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Age, growth, maturity and the overfishing of the iconic sciaenid, *Argyrosomus japonicus*, in south-eastern, Australia

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ABSTRACT

Mulloway (*Argyrosomus japonicus*) occur in estuarine and coastal waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan, where they are important in fisheries. This study identified that mulloway in south-eastern Australia had similar growth rates, but matured at smaller lengths and younger ages, to those in South Africa and Western Australia. Growth of both sexes was similar to about 5 years, after which females grew faster and attained a greater maximum length than males. Female mulloway matured at 4–5 years of age with a L_{50} of 68 cm, whereas males matured at 2–3 years of age with a L_{50} of 51 cm. The commercial fishery in New South Wales was characterised by declining catches and a reduction in the proportion of mulloway of mature lengths in landings. During 2002–2005 commercial landings were dominated (83%) by fish within 15 cm of the current minimum legal total length of 45 cm and aged 2 and 3 years (>80%), even though mulloway can attain lengths of 200 cm and live >30 years. Estimates of the rates of instantaneous total mortality ranged between 0.34 and 0.45, whilst the rate of instantaneous natural mortality (M) was estimated to be approximately 0.12. Yield-per-recruit analyses indicated that mulloway in New South Wales are being growth overfished and substantial increases in yield could be achieved by increasing the length at first harvest. Values of the spawning potential ratio were below 0.2 under a range of mortality estimates, suggesting that mulloway are at risk of recruitment overfishing. These results suggest that the spawning stock of mulloway in south-eastern Australia has been depleted and that remedial management action is required to protect this iconic species.

1. Introduction

Mulloway (*Argyrosomus japonicus*) are teleost fishes of the family Sciaenidae that are distributed through the Indian and western Pacific oceans (Silberschneider and Gray, 2008). In Australia, mulloway are found in estuaries and coastal waters from approximately the Burnett River in Queensland (153°13′E, 25°20′S), south around the continent to the North West Cape in Western Australia (114°01′E, 21°53′S) (Kailola et al., 1993). Sub-population structuring is evident through this range (Silberschneider and Gray, 2008). Mulloway are considered an iconic species and are highly targeted by commercial and recreational fishers as they grow to large sizes (>2 m long, Kailola et al., 1993), have an attractive silver colouration and are good table fish.

A synopsis of biological and fisheries information on mulloway (Silberschneider and Gray, 2008) highlighted important knowledge gaps, including stock structure, early life-history, local information on growth and reproduction and fisheries assessment. Significantly, there appears to be substantial differences in important biological parameters, including growth and reproduction, between mulloway from different regions. Such regional variation suggests that local biological parameters are required for informed management.

In New South Wales (NSW), Australia, mulloway are important components of the estuarine commercial gillnet (80–150 mm stretched mesh), and coastal commercial line fisheries (no restrictions on types or sizes of hooks), and juveniles are a significant bycatch in the prawn-trawl fisheries (Silberschneider and Gray, 2008). Mulloway are also captured by recreational fishers in these environments and the current recreational harvest is estimated to be approximately four times greater than the commercial fishery (Silberschneider and Gray, 2008). Current management arrangements for mulloway in NSW include a minimum legal total length (MLL) of 45 cm and a recreational bag (possession) limit of 5 fish per angler. There is concern for the status of the stock of mulloway in south-eastern Australia because of a perceived decline in their abundance and average length. A review of reported commercial catch records in NSW showed a steady and substantial decline from 380 tonnes during 1973/74 to 60 tonnes during 2005/06 (Silberschneider and Gray, 2008). Such concerns are exacerbated due to a lack of basic biological and fishery information on which

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to base management decisions. Further, sciaenids worldwide have been demonstrated to be prone to overfishing (Sadovy and Cheung, 2003; Piner and Jones, 2004) and mulloway have already been assessed as recruitment overfished in South Africa (Griffiths, 1997).

In this paper we redress the lack of information concerning the biology and commercial fishery of mulloway in south-eastern Australia. Specific biological characteristics investigated include growth and length and age at sexual maturity. The length and age compositions of the commercial fishery are examined, and the stock is assessed using estimates of mortality, yield-per-recruit and spawning potential ratio.

2. Methods

2.1. Sampling procedure

Commercial landings of mulloway caught in estuarine and ocean waters throughout NSW were sampled for length and age composition on a regular basis between November 2002 and February 2005. Sampling was primarily done at the Sydney Fish Market (SFM) and at several ports of landings and fishing co-operatives spread along the NSW coast. Additional samples for age and reproductive assessment were also sourced from catches of selected individual commercial and recreational fishers. Fish smaller than the MLL were collected on an ad hoc basis from other scientific research programs and also by a commercial fisher who was issued with a permit to retain small mulloway.

