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## Age validation and variation in growth, mortality and population structure of *Liza argentea* and *Myxus elongatus* (Mugilidae) in two temperate Australian estuaries

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This study investigated variation in the rates of growth and mortality, and age and fork-length ( $L_F$ ) compositions of two exploited species of Mugilidae, *Liza argentea* and *Myxus elongatus*, in two south-east Australian estuaries (Lake Macquarie and St Georges Basin). An ageing protocol was developed by counting opaque growth zones on sectioned otoliths which was validated by periodically examining the otoliths of captive-reared young-of-the-year fishes, and marginal increment analysis of wild fishes. The maximum recorded age was 17 years for *L. argentea* and 12 years for *M. elongatus*, which is greater than generally observed in other species of mugilids. Growth models of each species significantly differed between sexes and, except for male *L. argentea*, between estuaries. Fishes from Lake Macquarie generally had a greater mean  $L_F$  at age than those from St Georges Basin and females of both species generally attained a greater maximum  $L_F$  and age than males. Gillnet catches of *L. argentea* were of similar  $L_F$  and age compositions in both estuaries, whereas the age composition of catches of *M. elongatus* in Lake Macquarie contained a greater proportion of younger fish. Estimates of total, natural and fishing mortality were greater for *M. elongatus* than *L. argentea* across both estuaries, and estimates of total mortality were greatest for both species in Lake Macquarie. The data indicate that neither species has been overfished in these estuaries.

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Key words: ageing; fisheries assessment; life history; longevity; mullet; otolith.

## INTRODUCTION

The Mugilidae (grey mullet) is a diverse and widely distributed family of fishes consisting of *c.* 72 species that are found in marine, estuarine and fresh waters throughout most tropical and temperate regions of the world (Nelson, 2006). Mugilids are a dominant and important component of many ecosystems (Odum, 1970; Brusle, 1981; Cardona, 2001; Blanco *et al.*, 2003) and they form important commercial and

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recreational fisheries and aquaculture industries in numerous countries (Oren, 1981; Ibañez-Aguirre *et al.*, 1999; Hotos, 2003; Bacheler *et al.*, 2005; González Castro *et al.*, 2009). Although aspects of the life history of several mugilids have been well documented (Brusle, 1981; Chang *et al.*, 2004; McDonough *et al.*, 2005; Kendall & Gray, 2008), important age and length-based biological data are lacking for many exploited species. Age and length-based information, including estimates of growth and mortality, are fundamental for monitoring and assessing the status of exploited wild populations of fishes and for developing fisheries management plans (Ricker, 1975; Campana, 2001; Patterson *et al.*, 2001; Begg *et al.*, 2005). For example, age and length-based modelling has been used to monitor and help manage populations of, and fisheries on, *Mugil cephalus* L. in the U.S.A., Taiwan and Australia (Hwang *et al.*, 1990; Ibañez-Aguirre *et al.*, 1999; Mahmoudi *et al.*, 2001; Smith, 2003; Bell *et al.*, 2005).

It is essential that any age-based study be developed according to best practice. Although estimates of the age and growth of several mugilids have been made (Quignard & Farrugio, 1981; Hotos, 2003), few studies have provided evidence of validated ageing procedures. This is often an overlooked, but necessary component of any ageing study (Quignard & Farrugio, 1981; Campana, 2001). Further, most previous studies concerning ageing of mugilids have primarily been based on the interpretation of scales, which can be problematic as the ages of older fishes are frequently underestimated (Beamish & McFarlane, 1983; Carlander, 1987). Based on the most appropriate methodologies, there is a clear need for future studies investigating the age of mugilids to be properly validated.

In this study, an otolith-based ageing protocol is developed to investigate differences in the age, growth, mortality and population structure of two abundant and co-occurring exploited species of mugilids, *Liza argentea* (Quoy & Gaimard) and *Myxus elongatus* Günther, in south-east Australia. Both species are common in estuarine and coastal waters and are harvested by commercial and recreational fishers. Commercial catches of *L. argentea* and *M. elongatus* in New South Wales (NSW) waters generally exceed 60 and 150 t per annum respectively (Scandol *et al.*, 2008). Recreational catches can also be significant; it was estimated that up to 4 t of *L. argentea* and 10 t of *M. elongatus* were annually harvested in one estuary alone [Lake Macquarie (LM)] (Steffe *et al.*, 2005). The reproductive biology of both species has been investigated (Kendall & Gray, 2008), but there have been no studies of their age and growth. This lack of age-based data limits any assessments of current and alternative harvesting and management strategies on these species.

The specific objectives of this study were to: 1) develop a validated, otolith-based ageing protocol for *L. argentea* and *M. elongatus*; 2) use the developed protocol to determine and compare the patterns of growth between species, sexes, and across two estuaries; 3) estimate and assess differences in the age compositions, instantaneous rates of total mortality, natural mortality and fishing mortality of populations of both species in two south-east Australian estuaries. The data are used to assess the status of populations and consequences of current harvesting strategies on populations in these estuaries.

## MATERIALS AND METHODS

### STUDY AREA AND SAMPLING PROCEDURES

Samples of each species were obtained from two south-east Australian estuaries: LM ( $33^{\circ} 06' \text{ S}$ ;  $151^{\circ} 36' \text{ E}$ ) and St Georges Basin (SGB) ( $35^{\circ} 08' \text{ S}$ ;  $150^{\circ} 36' \text{ E}$ ) (Fig. 1). Both are shallow, micro-tidal, barrier estuaries (Roy *et al.*, 2001).

