Biology and Life Structure of Luderick in NSW

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Summary:
Differences in the age, growth and reproductive biology of the herbivorous fish - luderick (*Girella tricuspidata*) - across 3 estuaries (Clarence, Tuggerah and Tuross) in southeastern Australia were investigated. A validated otolith-based ageing procedure was developed by periodically examining the otoliths of wild fish and of captive young-of-the-year. Luderick were aged to 26+ years, but few > 12 years were observed in samples. The von Bertalanffy growth parameters varied between sexes, but these were not consistent across estuaries. Females grew faster and attained a larger maximum length in 2 estuaries, but the opposite was evident in another. The growth modelling indicated that luderick attained a greater maximum length in the Tuross River. Growth was rapid for both sexes until 5 years, after which it slowed. The reading of scales consistently underestimated the age of fish > 5 years. The estimated length at which 50% of individuals attained maturity varied greatly between sexes and estuaries; 218 and 276 for females and 189 and 283 for males in the Clarence and Tuross Rivers respectively. Spawning period varied according to estuary; primarily between June and September in the Clarence River, but between November and February in the Tuross River, indicating that spawning varies with latitude and latter in the year in higher latitudes. Estimated batch fecundity of luderick was length dependent, ranging from approximately 84000 to 444000 eggs for fish 290 to 420 mm FL. Tagged fish moved considerably between estuarine and coastal waters, with most individuals displaying a northward movement into the prevailing coastal currents.
**Background**

Luderick (*Girella tricuspidata*) is a member of the fish Family Girellidae, which are distributed throughout shallow subtropical and temperate waters of the Pacific, Indian and Atlantic Oceans (Yagishita and Nakabo 2000; www.fishbase.org). The family comprises 2 genera, Girella and the monotypic Graus. There are 17 recorded species of Girella; 4 occur in temperate waters of Australia (Miskiewcz and Trnski 1998).

Luderick is primarily a herbivore that inhabits estuaries and nearshore coastal waters along the eastern and southern seaboard of Australia, and around the north island of New Zealand (Anderson 1991; Kailola et al. 1993; Miskiewcz and Trnski 1998). Luderick are often observed in large schools and are important in estuarine and coastal commercial and recreational fisheries (West and Gordon 1994; Gray 2002; Gray and Kennelly 2003; Henry and Lyle 2003), having been exploited in southeastern Australia since at least the 1880’s and probably earlier by indigenous fishers. Despite their history of exploitation, little information exists concerning the age, growth, reproductive biology and movements of the species and how this varies throughout its distribution. Such information is important to assessing the status and potential impacts of fishing and other anthropogenic impacts on populations.

Luderick has a reported maximum length of 710 mm fork length (FL) and 4 kg (Kailola et al. 1993) and has been aged to 24 years (Pollock 1981; Gray et al. 2000), but few > 500 mm FL have been observed in catches in recent years (Gray and Kennelly 2003; Gray et al. 2005; Steffe et al. 2005). The development (Kingsford 1988; Niera et al. 1997; Miskiewcz and Trnski 1998) and coastal distributions of larval and pre-settlement staged juveniles (Kingsford 1988; Gray and Miskiewicz 2000), along with the distributions and habitat associations (Bell et al. 1984; Middleton et al. 1984) and growth of young-of-the-year (Worthington et al. 1992; Smith and Sinerchia 2004) have been described for populations in New South Wales (NSW), the middle of their east Australian distribution. Growth of luderick based on scales has been described (Pollock 1981), but there have been no reported studies on the species reproductive biology. There is clearly a need for better quantitative information concerning the biology and ecology of luderick to assist with the development of management options for the species.

The aim of this study was to redress the lack of biological information on luderick in NSW. The specific objectives were to: (1) develop a validated ageing protocol, (2) use this protocol to compare length-at-age and growth between sexes and populations in different estuaries, and (3) investigate length and age at maturity and the seasonality of spawning. Large-scale movements of the species along the south-eastern seaboard of Australia are also documented.

