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Age and growth of slender tuna (*Allothunnus fallai*) in an unexploited temperate population

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Abstract

Many large predatory fishes are in decline and tuna sustainability is high on the global agenda. Slender tuna (SLT), *Allothunnus fallai*, is data-poor and a rare contemporary example of a globally unexploited temperate tuna. This study analysed 214 otoliths for age and growth of fish collected in the South Atlantic. Observed ages varied between 9 and 42 years for a size range of 68–90 cm fork length. We reveal important life history data for SLT before exploitation and underline the relevance of data-poor stocks in understanding wider questions for exploited tuna.

KEYWORDS

baseline data, life history, longevity, scombridae, temperate, tuna

The depletion of large predatory fishes (Myers & Worm, 2003) emphasizes the importance of sustainable exploitation of tuna (Polacheck, 2006). Although life history parameters are known for many commercial fishes, fishing has often occurred prior to scientific investigation for many stocks and areas (Myers & Worm, 2003) and true "baseline data" are unknown (Pauly, 1995). Biological information on unexploited tuna populations is particularly rare (Block *et al*., 2001; Mather *et al*., 1995).

At present, virtually all tuna stocks in the world are close to being fully exploited or overexploited (Miyake *et al*., 2010). Temperate tunas' slow growth in the adult phase and long lifespans mean that they are particularly vulnerable to overexploitation (Fromentin & Fonteneau, 2001). Insight into baseline data will benefit exploration of alternative temperate tuna resources (Majkowski, 2007) or stock restoration (Myers & Worm, 2003) and contribute to sustainable future of temperate tunas.

Slender tuna (SLT), *Allothunnus fallai* Serventy, 1948, is a rare contemporary example of a globally unexploited species and a practically virgin tuna stock in the South Atlantic. SLT is found in the temperate Southern Ocean (Graham & Dickson, 2004). While similarly sized skipjack (SKJ, *Katsuwonus pelamis*) make up a large proportion of global catches (Miyake *et al*., 2010; Restrepo *et al*., 2016), SLT has a low commercial value due to its relatively low meat quality, which is grey (Collette & Nauen, 1983) with a high lipid content (9.7–50.1%) (Bishop *et al*., 1976). In addition, variability in abundance globally is not well documented (Collette & Graves, 2019; Collette & Nauen, 1983) and SLT is rarely caught in modern fisheries (Sepulveda *et al*., 2008). At present, SLT appears as a bycatch in low quantities by bottom trawlers in the South Atlantic and sporadically in the Japanese tuna longline fishery (Majkowski, 2007).

SLT reported annual catches in the Falkland Island Conservation Zone (FICZ) in 2016 (20 t) and 2017 (8 t) were higher than the global FAO reported catches (6–15 t) between 2002 and 2006 (FAO, 2009, Collette *et al*., 2011). The semi-regular appearance of small quantities as bycatch together with anecdotal evidence of large surface schools of SLT in coastal areas in the Falkland Islands suggest that there may be a local abundance. In the past, substantial quantities were caught by purse-seiners in Tasman waters, indicating that SLT were more abundant than previously assumed (Wolfe & Webb, 1975). Given most tuna stocks are nearly fully exploited or overexploited (Miyake *et al*., 2010), there may be potential to develop small tuna targeted fishery such as SLT in the South Atlantic as an alternative to fully exploited temperate tuna stocks (Majkowski, 2007).

SLT remains data poor (Collette *et al*., 2011; Restrepo *et al*., 2016), which is a common issue for small tuna stock assessments (ICCAT, 2018). Information on SLT's life history parameters will aid future sustainable exploitation of the species (Restrepo *et al*., 2016). While some previous studies have discussed diet, migration and spawning (Collette & Díaz de Astarloa, 2008; Wolfe &

Webb, 1975; Yatsu, 1995), this study aims to explore key life history parameters such as age and growth of this species.