Sampling was done on a monthly basis between August 2004 and July 2005 in both estuaries with further samples collected bi-monthly until November 2005 in SGB. Fishes were collected using multimesh gillnets, with each net (*i.e.* sampling unit) comprising of seven individual panels of netting of different stretched mesh sizes (36, 44, 54, 63, 76, 89 and 102 mm). Each panel was 50 m in length except for the 36 and 44 mm mesh, which were 20 m in length. A total of 12 nets were set across shallow seagrass ( $<2 \text{ m}$ ), and shallow and deep bare substrata ( $<2 \text{ m}$  and  $>4 \text{ m}$ , respectively), at two locations in the lower reaches in each estuary on each sampling occasion. All sampling was done between the first and last quarter of the moon and it took four nights to sample each estuary. All nets were bottom set at dusk (1700–2100 hours depending on time of year) and retrieved 1 h later (Rotherham *et al.*, 2006).

To enhance the generality of, and size ranges for, the analyses of growth, additional samples were collected opportunistically from the Clarence River, South West Rocks, Lake Illawarra, Tuggerah Lakes and Tuross River (*L. argentea*  $n = 324$ , *M. elongatus*  $n = 32$ ) (see Fig. 1). These samples were collected using a range of fishing gears, including gillnets and beach-seines. The data from these additional samples were used only in the all locations growth model.

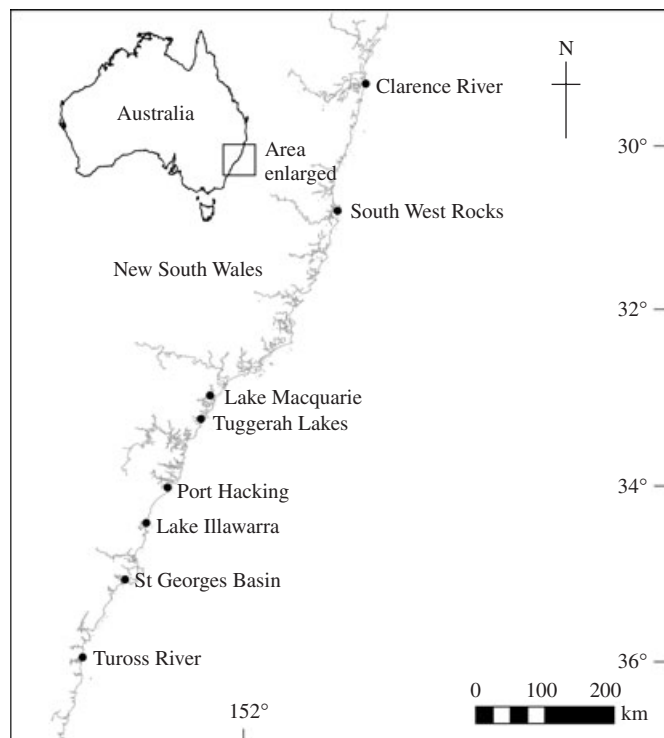


FIG. 1. New South Wales coastline showing the location of Lake Macquarie (LM) and St Georges Basin (SGB) and other locations.

All *L. argentea* and *M. elongatus* caught were measured for fork length ( $L_F$ ) (to 5 mm) and c. 30 individuals of each species were retained each month from each estuary for age and reproductive analyses (Kendall & Gray, 2008). For each specimen retained, information on date and location of capture, fish mass ( $M$ ; 0.1 g),  $L_F$  (to 1 mm) and sex (macroscopic examination of gonads; Kendall & Gray, 2008) was recorded. Both sagittal otoliths were extracted from each fish, cleaned, dried and stored in envelopes for a minimum of 3 days prior to further processing. One otolith from each pair was embedded in a block of clear resin and a transverse section 0.3 mm thick was taken through the core perpendicular to the longest axis using a Gemmasta saw (www.opticsa.com.au). Sections were then mounted using resin on a glass slide.

## AGE ESTIMATION

Age estimates of both species were made from examining sectioned otoliths viewed under a compound microscope with reflected white light against a black background. The opaque zones visible in the internal structure of the otolith were counted along a radius from the primordium to the outer edge of the ventral lobe. An opaque zone was only counted and considered complete when it was followed by translucent material on the distal side of the otolith. All sections were read without knowledge of the sample details (*i.e.*  $L_F$ , location and date of capture). Two months after the initial reading, 200 otoliths of each species were drawn at random and read a second time. The coefficient of variation (c.v.) for the two readings for each otolith was calculated for each species using the method described in Kimura & Lyons (1991) and Campana (2001).

An ageing protocol based on that described in Fowler & Short (1998) and Smith & Deguara (2003) was developed to convert counts of opaque zones in otoliths into an estimated age (years and months) for estimating growth coefficients and to model the growth of both species. This required an assigned birth date (based on the middle of the spawning season), the date of capture, the number of opaque zones, a classification of the status of the edge of the otolith, the age at which the first opaque zone formed and the period of timing of formation of opaque zones.

The growth of males and females of each species in each estuary was modelled using the von Bertalanffy growth function. For these analyses the theoretical zero  $L_F$  at  $t_0$ , was constrained to 0 as very small young fishes were not caught in the gillnets. Wild-caught fishes from all locations were combined to model the overall growth of males and females of both species from south-eastern Australia. Differences in growth curves were assessed using the technique of Kimura (1980), where 95% confidence ellipses were generated around the parameter estimates of the growth coefficient  $K$  and theoretical maximum  $L_F$ ,  $L_{F\infty}$ . Confidence ellipses that did not overlap indicated significant differences in growth.