**Materials and Methods**

**Sampling**

Luderick were sampled from the Clarence River, Tuggerah Lake and the Tuross River on a regular basis (generally monthly) between August 2003 and July 2005. Fish from the Clarence River and Tuggerah Lake were obtained from commercial catches, primarily gillnets (80 mm stretched mesh), whereas fish from the Tuross River were collected using research gillnets (50mm to 100mm stretched mesh) and a 140m beach-
seine with 25mm mesh. Most samples in the Tuross River were obtained from the beach seine as it captured small juveniles to large adults.

For each sampled fish, the total and fork length (FL) (mm) and total weight (0.1g) were determined. The sagittal otoliths, and several scales taken from directly behind the pectoral fin, were removed and stored in envelopes. The sex and reproductive stage (see Table 1) of each fish was determined macroscopically and the gonads removed and weighed (nearest 0.1g). A sample of the gonad tissue was kept from all females for determining mode of spawning and estimating batch fecundity. The liver was removed and weighed (nearest 0.1g), and the quantity of fat surrounding the intestine was assessed qualitatively.

**Age estimation - otoliths and scales**
Sectioned sagittal otoliths and whole scales were used to estimate the age of luderick. Otoliths were cleaned, dried, weighed, and one embedded in resin so that a thin (300 µm) transverse section could be made through the core perpendicular to the long axis. Sections were mounted on slides and viewed under a stereomicroscope, at 25x magnification, with reflected light against a black background. Sections generally displayed alternating bands of narrow opaque and broad translucent zones and counts of completed opaque bands along a radius from the core to the outer edge of the ventral lobe were made. All otoliths were read without knowledge of sampled details (i.e. length, sex, location and date of capture) and 25% of otoliths were drawn at random from each estuary and re-read by the same reader to assess within-reader variation in counts of opaque zones. The precision (repeatability) of counts of opaque zones was determined using the coefficient of variation (CV) and age bias plots (Campana 2001).

Scales were cleaned, dried and viewed under a stereomicroscope at 6x magnification, with reflected light against a black background. Each scale taken from each fish was examined briefly, and the most readable scale was selected for further examination. Scales generally displayed alternating thin opaque and broad translucent bands and counts of the opaque bands were used to estimate age. A total of 113 fish were excluded from analyses of scale ageing, as no suitable scales were available (i.e. only regenerated or deformed scales were collected). Within-reader variability in interpreting scale structure was determined by re-reading 25% of the Tuross River samples.

Growth was modelled separately for each sex in each estuary using length-at-age data from sectioned otoliths using the Von Bertalanffy growth function.

**Identification of first opaque zone on otoliths**
The position and timing of deposition of the first opaque zone on otoliths was determined by keeping young-of-the-year fish in an aquaria facility. Twenty five juveniles (20 – 80 mm FL) were captured in Botany Bay in March 2005, transferred and housed in a 5000 litre tank at the Cronulla Fisheries Research Centre. Fish were fed high protein fish pellets once a day and maintained at ambient water and air temperatures (water is pumped directly from the Port Hacking River), and exposed to natural diurnal cycles. Five fish were captured, euthanized and their otoliths dissected every three months between September 2005 and December 2006. One otolith from each pair was processed for age estimation as described above. The distance from the otolith core to the otolith edge and to the first opaque zone was measured using a
microscope mounted camera interfaced with an image processing computer. All measurements were done on the outer side of the sulcus, on the ventral lobe.

**Marginal Increment Analysis**

The periodicity of formation of opaque zones on otoliths was determined by marginal increment analysis on fish collected from Tuggerah Lake and the Clarence and Tuross Rivers. A subset of otoliths (at least 20 from each month) was selected at random and the otolith margins were determined to be either opaque or translucent, and the distance between each opaque band was measured using a digital imaging processor. Measurements were made along the ventral margin of the sulcus acusticus, and the last increment (opaque band to edge) was calculated as a proportion of the second last increment, to provide the value of the marginal increment. The mean marginal increment was then compared between months to determine the periodicity and timing of formation of opaque bands.

