**Age and growth validation of the small spotted grunt *Pomadasys commersonnii* (Lacepède, 1801) from the** **northwestern coast of the Arabian Sea of Oman.**

**Running Title:** Age and growth of small spotted grunt

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**Summary**

Age structure and growth parameters were determined for a population of small spotted grunt, *Pomadasys commersonnii* in the Arabian Sea. Small spotted grunt samples were collected monthly between September 2007 and August 2008 by beam trawl [40 mm cod-end mesh size] surveys conducted along the Arabian Sea coast of Oman from Ras Al-Had in the north to the Oman-Yemen border in the south west of Salalah between latitudes 16o 33' N and 22o 21' N and longitude 53o 09' and 59o 55' E and from depths of 20 to 250 m respectively. Marginal increment analysis of the sagittal otolith confirmed the deposition of annual increments on transverse sections, validating this technique for age and growth studies. Fish size (Fork Length, FL) ranged between 33-78 cm and age of fish ranged between 2 and 14 years with 5-9 year old fish comprising the majority of the catch. Both males and female exhibited asymptotic patterns of growth and the combined growth curve for both sexes provided von Bertalanffy growth (VBG) parameters of *L∞*=77.2 cm FL (≡83.8 cm Total Length), *k* =0.232 y-1 and *t0* =-0.058 y. VBG parameters, derived from Length-Frequency Distribution Analysis (LFA) using ELEFAN1, PROJMAT and SLCA, obtained similar values (average values for the 3 methods: *L∞* = 78.8 cm FL, *k* =0.35 y-1 and *t0* =-0.64 y) to those obtained from otolith analysis. A strong linear relationship was observed between otolith weight and age, and although age residuals ± 4 years was observed between sagittal otolith age and estimated age (depending on sex and otolith weight), the results indicated that otolith weight could be used as a rapid proxy to estimate age and derive VBG parameters. In conclusion, both otolith ageing and LFA methods provided similar *L∞* and *k* values and the average values derived from all 4 methods lies within the auximetric plot for the species providing confidence in the VBG parameters obtained for small spotted grunt in the Arabian Sea.

**1 | Introduction**

The small spotted grunt, *Pomadasys commersonnii* (Lacepède, 1801) is a Haemulid species found in the Western Indian Ocean ranging from the northwest coast of India to southern Oman in the north southwards to the Seychelles, Madagascar and South Africa (Froese & Pauly, 2017) with the Arabian Sea region identified as the northernmost location of a major population for the species (Randall 1995). Throughout its distribution the small spotted grunt comprises an abundant component of the fish fauna occurring in estuaries and inshore coastal waters, and can even tolerate fresh water (Whitfield et al., 1981). Small spotted grunt feed primarily on benthic macroinvertebrates such as crustaceans, worms and small bivalves, but can also eat small fish (van der Westhuizen & Marais, 1977; Randall, 1995).

The small spotted grunt is an important food fish and recreational angling species in southern Africa (e.g. Everett, 2016) and in addition, its potential as an aquaculture species has been investigated in South Africa (Hecht et al., 2003). In the Arabian Sea region, the small spotted grunt forms an important component of both the artisanal and industrial demersal fisheries in Omani waters where it has been the most abundant and important haemulid species in the catches for over 20 years (Al-Abdessalaam 1995) with recent catches increasing from 1000 tonnes in 2009 to 3613 tonnes in 2015 (DoFS, 2015). However, despite its commercial importance, the population biology of *P. commersonnii* in Omani waters has been little studied with only published data available on its reproductive biology (Al-Nahdi et al., 2013) and no data on age/size structure and growth. The number of small spotted grunt ageing studies are limited and have all been on populations at the southern end of its latitudinal range (Wallace & Schleyer, 1979; Van der Elst, 1981; Nzioka, 1982).