## AGE VALIDATION

Two methods were used to validate and develop an ageing protocol for each species: marginal increment analyses of wild fishes and the captive rearing of wild-caught young-of-the-year (YOY) fishes. Marginal increment analyses were used to examine the periodicity of opaque zone formation in the otoliths of both species. Measurements were made from the core of the sectioned otolith to the middle of each successive opaque zone and to the otolith edge along the ventral edge of the sulcus. These were made using a microscope mounted video camera interfaced with a computer running Image Pro Plus (Media Cybernetics Inc; www.mediacy.com) image analysis software. The marginal increment ( $I_M$ ) was defined as: for fishes with zero opaque zones, the distance from the core to the otolith edge; for fishes with one opaque zone, the distance from the first opaque zone to the otolith edge as a proportion of the distance from the core to the first opaque zone; and for fishes with two or more opaque zones, the distance from the most recently completed opaque zone to the otolith edge as a proportion of the last completed increment.

Between January and April 2005, c. 200 juvenile *L. argentea* (15–70 mm  $L_F$ ) were collected from Lake Illawarra and Tuggerah Lake and 200 juvenile *M. elongatus* (30–60 mm  $L_F$ ) were collected from Port Hacking. These fishes were collected using a fine-mesh seine

and hand-held scoop nets and transported to the Cronulla Fisheries Research Centre where they were given a mild antibiotic bath (oxytetracycline solution at  $0.1 \text{ g l}^{-1}$  of sea water) to reduce the risk of infection from handling and transportation. The species were separated and transferred into two 1000 l tanks. All fishes were fed commercial high protein fish pellets once a day and maintained at ambient water temperatures and exposed to natural diurnal cycles ( $34^\circ \text{ S}$ ). Each month between June 2005 and December 2006, 10 *L. argentea* and 10 *M. elongatus* were caught and euthanized. Sagittal otoliths were removed from these fish and the protocol for sectioning, age estimation and marginal increments analysis was the same as that described above.

## AGE CLASS COMPOSITION

Separate age- $L_F$  keys (Kimura, 1977; Lai *et al.*, 1996) were constructed for *L. argentea* and *M. elongatus* in each estuary using the  $L_F$ -at-age data combined across sexes. The age-class compositions of the multimesh gillnet catches of both species were estimated by applying the appropriate age- $L_F$  key for each species in each estuary to the corresponding total  $L_F$  composition data of catches.

## MORTALITY

Age-based catch curves of each species in each estuary were calculated by plotting the natural logarithms of the numbers of fish surviving in each year class against their corresponding year class. The instantaneous rate of total mortality ( $Z$ ) was estimated by calculating the slope of the descending limb of each catch curve as described by Beverton & Holt (1957) and Ricker (1975). These analyses assumed that recruitment and growth were constant across years in each estuary and that growth of each species was asymptotic.

Two independent estimates of natural mortality ( $M$ ) were made using: 1) the empirical relationship based on maximum age described in Hoenig (1983),  $\ln(M) = 1.44 - 0.984 \ln(t_{\max})$ , where  $t_{\max}$  = the maximum age; 2) the relationship between water temperature and age described in Pauly (1980),  $\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$ , where  $T$  = average water temperature. The Pauly-based estimates of  $M$  were multiplied by 0.6 to adjust for schooling fishes (Pauly, 1980; Jones, 1990).

For these analyses, the von Bertalanffy coefficient from all locations and both sexes ( $^\circ \text{C}$ ) combined were used: *L. argentea*  $L_\infty = 300 \text{ mm } L_F$  and  $K = 0.25$ ; *M. elongatus*  $L_\infty = 349 \text{ mm } L_F$  and  $K = 0.44$ . Water temperature was set at  $19.8$  and  $18.2^\circ \text{ C}$  for fishes from LM and SGB, respectively (observed mean annual temperatures). Fishing mortality ( $F$ ) was calculated as  $F = Z - M$ , and the exploitation rate ( $E$ ) was calculated as  $E = FZ^{-1}$  (Beverton & Holt, 1957; Ricker, 1975).

## RESULTS

### MARGINAL INCREMENT ANALYSES OF WILD-CAUGHT FISHES

Considerable variation was evident in the marginal increments of wild-caught *L. argentea* and *M. elongatus* (Fig. 2). Despite this, lowest marginal increment values in fishes with two or more visible opaque zones were mostly observed between November 2004 and April 2005 for *L. argentea* and between October 2004 and February 2005, and August and November 2005 for *M. elongatus*. Newly deposited opaque zones were therefore first visible in most fishes during these periods. No individuals with zero or one visible opaque zones were sampled between December and February. The mean  $\pm$  s.d. distance from the core to the middle of the first