**Reproductive period**

The timing of reproduction was investigated by assessing changes in the Gonadosomatic Index (GSI) and the macroscopic staging of male and female gonads. Macroscopic staging of gonads followed the criteria detailed in Scott and Pankhurst (1992) (Table 1). The GSI was calculated for all fish using the formula: GSI = Wg / WT x 100; where Wg is the gonad weight and WT is the total fish weight.

**Length and age at maturity**

The length and age at which 50% of the population attained sexual maturity was determined by fitting a logistic curve to the proportions of mature and immature fish per 1mm length class, and for each age class, for each sex in each estuary. This was done for fish caught only during the identified spawning season.

**Mode of spawning and batch fecundity**

Patterns of oocyte development and mode of spawning were determined by examining the ovaries of 10 fish chosen at random that had different staged ovaries. Individual oocytes were removed from each gonad and placed in a Petri-dish; 200 oocytes chosen at random were measured (mm) using a digital camera mounted on a dissecting microscope interfaced with a computer installed with image analysis software. Size-frequency plots of oocyte diameters were produced for each stage.

Estimates of batch fecundity were made by counting the number of hydrated eggs present in sub-samples of female gonad tissue determined stage IV (i.e. contained hydrated eggs). Each of four sub-samples was blotted, weighed and aspirated in alcohol to separate the hydrated eggs from the ovary tissue. The number of hydrated eggs in each sub-sample was made and the batch fecundity for each fish was calculated by multiplying the number of eggs per total sub-sample weight by the total gonad weight.

**Movements**

Between 1990 and 1995 luderick in 9 estuaries scattered along the NSW coast were captured in beach-seine nets, tagged with a plastic T-bar type tag on dorsal area and released (Table 2). The tag-release project was highly publicised and fishers were offered rewards upon return of the tagged fish and information on where and when it was recaptured. The extent of movements between point of release and subsequent capture were plotted on maps.
Table 1. Macroscopic appearance and corresponding histological condition used to stage luderick gonads. (Adapted from Scott and Pankhurst 1992).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Classification</th>
<th>Macroscopic appearance</th>
<th>Histological characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Immature</td>
<td>Ovary clear threads, pink in colour</td>
<td>Previtellogenic oocytes</td>
</tr>
<tr>
<td>2</td>
<td>Regressed</td>
<td>Ovary small clear and pink in colour</td>
<td>Cortical alveoli stage oocytes appear</td>
</tr>
<tr>
<td>3</td>
<td>Vitellogenic</td>
<td>Ovary colour orange, opaque oocytes visible through epithelium</td>
<td>Oocytes in exogenous vitellogenesis</td>
</tr>
<tr>
<td>4</td>
<td>Hydrated</td>
<td>Ovary with hydrated oocytes visible through epithelium</td>
<td>Final oocyte maturation and hydration</td>
</tr>
<tr>
<td>5</td>
<td>Ovulated</td>
<td>Eggs in the oviduct which can be extruded with gentle pressure</td>
<td>Hydrated oocytes in the oviduct and/or in the tissue and post-ovulatory follicles present</td>
</tr>
<tr>
<td>6</td>
<td>Spent</td>
<td>Ovary bloody and flaccid</td>
<td>Atretic vitellogenic oocytes but predominantly previtellogenic oocytes present</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage</th>
<th>Classification</th>
<th>Macroscopic appearance</th>
<th>Histological characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Immature</td>
<td>Testis white threads</td>
<td>Spermatogonia</td>
</tr>
<tr>
<td>2</td>
<td>Spermatogenic</td>
<td>Testis firm and ivory white in colour</td>
<td>Secondary spermatocytes and spermatozoa present</td>
</tr>
<tr>
<td>3</td>
<td>Partially spermiated</td>
<td>Testis firm, ivory white in colour with viscous milt in spermduct</td>
<td>Spermatozoa predominate</td>
</tr>
<tr>
<td>4</td>
<td>Fully spermiated</td>
<td>Testis firm, ivory white in colour with free flowing milt in spermduct</td>
<td>Spermatozoa predominate</td>
</tr>
<tr>
<td>5</td>
<td>Spent</td>
<td>Testis grey to bloody in colour and flaccid</td>
<td>Residual spermatozoa, reduced spermatocytes and increased connective tissue</td>
</tr>
</tbody>
</table>

Results

A total of 2571 luderick were collected for biological examination; 799 in the Clarence River, 770 in Tuggerah Lakes and 946 in the Tuross River.