SLT were sampled as bycatch in the bottom trawl shelf fishery targeting Patagonian squid *Doryteuthis gahi* and various demersal finfish, primarily to the south-east of the Falkland Islands. Biometric data recorded included fork length (FL) (± 1 cm), identification of sex (M/F) and maturity stages (1–8). For a small number of samples total length (TL) was recorded, which was converted to FL with a regression (Equation 1) calculated using Falkland Island Fisheries Department (FIFD) observer data. Between January and May 2016 and 2017, otoliths were collected from 193 fish and stored in Eppendorf vials in 96% ethanol. Additionally, 21 otoliths were added from the FIFD archive collection, sampled in February 2010, May 2011 and January–December 2015.

$$\left(\mathrm{FL}=0.9015\times\mathrm{TL}+2.2065, R^2=0.9137\right) \tag{1}$$

Otoliths were embedded in DMS 660 Amber fillable casting resin activated by a methyl ethyl ketone peroxide catalyst. The blocks were sectioned along the otoliths' dorsal-ventral axis to obtain sections ~0.3–0.4 mm thick, using a Buehler Isomet Low speed saw (~0.25 mm blade). Sections were mounted on microscopic slides using clear casting resin activated with the same catalyst.

Otoliths were read using a compound microscope Olympus BX51 under 100× magnification (Figure 1). SLT otoliths displayed opaque bands that were assumed to represent annual growth rings, which resembled annuli in other temperate tuna otoliths (Gunn *et al*., 2008; Hurley & Iles, 1983; Neilson & Campana, 2008; Shimose *et al*., 2009).

Growth parameters were identified by fitting a von Bertalanffy Growth Model (VBGM) to age at length data, with a constrained t_0 value (hence "0" in equations) (Equation 2). This provided VBGM parameters for the population before a sex effect was added (Equation 3). The model was refitted to allow stable estimation (Kimura, 2008). All statistical analyses were completed using R and VBGM with the FSA package (Ogle *et al*., 2019).

$$\mathrm{FL}=L_\infty\times\left(1-e^{(-K*(t-0))}\right) \tag{2}$$

$$\mathrm{FL}=L_\infty(\mathrm{sex})\times\left(1-e^{(-K(\mathrm{sex})*(t-0))}\right) \tag{3}$$

The precision between the first author (n = 214) and the subsample read by the second author (n = 93) was better than recommended by Campana (2001). The average percentage error (APE) was 2.49 and the average coefficient of variation (ACV) was 3.52%. Ages ranged from 9 to 42 years with a mean of 22 years for a size range between 68 and 90 cm FL. The age composition of the catch showed that 95% of the fished population were aged between 13 and 31 years. Males had a greater age range (9–42 years) and smaller size range (68–85 cm FL) than females (12–34 years and 71–90 cm FL, respectively). However, the 5% and 95% percentiles of these parameters were similar in both sexes.

The original fit of VBGM provided a negative t_0 value of approximately −5 years, mainly due to the lack of small-sized juvenile fish, therefore the VBGM was forced through the origin by constraining t_0 = 0 in the model. The VBGM curve plateaued at a value close to