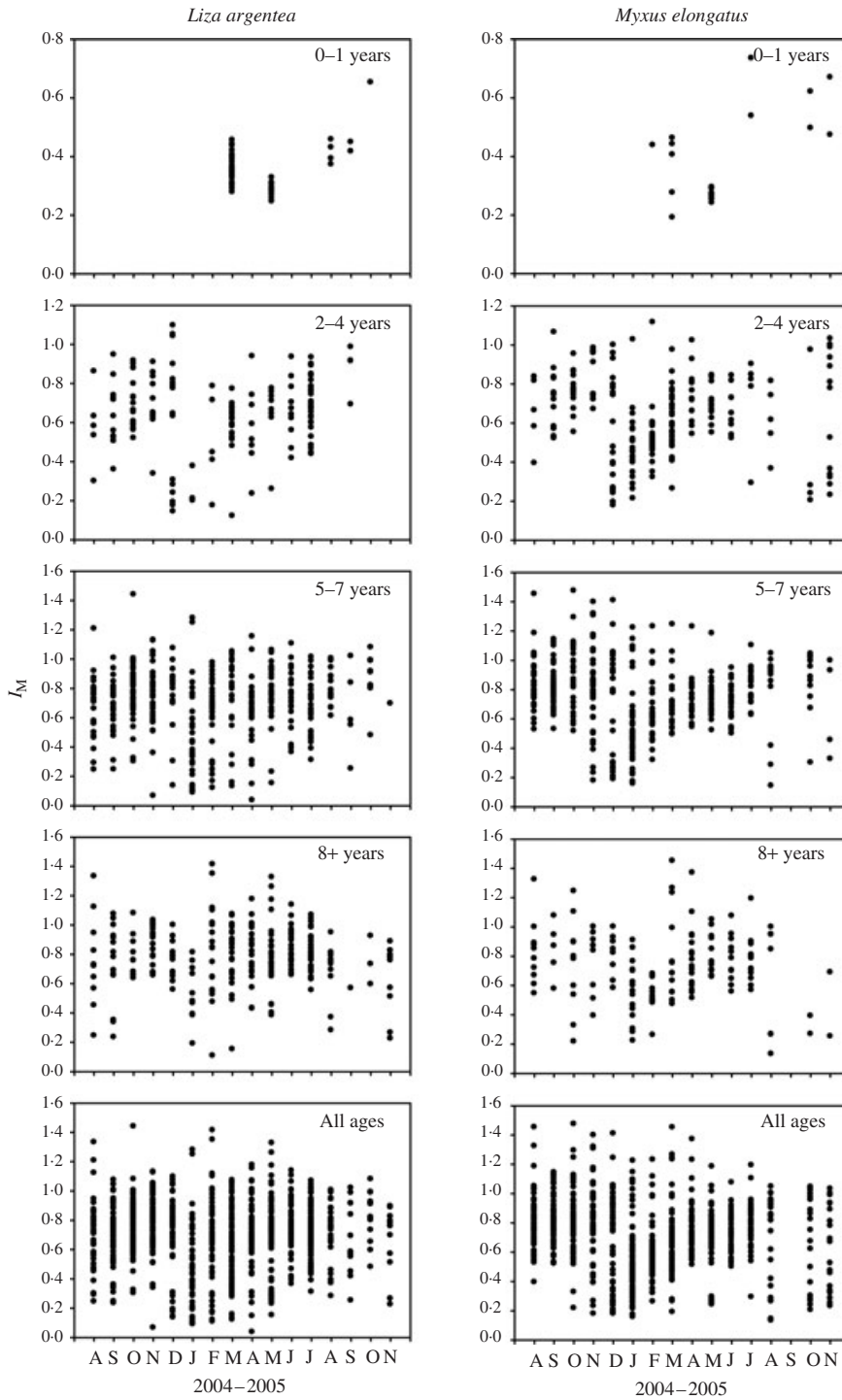


FIG. 2. Marginal increment ( $I_M$ ) plots for *Liza argentea* and *Myxus elongatus* between August 2004 and November 2005.



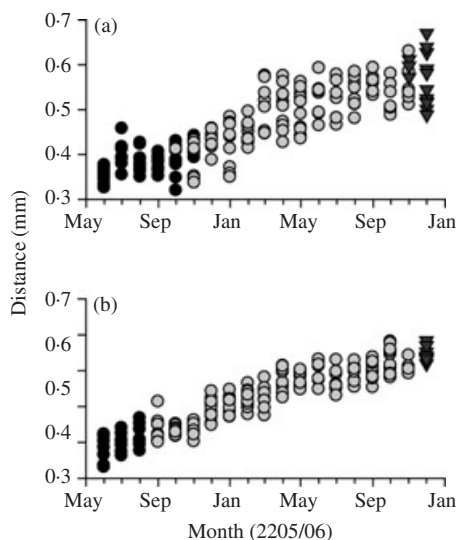


FIG. 3. Distance from the core to the otolith edge for (a) *Liza argentea* and (b) *Myxus elongatus* held in captivity between May 2005 and January 2006: (●) fish that had zero opaque zones; (○) fish that had one opaque zone; (▼) fish that had two opaque zones.

opaque zone for all *L. argentea* and *M. elongatus* with one or more opaque zones was  $0.35 \pm 0.05$  and  $0.31 \pm 0.07$  mm, respectively.

#### VALIDATION OF FIRST AND SECOND OPAQUE GROWTH ZONE IN CAPTIVE-REARED FISHES

The first opaque zone was first visible between October and December 2005 for *L. argentea* and in September 2005 for *M. elongatus* (Fig. 3). The second opaque zone was visible in all *L. argentea* and *M. elongatus* in December 2006 (Fig. 3). The mean  $\pm$  s.d. distance from the core to the middle of the first opaque zone for all *L. argentea* and *M. elongatus*, with one or more opaque zones was  $0.37 \pm 0.04$  and  $0.31 (\pm 0.03)$  mm, respectively.

#### DEVELOPMENT OF AGEING PROTOCOLS

Counts of opaque zones were converted to an appropriate age class based on the assigned birth dates, the age when the first opaque zone was deposited, the width of the otolith edge and the month of capture. Based on observed spawning seasons (Kendall & Gray, 2008), *L. argentea* in LM was assigned a birth date of 1 July, whereas those in SGB were assigned a birth date of 1 February. *Myxus elongatus* was assigned a birth date of 1 February for all estuaries. For *L. argentea* assigned a birth date of 1 July, 1 year was added to their estimated age as validation studies of mugilids and other species in the region have shown that winter-born fishes deposit their first opaque zone at an age between 13 and 23 months (Fowler & Short, 1998; Smith & Deguara, 2003; Hughes *et al.*, 2008).