Ageing fish using otoliths is standard practice in studies of fish population biology and is based on the deposition of annual growth rings (Campana & Thorrold, 2001). Although annuli may not be clear in tropical species, due to the more limited seasonal differences in water temperature and more uniform growth rates throughout the year, there is a growing body of evidence that aseasonality is rare in the Tropics and many species of tropical reef fish do form annuli in their otoliths (Morales-Nin & Panfili, 2005). This has been shown for fishes in the Arabian Sea using marginal increment analysis and is due to seasonal temperature differences due to the monsoon (Al-Mamry et al., 2007, 2009; Al-Marzouqi, 2013b). Annual periodicity in ring formation has been reported for other grunt species (*e.g.,* *P. kaakan*, Al- Hussaini et al., 2001; *P. incisus*, Pajuelo & Lorenzo, 2003, Chater et al., 2015), but it has not yet been examined for *P. commersonnii*.

For some species, otolith age determination may be time-consuming and expensive due to a need to prepare samples prior to ageing (McCurdy et al., 2002), potentially impeding stock assessment studies (Francis & Campana, 2004; Williams et al., 2015). In addition, in long-lived species the annuli towards the otolith edge can lie very close together making them difficult to identify. Therefore, alternative approaches such as length-frequency distribution analysis (LFA, Gulland & Rosenberg, 1992) have been adopted in order to determine age and describe growth patterns in fishes (*e.g.*, Leonce-Valencia & Defeo, 1997; Al-Marzouqi et al., 2013; Jayabalan et al., 2016). In addition, there has also been interest the use of otolith morphometrics (*e.g.*, length or weight) as an easy, rapid and cost-effective proxy method to estimate fish age (reviewed in Francis & Campana, 2004).

The aims of the current study were to (1) confirm annual periodicity of ring formation in the otoliths of small spotted grunt *P.* *commersonnii* in the Arabian Sea, Oman, and to describe the age structure and growth pattern (*i.e.*, von Bertalanffy growth parameters) for this stock, (2) to determine the growth pattern using LFA for comparative purposes and, (3) to investigate the possibility of using otolith weight as a proxy approach to determine age in small spotted grunt.

**2 | Materials and Methods**

**2.1 | Sample and Data collection**

Small spotted grunt *P. commersonnii* were caught during monthly beam trawl [40 mm cod-end mesh size] surveys conducted by the Research Vessel *Al Mustaqila 1* between September 2007 and August 2008 in the region of the Arabian Sea from Ras Al-Had in the north to the Oman-Yemen border in the south west of Salalah between latitudes 16o 33' N and 22o 21' N and longitude 53o 09' and 59o 55' E and from depths of 20 to 250 m respectively. In total, 6115 *P. commersonnii* were collected during the survey and their fork length (FL) measured to the nearest mm. A subsample of 30-35 fish were retained every month and dissected to identify sex by macroscopic examination of the gonads (Al Nahdi et al., 2013) and to remove the sagittal otoliths for marginal increment analysis and ageing purposes. Prior to preparation, one sagittal otolith was weighed (to the nearest 0.001 g), and embedded in a small mould containing epoxy resin for sectioning on the transverse plane using standard approaches outlined in Secor et al., (1991), mounted on a microscope slide and age determined by counting the annuli using transmitted light (x10 magnification) with a binocular stereomicroscope. According to Wallace & Schleyer (1979), each annulus, where a narrow opaque zone terminates the translucent zone, represents one year of age. However in the present study, marginal increment analysis (MIA) was used to validate the annual deposition of the opaque zone on the otolith of *P. commersonnii* by inferring the time of the year that the increments are formed (Geffen, 1993). For MIA, digital measurements of the sectioned otoliths from the monthly samples were made using Carl Zeiss Microscopy. The incremental measurements of otoliths with opaque margins were plotted against their respective month to determine when deposition took place (*e.g.* Al-Husaini et al., 2001; Al-Mamry et al., 2009).