Precision of age estimation (and comparison between otoliths and scales)
The within-reader agreement for counting opaque zones on sectioned otoliths was 93.4% for +/- 1 count and the corresponding CV value was 10.6. The within-reader variation for scale interpretation was 90.1% for +/- 1 count and the CV value was 12.8.

The comparison of age estimation between sectioned otoliths and scales showed similar values for fish aged ≤ 5 years, after which the agreement between otoliths and scales decreased (Fig. 1). The maximum discrepancy between age estimation from otoliths and scales was 8 years, and this was for fish aged 16 years based on otoliths (Fig. 1). Based on the assumption that otoliths provided a more accurate estimate of age, scales consistently underestimated the age of fish > 5 years.
Figure 1. Relationship between the estimated ages of luderick from sectioned otoliths and whole scales. Straight line shows 1:1 relationship.

Validation of age estimation (opaque zone formation)

Juvenile fish held in captivity were first sampled in September 2005 and all 5 fish displayed a newly deposited opaque zone on otoliths. No further opaque zones were observed in fish sampled between December and June. A second opaque zone was visible on the remaining 5 fish sampled in December 2006. These observations indicate that the first opaque zone was formed between July and September. The distance from the otolith core to the first opaque zone was 0.36 (± 0.04 S.D.) mm.

The marginal increment analysis identified that 1 opaque and 1 translucent zone was deposited annually, but the timing of the formation of the opaque zone differed slightly between estuaries and years (Fig 2). The marginal increment was lowest in January/February in samples from the Clarence River and Tuggerah Lake, whereas it was least in March 2004 but January in 2005 in the Tuross River. These trends were not clear in all age classes due to low sample sizes (data not shown for brevity). Nevertheless, in all estuaries and for all age classes, the marginal increment decreased from October, identifying that newly deposited opaque zones are first visible in spring/summer and that this pattern is repeated throughout the life of a fish.
Figure 2. Changes in the mean marginal increment (+ 1 SE) for luderick (pooled across ages) in the Clarence and Tuross Rivers.

Length-at-age and growth

The length of luderick at any given age varied considerably within and between estuaries (Fig. 3). For example, a fish aged 4 years ranged between 230 and 380 mm FL. The oldest and largest fish sampled was a 26 year old female (426mm FL) from the Tuross River. Few fish > 12 years were sampled and most were 3-10 years.

The von Bertalanffy growth parameters differed slightly between males and females in each estuary; females grew faster and attained a greater maximum length in the Clarence and Tuross Rivers, but the opposite was evident in Tuggerah Lake (Fig. 3). Growth also differed between estuaries for fish of the same sex, with the the von Bertalanffy growth parameters indicating that males and females attained an overall greater maximum length in the Tuross River (Fig. 3).

Reproductive period

The mean GSI peaked between June and September for males and females in the Clarence River, but between November and February in the Tuross River (Fig. 4). The GSI values changed little throughout the year for samples collected in Tuggerah Lakes, although a very small rise in mean GSI was evident in August and September 2003 and in August 2004 (Fig. 4). The highest mean GSI for females was 8.62 in the Clarence River, 7.18 in the Tuross River, but only 1.83 in Tuggerah Lakes (Fig. 4). The macroscopic staging of gonads identified that the greatest percentage of mature fish (stage IV to stage VI) occurred between May and October in the Clarence River and between October and March in the Tuross River (Fig. 5). Very few mature fish were sampled in Tuggerah Lake in any month.
Figure 3. Von Bertalanffy growth curves for male and female luderick in the Clarence River, Tuggerah Lakes and Tuross River.
Figure 4. Changes in mean monthly Gonadosomatic Indices for male and female luderick in the Clarence River, Tuggerah Lakes and Tuross River.
**Figure 5.** The proportion of macroscopically assigned gonad stages for female luderick in the Clarence River, Tuggerah Lakes and Tuross River.
**Length at maturity**

The length at which 50% of individuals attained sexual maturity was estimated to be 218 mm for females and 189 mm for males in the Clarence River, and 276 mm for females and 283 mm for males in the Tuross River (Fig. 6). No sensible estimates could be made for fish in Tuggerah Lake because of the lack of mature fish in samples.