Because the marginal increments showed variation between individuals in the timing of newly completed opaque zones (see above), a protocol was developed to assign an individual into its most likely age class for this period. Otoliths were assigned an edge status of wide ( $I_M > 0.9$  mm), medium ( $0.4 < I_M < 0.9$  mm) or narrow ( $I_M < 0.4$  mm). For individuals of both species collected between November and January (*i.e.* before the nominal birth dates) and assigned a narrow edge status (*i.e.* just completed opaque zone formation), one was deducted from the number of opaque zones counted. For individuals collected after February and assigned a wide edge status it was assumed they were about to form an opaque zone, so one was added to the number of opaque zones counted. The number of days from the assigned birth date to the capture date (as a proportion of a year) was added to the age class to give the final age estimate in years and months for each individual fish. This followed a similar procedure described in Fowler & Short (1998) and Hughes *et al.* (2008).

### AGE ESTIMATION AND PRECISION

Otoliths from both species had clear patterns of alternating translucent and opaque zones. A total of 1088 *L. argentea* and 790 *M. elongatus* individuals were examined for age estimation. Individual *L. argentea* ranged from 59 to 346 mm  $L_F$  and *M. elongatus* from 57 to 393 mm  $L_F$  and their estimated ages ranged from 2 to 12, and 2 to 17 years for each species, respectively.

The agreement between comparative readings of opaque zones was 93% for *L. argentea* and 92.5% for *M. elongatus* (all readings for all individuals were within  $\pm 1$ ). Error due to interpretation of a newly formed opaque zone (near the otolith edge) accounted for 35.7 and 40% of error, respectively, and error due to interpretation of the first opaque zone accounted for 28.6 and 53.3% of error, respectively. A large proportion of error occurred in individuals aged  $\geq 6$  years (*L. argentea* = 64.3%; *M. elongatus* = 80%). The c.v. averaged across all ages was 0.01 for both species.

### GROWTH

The confidence ellipses around the growth coefficients  $L_{F\infty}$  and  $K$  indicated that the growth of *L. argentea* and *M. elongatus* differed between sexes and except for male *L. argentea*, between estuaries (Figs 4 and 5 and Table I). Both species grew relatively fast until *c.* 2–3 years of age, after which the rate of growth slowed (Figs 4 and 5). Females attained a greater  $L_{F\infty}$  than males, with observed  $L_{F\infty}$  for females and males being 346 and 286 mm  $L_F$  for *L. argentea* and 393 and 315 mm  $L_F$  for *M. elongatus*. The observed longevity of females of both species was greater than males; the maximum estimated ages of females and males was 17.0 and 12.4 years for *L. argentea* and 12.7 and 10.7 years for *M. elongatus* (Figs 4 and 5 and Table I). Both species had a greater mean  $L_F$  at age and  $L_{F\infty}$  in LM than in SGB.

### FORK LENGTH AND AGE-CLASS COMPOSITION

Individuals of both species were caught in all mesh sizes in both estuaries. Overall, 61% of *L. argentea* and 63.5% of *M. elongatus* were captured in the 54 and 63 mm



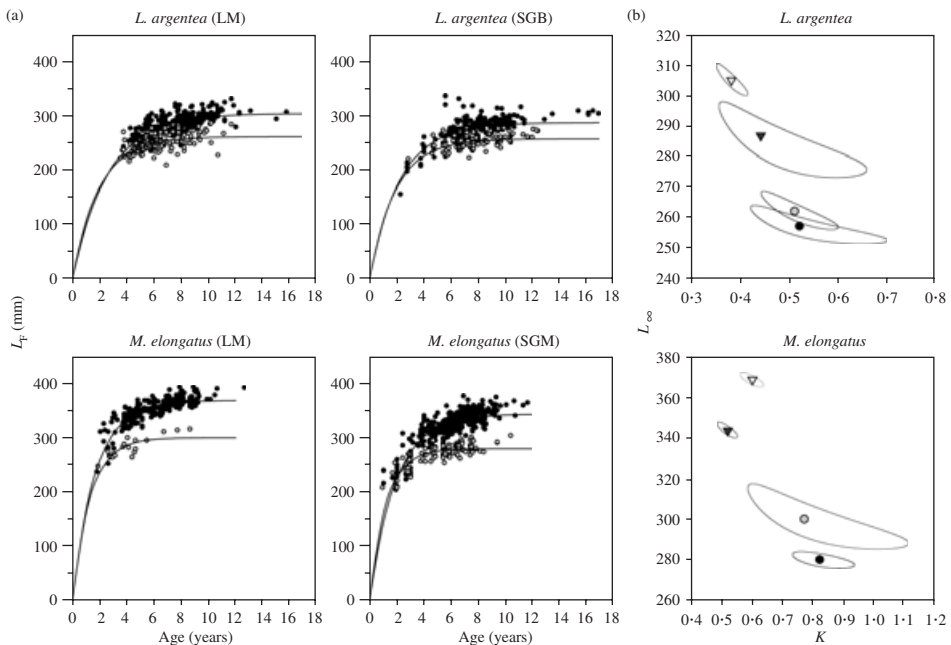


FIG. 4. (a) Fork length ( $L_F$ ) at age and von Bertalanffy growth curves for male (●) and female (●) *Liza argentea* and *Myxus elongatus* collected from LM and SGB. (b) 95% confidence ellipses are given for the growth coefficient ( $K$ ) and mean asymptotic length ( $L_{F\infty}$ ) (●, males from SGB; ●, males from LM; ▼, females from SGB; ▼, females from LM).

meshes combined. Less than 1.8% of either species were caught in the 89 and 102 mm meshes combined, whereas 8.9% of *L. argentea* and 12.4% of *M. elongatus* were captured in the 36 mm mesh. The  $L_F$  compositions of the multimesh gillnet samples of *L. argentea* were similar in LM and SGB; most fish were between 230 and 300 mm  $L_F$  (Fig. 6). In contrast, the  $L_F$  composition of samples of *M. elongatus* differed between estuaries; a larger  $L_F$  class (>350 mm) was captured in LM (Fig. 6).