**2.2 | Data analysis**

Growth in *P. commersonnii* was described using the von Bertalanffy growth (VBG) model and the VBG parameters (*L∞*, *k*, and to) were determined in two ways. Firstly, the VBG growth curve, *Lt = L∞[1-e-k(t- to)]* (King, 2007) was fitted to the size at age data, where Lt is the average FL (cm) at age *t* (years), *k* is the growth coefficient (year-1), *L∞* is the asymptotic total length and *to* is the theoretical age at length zero (year). Secondly, LFA version 5.0 in the FMSP- Fish Stock Assessment Software (Hoggarth et al., 2006) was used with the monthly FL-frequency data (5 cm class intervals) to determine the VBG parameters (Al-Marzouqi, 2013a). As recommended by Pitcher (2002), three alternative non-parametric fitting techniques, Shepherd’s Length Composition Analysis (SLCA), Projection Matrix (PROJMAT) and ELEFAN 1 (Electronic Length Frequency Analysis), were applied using a non-seasonal version of the VBG curve. Since not all fish were sexed, LFA models were used to derive VBG parameters for both sexes combined. VBG curves were derived for males and females separately and for both sexes combined from otolith data. The growth performance index (phi prime, Ø’) for *P. commersonnii* was calculated using Ø’ = 2Log10*L∞* + Log10k (Pauly & Munro, 1984). The relationships between otolith weight and age were described for male and female fish using least-squares linear regression and the slopes of the two regression lines compared using a General Linear Model (GLM).

**3 | Results**

**3.1 |Otolith marginal increment analysis, age and growth**

Marginal increment analysis indicated an annual periodicity in ring formation, with the band of the opaque zone in the marginal increment deposited in August and complete by the end of November when there was an indication of formation of the next translucent zone (Fig. 1). The trend of marginal width measurement decreased alongside a decrease in seasonal water temperature.

Amongst the *P. commersonnii* sampled, otolith age ranged from 2 to 14 years with the 5-9 year classes dominating the sample (Fig. 2). Most males (53.5%) were found in the 5-7 year classes whilst females were more prevalent in the older age classes (8-14 years; 55%) (Fig. 2). The size-at-age growth curves are presented in Figure 3. For both sexes, growth in length was relatively fast for younger fish up to the age of 4, however, males had faster growth rates than females in fish of up to 8 years whilst in fish individuals over 8 years old, the growth rate slowed down to a similar rate for both sexes (Fig. 3). The VBG equations for both sexes are presented in Figure 3a and 3b respectively. The growth curve for the combined male and female data is presented in Figure 3c and was described by *Lt* = 77.2(1-e-0.232 (*t* + 0.058)) (r2 = 0.818, n=422, *p* < 0.001). The growth performance index (Ø’) calculated for *P. commersonnii* from the Arabian Sea, based on the VBG constants derived from the size-at-age data, was 3.14 for males and females combined.

**3.2 | Length-frequency data and growth**

Monthly length-frequency data showed a clear progression of modes over the period between October 2007 and March 2008 (Fig. 4). LFA analysis indicated that the smallest year class appeared in October 2007 at 30-35 cm and reached 50-55cm by March 2008. Generally, the growth estimated at the end of second year ranged from 27 cm to 33 cm and at the end of the final year from 75 cm to 78 cm. Comparing the VBG parameters derived using the three LFA methods; ELEFAN gave the highest lengths for all cohorts whilst SLCA gave comparatively lower values. The VBG parameters (L∞, k and t0) estimated by SLCA, PROJMAT and ELEFAN techniques all gave comparable values for L∞ with an average of 78.8 cm (Table 1). All three LFA techniques calculated identical values for the growth coefficient k (0.35 y-1), whilst t0 was estimated to range between -0.47 and -0.86 years with an average of was -0.64 (Table 1). PROJMAT and ELEFAN both suggested a maximum age of *ca.* 12 years for *P. commersonnii* in Omani waters in the Arabian Sea, whereas SLCA indicated a higher life span of up to 14 years.