![Figure 6](image-url)  
**Figure 6.** Logistic curves showing estimated length at 50% sexual maturity for male and female luderick in the Clarence and Tuross Rivers.
*Estimates of batch fecundity*

Estimates of batch fecundity ranged between approximately 64000 to 834000 eggs for fish between 290 and 420 mm FL (450 to 1300 g total weight) respectively. There was a positive correlation between relative batch fecundity and FL and between relative batch fecundity and total weight (Fig. 7), although the $r^2$ values were low (0.19 and 0.34 respectively).

**Figure 7.** Relationship between relative batch fecundity and total weight and fork length of luderick, based of fish with Stage IV ovaries with hydrated oocytes.
**Movements**

A total of 6874 luderick were tagged and released, of which 1030 (15%) were reported to be recaptured (Table 2). Most luderick were recaptured in the estuary of release and most of these were within 6 months of tagging. Of the fish that were recaptured external to the estuary of release, all but 5 were recaptured in an estuary or coastal zone north of the original estuary (Fig. 8).

**Table 2.** The number of luderick tagged in each estuary between 1990 and 1995.

<table>
<thead>
<tr>
<th>Estuary</th>
<th>No. Tagged</th>
<th>No. Recaptured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richmond</td>
<td>845</td>
<td></td>
</tr>
<tr>
<td>Clarence</td>
<td>907</td>
<td></td>
</tr>
<tr>
<td>Bellinger/Kalang</td>
<td>597</td>
<td></td>
</tr>
<tr>
<td>Nambucca</td>
<td>1115</td>
<td></td>
</tr>
<tr>
<td>Macleay</td>
<td>742</td>
<td></td>
</tr>
<tr>
<td>Shoalhaven</td>
<td>813</td>
<td></td>
</tr>
<tr>
<td>St Georges Basin</td>
<td>389</td>
<td></td>
</tr>
<tr>
<td>Conjola</td>
<td>763</td>
<td></td>
</tr>
<tr>
<td>Burrill</td>
<td>703</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6874</strong></td>
<td><strong>1030 (15%)</strong></td>
</tr>
</tbody>
</table>
**Figure 8.** Movement of tagged luderick showing recaptures in estuaries. Numbers adjacent to estuary names indicate number of fish tagged and recaptured within that estuary.
Discussion

**Ageing**

This study showed that compared to sectioned otoliths, scales were harder and less precise to interpret, and consistently underestimated the ages of luderick > 5 years old. These results concur with the general paradigm that for most species of fish, sectioned otoliths provide a more accurate estimate of age than scales, particularly for larger and older individuals (Casselman 1990; Campana 2001). We therefore assume that previous scale-based ageing of luderick by Pollock (1981) underestimated the true ages of fish.

The first opaque zone on the otoliths of captive young-of-the-year fish was first visible between August and December, when these captive fish were approximately 12-15 months old. The 1st opaque zone therefore forms over winter/early spring, which is in general agreement with that observed in similar validation studies of young-of-the-year of other species of fish in southeastern Australia (see age validation final report). The actual timing of formation of the 1st opaque zone, and the actual age of fish at that time, may vary, however, among individuals according to location (latitude) along the coast, due to variation in timing of spawning, subsequent recruitment and water temperatures (see below). Future validation studies need to account for such variation and should not just be done in one place and time and based on one spawning cohort. Such validation studies should also follow wild caught fish in different places (Campana 2001).

The marginal increment analyses indicated that 1 opaque zone formed annually on otoliths, validating our counts as annuli. The time of opaque zone formation varied between estuaries, leading us to hypothesise that there may be a latitudinal gradient in the timing of opaque zone formation. The consistency of this would need to be tested over longer periods.