The estimated age compositions of samples differed between species and estuaries. Catches of *L. argentea* ranged from 3 to 16 years in LM and 2 to 17 years in SGB. The 5 and 6 year-old age classes dominated samples in LM, whereas the 6 and 7 year-old age classes were most abundant in SGB (Fig. 6). Catches of *M. elongatus* in LM ranged from 1 to 12 years, with the 3, 4, 6, 7 and 8 year-old age classes being strongest. In SGB, catches of *M. elongatus* contained individuals from 1 to 11 years, with the 6 and 7 year olds being the strongest age classes (Fig. 6). There was a greater proportion of 3 and 4 year-old *M. elongatus* in catches in LM compared with SGB.

## MORTALITY

Estimates of  $Z$ ,  $M$ ,  $F$  and  $E$  were greater for *M. elongatus* than *L. argentea* across both estuaries (Table II). The estimates of  $Z$  were slightly lower for both species in SGB than LM, but no consistent pattern was observed for estimates of  $M$ . Estimates of  $M$  of both species across both estuaries made using the Hoenig (1983) method

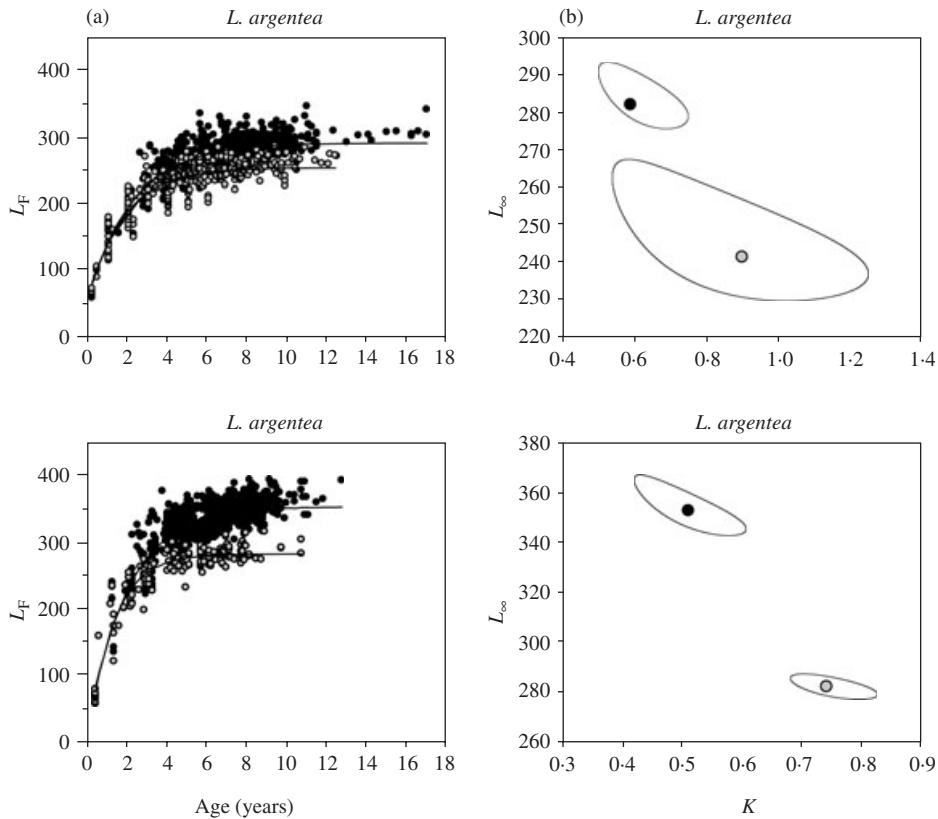


FIG. 5. (a) Fork length ( $L_F$ ) at age and von Bertalanffy growth curves for male (○) and female (●) *Liza argentea* and *Myxus elongatus* combined across all locations. (b) 95% confidence ellipses are given for the growth coefficient ( $K$ ) and mean asymptotic length ( $L_{F\infty}$ ).

were lower than the corresponding estimates made using the Pauly (1980) method. The estimates of  $E$  were similar for each species across estuaries.

## DISCUSSION

### AGE AND GROWTH

Sectioned otoliths were an effective method for ageing *L. argentea* and *M. elongatus* as alternating bands of opaque and translucent zones were clearly visible on sections, and relatively high levels of precision (c.v. = 1%) were obtained between readings (Campana, 2001). Individuals of both species reared in the aquaria were YOY most likely hatched during the spring and summer (September to February) of 2004. This was based on their  $L_F$  at time of collection, otolith width and the fact they did not exhibit any opaque growth zone on otoliths. The first opaque zone on otoliths of these fishes was observed the following spring and summer, when the fishes were c. 8–13 months old. Both species, however, have protracted spawning

TABLE I. Comparison of von Bertalanffy growth coefficients for populations of *Liza argentea* and *Myxus elongatus* collected from Lake Macquarie (LM) and St Georges Basin (SGB)

Species	Location (F or M)	$L_{F\infty}$ (mm)	$K$	$t_0$	Age range (years)	$r^2$	$n$
<i>L. argentea</i>	LM (F)	304.9	0.38	0*	3.7–15.9	0.44	245
	LM (M)	261.9	0.50	0*	3.6–11.8	0.51	145
	SGB (F)	286.7	0.44	0*	2.3–17.0	0.22	279
	SGB (M)	257.0	0.52	0*	2.9–12.4	0.29	89
	All locations (F)	297.2	0.33	−0.89	0.2–17.0	0.92	684
	All locations (M)	257.4	0.40	−0.97	0.2–12.4	0.62	404
<i>M. elongatus</i>	LM (F)	368.8	0.60	0*	1.8–12.7	0.69	230
	LM (M)	299.7	0.77	0*	1.9–8.7	0.62	18
	SGB (F)	343.6	0.52	0*	1.1–11.7	0.73	405
	SGB (M)	279.7	0.82	0*	1.0–10.5	0.63	101
	All locations (F)	354.7	0.48	−0.13	0.4–11.0	0.81	653
	All locations (M)	282.4	0.74	−0.01	0.4–10.7	0.92	137

$L_F$ , fork length;  $K$ , growth coefficient;  $L_{F\infty}$ , maximum  $L_F$ ; F, female; M, male; 0\*, the model was constrained to pass through 0 mm  $L_F$  at 0 years of age.