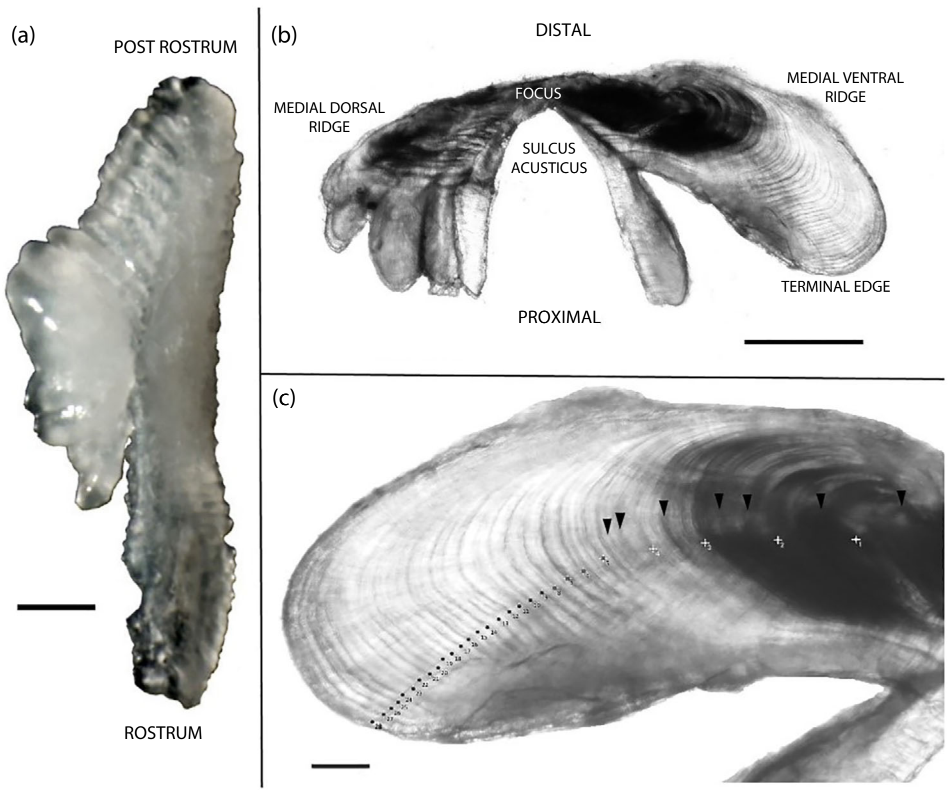
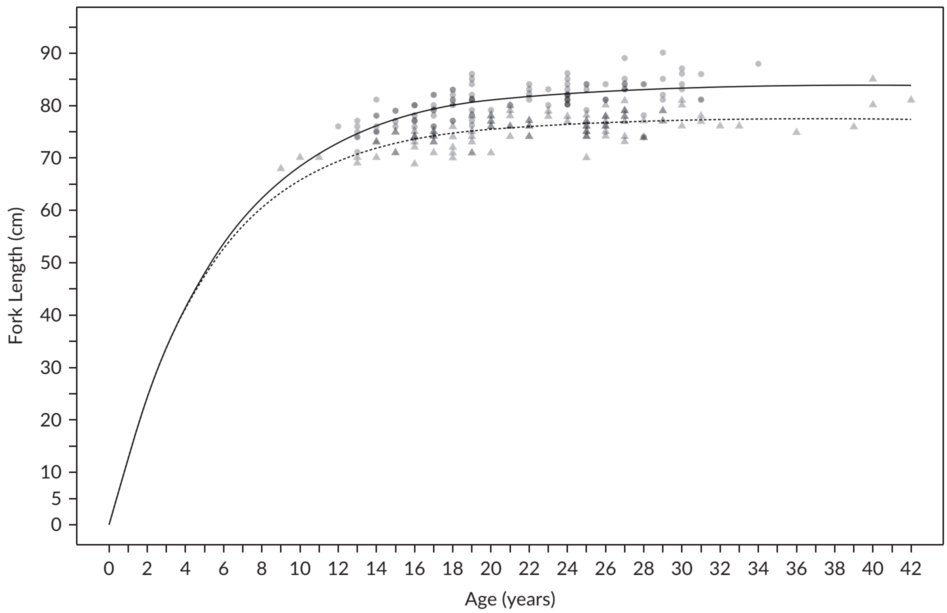


FIGURE 1 (a) Whole right otolith of SLT (*Allothunnus fallai*) (77 cm FL, distal view) (scale bar: 1 mm), (b) section of the same otolith (scale bar: 0.5 mm) and (c) otolith microstructure of the same otolith showing 28* marked annuli (first transition zone (*white*; 1-4 years); second (*grey*; 5-8 years) third (*black*; 9 + years). Triangle symbols shows diffractive optical effects that appear as growth rings due to out-of-focus position of that area during photographing and hence not counted) (scale bar: 0.1 mm). *A year was added to all age estimations to account for the margin (i.e. distance between last growth ring and edge). Thus, for this otolith the growth rings (28 years) plus margin equals 29 years

FIGURE 2 Relationship between SLT (*Allothunnus fallai*) FL and age with fitted VBGM with sex effect (Equation 3), for females (●, solid line) and males (▲, dashed line). Table of VBGM parameters supplied for both Equation 3 (sex effect) and 2 (combined).