**3.3 | Age estimation from otolith weight**

The relationships between otolith weight and age are presented in Figure 5 with considerable variation in age for a given otolith weight. The slope of the regression lines relating otolith weight and age were significantly different between sexes (GLM, *F*1,416 = 6.15, *p* = 0.014). When the difference between age determined from direct otolith reading and that estimated from the otolith weight:age regression is calculated, age residuals of ± 3 years were observed for male fish (Figure 6A) and ± 4 years for female fish (Figure 6B), especially amongst the larger fish. However, 65% of male fish and 67% of female fish were ± 1 year of the age determined by reading the sagittal otolith (Figure 6C). Using age estimated from otolith weight to calculate the VBG parameters provided L∞ values of 76.9, 75.7 and 75.4 cm FL, k values of 0.202, 0.309 and 0.277, t0 values of -0.572, 1.539 and 0.983 and Ø’ values of 3.08, 3.25 and 3.20 for male, female fish and both sexes combined respectively.

**4 | Discussion**

The present study confirms annual periodicity in ring formation in the sagittal otolith of *P. commersonnii*, as observed for other grunt species (Al- Hussaini et al., 2001; Pajuelo & Lorenzo, 2003; Chater et al., 2015). For fish species in the Arabian Sea (*e.g.* Al-Mamry et al., 2007, 2009; Al-Marzouqi, 2013b; present study), marginal increment analysis (MIA) of the sectioned sagittal otoliths has shown a strong seasonal cycle in ring formation (one opaque and one translucent zone per year) with the timing of opaque zone formation coinciding with the reduction of sea water temperature (17-21oC) during the post SW monsoon period (August-November; Fig. 1).

Growth of small spotted grunt in Omani coastal waters was rapid in the first 3-5 years with fish *ca.* 35-40 cm FL by 3 years old and *ca.* 50 cm FL at 5 years old (Fig. 4) attaining an *L∞* value of 77.2 cm FL (≅ 83.8 cm TL; see footnote to Table 2). The reduction in growth rate after 3-5 years older is most likely due to energy being diverted to gonad development and subsequent spawning as the size at 50% maturity is 42 and 44 cm FL for female and male small spotted grunt respectively (Al-Nahdi et al., 2011). Using the equations of Binohlan & Froese (2009) relating *Lmaz* to L50 and Froese & Binohlan (2000) relating *Lmaz* to *L∞*, estimates of *L∞* that are independent of otolith age can be calculated for small spotted grunt. This provides *L∞* values of 74.4 (♀), 78.0 (♂) and 76.2 (♀+♂) cm FL that are similar to the *L∞* values determined by the various techniques used in the present study (otolith age, LFA). Previous data on age and growth of small spotted grunt are limited (see Table 2) but studies in South Africa indicate similar rapid rates of growth attaining a maximum size of 87.0 cm TL at an age of approximately 15 years (Wallace & Schleyer, 1979).

In the present study, three of the most popular LFA procedures, ELEFAN, SLCA and PROJMAT, were used to derive VBG coefficients for small spotted grunt that could be compared with each other and with the values obtained from otolith ageing (Table 1). There has been some discussion about which LFA methods are the most robust or may be most appropriate to describe species-specific patterns of growth (Basson et al., 1988; Leonce-Valencia & Defeo, 1997; Pitcher, 2002). For example, SLCA is a better method to use for slow growing fish species whilst ELEFAN is better for fast growing fishes (Isaac, 1990). In addition, SLCA is considered to be more robust than ELEFAN whilst PROJMAT is considered the most robust of the non-parametric LFA methods (Basson et al., 1988; Pitcher, 2002). Although differences in *L∞* and *k* were observed between LFA methods and in comparison to otolith ageing, these differences were small (Table 1). When conducting LFA to derive VBG coefficients, Pitcher (2002) has recommended that several models are run and results compared and if similar values are obtained then confidence can be placed in the result. In this study, small differences in *L∞* and *k* values were observed using the four different techniques providing confidence in the VBG coefficients determined producing overall average values of *L∞* = 78.4 cm FL and *k* = 0.32 year-1 (Table 1)