TABLE II. Estimates of the instantaneous rate of total mortality ( $Z$ ), natural mortality ( $M$ ), fishing mortality ( $F$ ) and exploitation rate ( $E$ ) for *Liza argentea* and *Myxus elongatus* collected from Lake Macquarie (LM) and SGB. Estimates of  $M$  were made using the methods of Hoenig (1983) and Pauly (1980)

Population	Z(age-range used, years)	$r^2(Z)$	$M$ (Hoenig)	$M$ (Pauly)	$F$	$E$
<i>L. argentea</i> (LM)	0.61 (6–13)	0.89	0.29	0.37	0.24–0.32	0.39–0.52
<i>L. argentea</i> (SGB)	0.56 (7–13)	0.84	0.26	0.35	0.21–0.30	0.38–0.54
<i>M. elongatus</i> (LM)	0.94 (7–10)	0.85	0.37	0.51	0.43–0.57	0.46–0.61
<i>M. elongatus</i> (SGB)	0.92 (6–11)	0.95	0.40	0.49	0.43–0.52	0.47–0.57

seasons (*L. argentea* up to 9 months and *M. elongatus* up to 5 months; Kendall & Gray, 2008), and based on studies of mugilids and other species (*M. cephalus*, *Rhabdosargus sarba* Forsskal) in this region (Smith & Deguara, 2003; Hughes *et al.*, 2008), it is hypothesized that individuals born during the austral autumn and winter (March to July) deposit their first opaque growth zone at 13–19 months of age. Counts of daily increments on otoliths of small fishes would be useful to improve the estimates of early growth and the actual age when the first opaque zone is formed from fishes spawned at different times.

The marginal increment analyses for *L. argentea* and *M. elongatus* showed patterns consistent with annual increment formation. Opaque zones near the otolith edge were generally first visible between October and March, which is similar to that observed for a range of other species of fishes, including *M. cephalus* (Smith & Deguara, 2003), *Hyporhamphus australis* Steindachner and *Hyporhamphus*

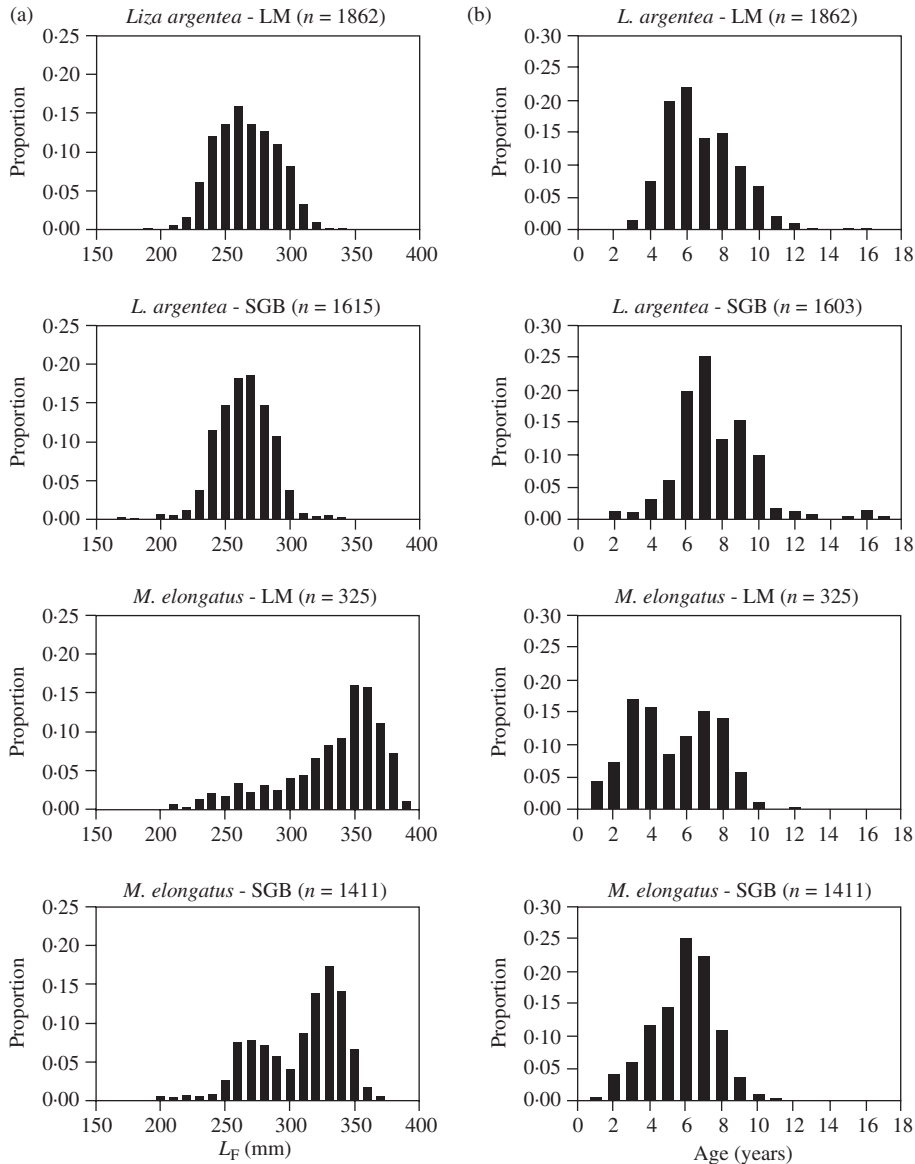


FIG. 6. (a) Fork-length ( $L_F$ ) and (b) age-class compositions of *Liza argentea* and *Myxus elongatus* sampled from LM and SGB with multimesh gillnets of stretched mesh sizes from 36 to 102 mm.