The timing of opaque zone formation also differed to that reported by Pollock (1981) based on scale readings. Here, opaque zones were first observed in the otoliths of some fish in January in all 3 estuaries. Some variation was evident between estuaries, which may be related to differences in water temperature. Nevertheless, this general summer/autumn timing of opaque zones being visible on otoliths is slightly later in the year than generally observed for many other species of fish (spring/summer) in southeastern Australia (Stewart and Hughes 2007). This could be related to differences in the physiology and biochemistry of the herbivorous luderick compared to other non-herbivorous species. Alternatively, it may also be related to the fact that the otoliths of luderick are generally harder to interpret than many other species, and therefore the new growth zones are not identified as easily and as early as the other species.

**Growth**

The growth of luderick modelled using the von Bertalanffy growth function differed between sexes and estuaries. Differences in growth modelling between sexes or estuaries were not consistent, with males attaining a greater maximum length and mean length-at-age in Tuggerah Lakes but not in the other estuaries. The greatest estimated maximum length for males and females was observed in the Tuross River, indicating that the fish in this river are likely to grow the largest. In contrast, the greatest growth rate was observed in Tuggerah Lakes. Overall, growth of males and females was relatively rapid until approximately 5 years of age, after which it slowed. There was
considerable variation in the length-at-age of male and female luderick, which is not uncommon in estuarine and coastal fish (Gray et al. 2000; Stewart and Hughes 2007).

It is reasonable to conclude that the observed large variation in length-at-age of luderick is partly due to the extended spawning periods within the luderick distribution which potentially provides recruitment of juveniles to the stock throughout nine months of the year. Further, the movements of individuals among populations may blur specific estuary-to-estuary growth differences.

Reproduction
The timing of high GSI values varied greatly between estuaries; June to September in the Clarence River and November to February in the Tuross River. This suggests that the timing of spawning is delayed along a latitudinal gradient within the range of luderick. Latitudinal/longitudinal variations in reproduction are common in widely distributed fish species (Stewart and Hughes 2007) and are generally related to variations in water temperatures. Spawning of luderick can occur over at least 8 months in NSW, thereby supplying juveniles to populations over a wide time period. Planktonic larvae of luderick have been captured in coastal and estuarine waters of central NSW between September and January (Miskiewicz 1987, Gray 1995) and small post-settlement juveniles have been sampled in estuaries between June and April (Gray et al. 2000; Worthington et al. 1992; Smith and Sinerchia 2004).

Luderick in spawning condition were caught only in the immediate vicinity of the estuary mouth in both the Clarence and Tuross Rivers. No fish in spawning condition were sampled in Tuggerah Lake and this may because most samples came from within the lake and not near the entrance. Although luderick in spawning condition may be capable of moving out of each estuary to spawn, the data indicate that luderick potentially spawn in the marine dominated lower reaches of estuaries. We did not sample luderick in the coastal zone so we can not confirm this as an actual spawning location. It is presumed, however, that luderick spawn in the immediate nearshore zone of coastal waters near estuaries.

The estimated mean length at maturity for males and females was considerably smaller in the Clarence River compared to the Tuross River. Again, this may be related to water temperatures, which are on average greater in the Clarence River compared to the Tuross River. The estimated mean length at maturity was greater for females than males in the Clarence River, but the opposite was evident for samples in the Tuross River. The reasons for such observations are not identifiable, but may be artefacts of the composition of samples.

Estimates of fecundity of luderick were positively related to length; this is common as larger fish generally can produce and carry more eggs (Beverton 1992). There was no evidence of decreasing fecundity in the largest individuals as observed in some other fish species.

Movements
Although there is no information on the genetic stock structure of luderick in Australian waters, the tag-recapture data show that there is considerable mixing of individuals between estuaries and coastal waters. Most individuals travelled in a north direction into the prevailing southward flowing East Australian Current. Some movements may be
related to spawning, as it is hypothesised that some luderick migrate out of estuaries to spawn in the nearshore coastal zone.

Conclusions
This study has provided new information on luderick; a common and important fish inhabitant of estuaries and nearshore coastal waters of NSW. The current exploitation status of the luderick stock in NSW is moderately fished (Scandol et al. 2008). The information collected here will help aid future assessments of luderick by filling important knowledge gaps concerning its biology and ecology.

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