Where multiple *L∞* and *k* values exist for a species in the literature, auximetric plots can be used to indicate the accuracy of the *L∞* and *k* values obtained by a new study as any values of that fall outside the boundaries of region characteristic for a given species can be considered as incorrect (Pitcher, 2002). Figure 7 shows the auximetric plot for the genus *Pomadasys* with the expected general negative relationship between *L∞* and *k* (Pitcher, 2002) observed. Although the data for small spotted grunt are very limited (3 published studies, Table 2), the *L∞* and *k* values obtained in the present study fall within the auximetric plot for the species and within the spread of data observed for the genus (Figure 7) providing confidence in the VBG data. *P. commersonnii* shows a high *L∞*/low *k* pattern of growth compared to *P. argyreus* and *P. maculatus* which are low *L∞*/high *k* *Pomadasys* species. The *L∞* and *k* values for *P. incisus* and *P. striatus* appear to be outliers in the auximetric plot for the genus (Figure 7). Growth performance index (phi prime index, Ø’) values of 2.75 to 3.37 have been reported for *P. commersonnii* (Table 2) and the Ø’ obtained for the fish from the Arabian Sea coast of Oman (3.35) is within this range.

Given the time and cost constraints in preparing the otoliths of some fish species for ageing, there has been interest the use of otolith morphometrics as a rapid and easy proxy to predict fish age (reviewed in Francis & Campana, 2004). In the present study, although age residuals of ± 4 years was observed between sagittal otolith age and estimated age (depending on sex and otolith weight), the results indicated that otolith weight could be used as a rapid proxy to estimate age and derive VBG parameters as the estimates of *L∞* and *k* were similar to those derived from sagittal otolith ageing or LFA and the estimates of *L∞* and *k* lie within the auximetric plot for *P. commersonnii* (Fig. 7). This proxy approach has been recently extended from a simple linear regression approach (*e.g.*, otolith weight *vs.* age) to also include additional parameters, such as otolith thickness, fish size, sex, and season and location of capture, in assignment tests such as Random Forest to predict the likely age of the fish (*e.g.*, Dub et al., 2013; Williams et al., 2015). It is possible that this more refined approach may be able to better predict age and could be attempted in future studie*s on P. commersonnii*.

In conclusion, this study provides the first data for age structure and growth parameters for small spotted grunt, *P. commersonnii* in the Arabian Sea at the northern limit of the species’ latitudinal range. MIA of the sagittal otolith confirmed the deposition of annual increments, validating its use in age and growth studies for this species. Similar VBG parameters (both sexes combined) were obtained using otolith age, LFA (using ELEFAN, PROJMAT and SLCA) or using otolith weight as a rapid proxy for age with the *L∞* and *k* values derived from all 4 methods lying within the auximetric plot for the species providing confidence in the VBG parameters obtained for small spotted grunt in the Arabian Sea. Given the increased catches in recent years (DoFS, 2015), regular monitoring is recommended to ensure sustainable exploitation of the stock.

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**TABLE 1.** von Bertalanffy growth parameters for *Pomadasys commersonnii* (sampled between September 2007 - August 2008) estimated by different methods based on fork length-frequency data, sagittal otolith ageing or estimated from the sagittal otolith weight-age relationship (for both sexes combined).

|  |  |  |  |
| --- | --- | --- | --- |
| Technique | *L∞* (FL, cm) | *k* (year-1) | to (year) |
| SLCA | 81.1 | 0.35 | -0.47 |
| PROJMAT | 79.2 | 0.35 | -0.60 |
| ELEFAN 1 | 76.1 | 0.36 | -0.86 |
| Sagittal otoliths | 77.2 | 0.23 | -0.06 |
| Average (n=4) | 78.4 | 0.32 | -0.50 |
| Otolith weight | 75.4 | 0.28 | 0.98 |