*regularis ardelio* (Whitley) (Stewart & Hughes, 2007) and *R. sarba* (Hughes *et al.*, 2008) from south-eastern Australia.

The information on the visibility and timing of newly formed opaque zones, combined with an estimated birth date (Kendall & Gray, 2008), allowed the development of a model that converted counts of opaque zones of each species into age estimates based on years and months. Because populations of both species in estuaries are likely to be a mix of fishes spawned at different times, it is acknowledged that

having one birth date for an entire population will result in some under and over estimation of the true age of some fishes by several months. This is a common problem in such studies, but allows for more accurate modelling of growth (Fowler & Short, 1998; Campana, 2001).

Both *L. argentea* and *M. elongatus* are relatively long-lived for mugilids, particularly *L. argentea*, which attained a maximum age of 17 years. Studies on other mugilids rarely report individuals older than 8 years of age (Quignard & Farrugio, 1981; Ibañez-Aguirre *et al.*, 1999; Hotos, 2003). The relative longevity of *L. argentea* and *M. elongatus* potentially demonstrates differences in the life-history characteristics among mugilids, but it could also be attributable to a plethora of environmental and anthropogenic interactions, such as fishing. Alternatively, it potentially reflects that many mugilids have been under-aged in past studies because they have been based on the interpretation of growth zones on scales (Quignard & Farrugio, 1981; Beamish & McFarlane, 1983; Hotos, 2003).

Females reached a greater  $L_{F\infty}$  and age than males for both species, which is common for mugilids (Quignard & Farrugio, 1981). As fecundity increases with length, and assuming that each female *L. argentea* and *M. elongatus* spawns more than once, the increased overall size and longevity of females would enhance their potential total reproductive output (Kendall & Gray, 2008).

The growth of *L. argentea* and *M. elongatus* differed between estuaries with fishes from LM having a greater mean  $L_F$  at age compared with those from SGB. Spatial variation in the rates of growth of other mugilids is common (Thompson *et al.*, 1991; Ibañez-Aguirre *et al.*, 1999; Kraïem *et al.*, 2001; Curtis & Shima, 2005) as fish growth is influenced by a complex combination of biotic and abiotic factors (Quignard & Farrugio, 1981). Although such determining factors could not be isolated here, water temperature may be important, as water temperatures were greater in LM than in SGB year-round by approximately 1.5° C.

#### FORK LENGTH, AGE-CLASS COMPOSITION AND MORTALITY

The multimesh gillnets sampled a wide  $L_F$  range of individuals of both species. Most individuals were caught in the middle mesh sizes and mesh selectivity did not restrict the sampling of larger and older individuals. It is acknowledged that very small and young individuals (<20 cm  $L_F$ ) were underestimated in samples. It is therefore assumed that these samples were representative of the population structures of both species in both estuaries, except that of small individuals. The  $L_F$  compositions of samples of both species were similar to those obtained from surveys of recreational catches (Steffe *et al.*, 2005).

The age-class compositions of *L. argentea* and *M. elongatus* in both estuaries included greater proportions of older fishes than generally reported for other exploited mugilid populations, including populations of *M. cephalus* in eastern Australia (Bell *et al.*, 2005) and populations of *Liza aurata* (Risso), *Liza grandisquamis* (Valenciennes), *Liza saliens* (Risso), *M. cephalus* and *Mugil curema* Valenciennes elsewhere (Su & Kawasaki, 1995; Njoku & Ezeibekwe, 1996; Cardona, 1999; Ibañez-Aguirre *et al.*, 1999; Hotos, 2003; McDonough *et al.*, 2005). Although it is not possible to ascertain the causative factors of such observed differences, a contributing factor would be quantities of harvest; for example, c. 3700 t of *M. cephalus* compared with

140 t of *M. elongatus* and 60 t of *L. argentea* are harvested annually by commercial fishers in NSW (Scandol *et al.*, 2008). Despite the differences in the reported age compositions of harvested mugilid populations, the estimates of  $Z$  for *M. elongatus* (0.92–0.94) were similar to values reported for *M. cephalus* from the same coastline (0.95; Bell *et al.*, 2005) and studies elsewhere on *M. cephalus* and *L. aurata* (Marquez, 1974; Kraljevic & Dulcic, 1996). In comparison, the estimates of  $Z$  for *L. argentea* (0.56–0.61) were relatively low; this species had lower estimated levels of  $M$  and  $F$ . Despite this, the data suggest that *L. argentea* and *M. elongatus* are being exploited at similar rates.

Harvest strategies, where  $F$  does not exceed  $M$ , have been prescribed for several exploited stocks (Patterson, 1992; Witherell *et al.*, 2000). Depending on the method used to estimate  $M$  (Pauly, 1980; Hoenig, 1983), the estimates of  $E$  for both species were slightly less, or slightly greater, than 0.5. These data together with the findings that the age class compositions of samples of both species contained significant contributions of old fishes indicate that these populations have not been overfished. Should recreational or commercial catches of either species greatly increase, there will be a need to reassess the demographic characteristics of these populations. Future assessments on either species should incorporate more estuaries than examined here so that the potential effects of different harvesting regimes can be tested, and any consequential implications included in fisheries management plans.

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