All fish sampled were measured to the nearest millimetre and weighed to either the nearest: (1) gram (fish < 0.7 kg), (2) 10 g (fish 0.7–5 kg), (3) 25 g (fish 5–10 kg) and (4) 50 g (fish 10–25 kg). Mulloway have a convex tail and all length measurements were therefore total length (TL). When possible, each fish was also sexed, gonads weighed (nearest gram) and the sagittal otoliths removed for age estimation.

2.2. Estimation of age and growth

Sectioned sagittal otoliths were used to estimate the age of mulloway, after the method of Griffiths and Hecht (1995). One whole sagittae from each fish was weighed to the nearest 0.001 g, embedded in clear resin and sectioned transversely through the core using a low-speed saw fitted with two diamond blades. Both sides of the resulting thin section were polished with 9 μm lapping film after which the section was mounted on a standard glass slide with glue and a cover slip and viewed under a binocular microscope (6–12×) with reflected light against a black background. Age was estimated by counting opaque zones that were evident in sections. The precision of counts of opaque zones was assessed by re-reading 2955 otoliths. This was done by the same reader (VS) without the knowledge of the interpretation of the previous reading. When the two independent readings differed, a third reading was done after which a final age was assigned. The coefficient of variation (CV) for the two readings for each otolith was calculated and an average across all otoliths was obtained as described in Kimura and Lyons (1991).

The timing of formation of the first opaque zone in the otoliths of mulloway was estimated by examining the otoliths from young-of-the-year fish that were kept in captivity for 15 months. These fish were spawned in an aquaculture facility during January 2004 and were kept in outdoor 4500 l tanks with flow-through seawater at ambient temperature (~15–23 °C) and salinity. Fish (5–10) were sampled at approximately monthly intervals and their otoliths were sectioned and examined as described above. Measurements were made from the otolith core to the centre of each opaque zone and to the otolith edge. All otoliths from these fish were examined after the experiment was terminated in July 2005.

Table 1
Macroscopic ovary and testes staging schedule used for mulloway (after Laevastu, 1965)

Stage	Classification	Macroscopic characteristics
I/II	Virgin and Immature/resting	Ovaries small and translucent, pink or orange in colour. Oocytes not visible through ovarian wall. Testes very thin and flat, light pink in colour.
III	Developing	Ovaries slightly larger. Oocytes visible through ovarian wall. Testes slightly larger, triangular in cross-section, beige in colour. Sperm present in main sperm duct.
IV	Maturing	Ovaries larger, opaque, yellow or orange in colour. Yolk granule oocytes visible through ovarian wall. Testes larger, mottled beige and cream in colour. Softer texture, sperm present in tissue. Testes rupture when pinched.
V/VI	Mature/Spawning	Ovaries larger than stage IV, orange in colour. Testes larger, cream in colour, ruptures under slight pressure.
VII	Spent	Ovaries and testes far smaller than stage V/VI. Ovaries flaccid. Some yolk granule oocytes still visible through ovarian wall. Testes mottled-beige and cream in colour. Some sperm present in main duct and tissue.
VIII	Recovering spent	Ovaries and testes were small. Similar to stage II, but ovaries red in colour.

The periodicity of opaque zone formation was validated by marginal increment analysis and the proportion of otoliths with opaque margins that were observed through the year. The marginal increment of fish with more than 1 opaque zone was measured as the distance from the last opaque zone to the edge as a proportion of the distance between the last and second last opaque zones.

Growth was estimated by fitting the length-at-age data to the von Bertalanffy growth function:

$$L_t = L_\infty \left[l - e^{-k(_0^{t-t})} \right]$$

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. The growth function was fitted using a non-linear least squares procedure in Microsoft Excel. Separate analyses were done for males and females and for both sexes combined. The growth curves for male and female fish were compared across equal size and age ranges using the analysis of residual sums of squares (ARSS) (Chen et al., 1992).

2.3. Length and age at sexual maturity

Mulloway in central NSW are thought to have a late summer/autumn spawning period (Gray and Miskiewicz, 2000; Silberschneider and Gray, 2008) and we sampled fish to assess their reproductive condition between December and February during 2004 and 2005. Macroscopic examination of gonads was used to determine the sex of fish and stage of gonad development. A reproductive stage was assigned to each gonad for male and female fish according to the developmental criteria of Laevastu (1965), based on size, colour and visibility of oocytes as outlined in Table 1. Fish