal rivers. *Australian Journal of Marine and Freshwater Research* **45**, 1259–79

Worthington, D. G., Fowler, A. J., and Doherty, P. J. (1995). Determining the most efficient method of age determination for estimating the age structure of a fish population. *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 2320–6.

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