	L∞	Standard Error	K	Standard Error	t0 (constrained)
Female	83.8*	0.48	0.171	0.0071	0
Male	77.4*	0.37	0.190	0.0089	0
Combined	80.0	0.43	0.192	0.0095	0

the age of 20–23 years for both sexes (Figure 2). SLT showed significant sexual difference between VBGMs, which was linked to size. Step-by-step likelihood ratio tests revealed that the significant result was due to L_∞ values (chi-squared = 163.82, $P < 0.001$). The female L_∞ value was 6.34 cm greater than that of males. There was no significant difference in K values between the sexes.

Previous age estimations for SLT were 4–6 years based on a small sample size of 39 individuals (Wolfe & Webb, 1975) and longevity was previously documented as <11 years based on a correlation using maximum size (Juan-Jordá *et al*., 2013). Our results showed that SLT in the South Atlantic may live up to 42 years, much longer than previously thought, which is important for future management.

The absence of any significant exploitation pressure might suggest that SLT could reach a maximum age greater than that of exploited commercial temperate tunas. However, SLT's maximum age is similar to that of exploited temperate species (26–41 years): (Gunn *et al*., 2008; Kalish *et al*., 1996; Neilson & Campana, 2008; Shimose *et al*., 2009). In contrast, Albacore (*Thunnus alalunga*, ALB) had a documented maximum age of 14–15 years (Chen *et al*., 2012; Farley *et al*., 2013; Wells *et al*., 2013), which may be due to a subtropical and temperate classification, whereas Southern bluefin (*T. maccoyii*, SBT) and SLT are classified as temperate (Fromentin & Fonteneau, 2001) and show similar maximum age estimations.

Maturity is another key parameter used in management of modern fisheries (Die, 2006; Schaefer, 2001). The smallest documented mature SLT male was 71.5 cm FL (Collette & Nauen, 1983; Wolfe & Webb, 1975) and although our smallest SLT was 68 cm FL, we assumed that sampled individuals were resting adults during their feeding migration to higher latitudes (Collette & Díaz de Astarloa, 2008; Collette & Nauen, 1983).

The SLT otoliths analysed had an equal sample sex ratio. For tunas, males are normally larger (Juan-Jordá *et al*., 2013; Shimose *et al*., 2009). Specifically, other temperate tuna species such as SBT (Gunn *et al*., 2008) and ALB (Williams *et al*., 2012) have larger males, which could be be linked to natural mortality (Juan-Jordá *et al*., 2013; Schaefer, 1998). However, in contrast, SLT females were significantly larger than males, which reflects the sexual dimorphism of smaller scombrids, such as Spanish mackerels (Juan-Jordá *et al*., 2013).

Our study reveals important life history parameters such as age and growth to support sustainable exploitation of SLT if it were to be developed as an alternative temperate tuna fishery. SLT life history parameters were comparable to other temperate tunas, highlighting the relevance of data-poor or unexploited stocks when considering wider tuna topics, such as interspecific management (King & McFarlane, 2003), restoration of valuable species (Myers & Worm, 2003) and longevity. Future studies should collect samples across a greater size range to provide more robust estimation of age and growth parameters. However, the sporadic distribution and lack of knowledge on global catches paired with a lack of commercial interest in SLT may limit the resources available for such study.

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CONFLICT OF INTEREST

We do not envisage any conflicts of interest to arise from this study.

CONTRIBUTIONS

K.A.B.: conceptualization, formal analysis, visualization, investigation, writing – original draft preparation. A.A.: conceptualization, formal analysis, methodology, supervision, writing – reviewing and editing, funding acquisition, validation.

ETHICAL STATEMENT

There were no live experimental animals used in this study. All sample material was extracted from dead individuals caught in fishing trawls in the Loligo and finfish fisheries.

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