**TABLE 2.** Comparison of growth parameters of *P. commersonnii* and other *Pomadasys* species. Data are presented for the coefficients from the von Bertalanffy growth function (*L∞*, *k*, t0) and the growth performance index Ø’ (Pauly & Munro, 1984) and length at 50% maturity (L50). N = number of studies. All length values are Total Length (cm).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Species | *Location* | *N* | *L∞* (range, cm) | *k* (year-1) | Ø’ | Reference |
| *P. commersonnii* | Oman | 1 | 84.01 | 0.32 | 3.35 | This Study |
| *P. commersonnii* | Kenya | 1 | 75.0 | 0.42 | 3.37 | Nzioka (1982) |
| *P. commersonnii* | South Africa | 1 | 89.5 | 0.07 | 2.75 | Wallace & Schleyer (1979) |
| *P. commersonnii* | South Africa | 1 | 91.7 | 0.19 | 3.20 | Froese & Pauly (2017) |
| *P. argenteus* | Kuwait, Iran, India  Bangladesh, Indonesia | 7 | 61.1 (54.0-74.1) | 0.38 (0.21-0.52) | 3.15 | Froese & Pauly (2017) |
| *P. argyreus* | Brunei, Philippines | 5 | 14.8 (12.9-18.0) | 0.77 (0.62-0.83) | 2.23 | Froese & Pauly (2017) |
| *P. incisus* | Tunisia, Canary Isles | 3 | 29.6 (23.9-33.3) | 0.22 (0.19-0.27) | 2.29 | Froese & Pauly (2017),  Pajuelo et al. (2003) |
| *P. jubelini* | Sierra Leone | 1 | 45.0 | 0.30 | 2.78 | Froese & Pauly (2017) |
| *P. kaakan* | Kuwait, Iran, Pakistan | 5 | 69.1 (62.2-94.0) | 0.30 (0.18-0.57) | 3.16 | Froese & Pauly (2017) |
| *P. maculatus* | Brunei, Yemen | 2 | 23.5, 75.0 | 0.75, 0.16 | 2.62, 2.95 | Froese & Pauly (2017) |
| *P. striatus* | Gulf of Suez | 1 | 18.0 | 0.30 | 1.99 | Froese & Pauly (2017) |

1 calculated from a Fork Length value of 78.4 cm using FL = 0.926TL + 0.607 (Al-Nahdi, unpublished data)

**FIGURE LEGENDS**

**Fig. 1.** Monthly changes in deep seawater temperature (solid circles, dotted line) and marginal increment (MI, mm; solid line) of the sagittal otoliths of small spotted grunt *Pomadasys commersonnii* sampled from the Arabian Sea, Oman on a monthly basis between September 2007 and August 2008. Data are presented as mean values (± SD) for each month with the sample size for each monthly sample indicated on the plot.

**Fig. 2.** Age-frequency distributions for male and female small spotted grunt *Pomadasys commersonnii* from the coastal waters of Arabian Sea, Oman. Age was determined from sectioned sagittal otoliths for fish collected between September 2007 and August 2008.

**Fig. 3.** Von Bertalanffy growth curves for small spotted grunt *Pomadasys commersonnii*, in the coastal waters of Arabian Sea, Oman (collected between September 2008 and August 2008). Data are presented for (a) males (n=189), (b) females (n=233) and (c) both sexes combined (Females, circles; males, triangles). The von Bertalanffy growth equations fitted to each data set are presented on the plots.

**Fig. 4.** Monthly length-frequency data (Fork Length, cm) for small spotted grunt *Pomadasys commersonnii* collected from the coastal waters of the Arabian Sea (between September 2007 and August 2008).

**Fig. 5.** Relationships between otolith weight (g) and age (years) for male (triangles) and female (circles) small spotted grunt *Pomadasys commersonnii*, in the coastal waters of the Arabian Sea, Oman (collected between September 2008 and August 2008). The least-squares linear regression equation fitted to each data set are presented on the plot).

**Fig. 6.** Relationships between Total length and the difference in age between sagittal otolith age and the age estimated from the otolith weight-sagittal otolith age relationship for male (A) and female (B) small spotted grunt *Pomadasys commersonnii*, in the coastal waters of the Arabian Sea, Oman (collected between September 2008 and August 2008). (C) Histogram showing the number of male and female small spotted grunt in different Age Difference classes.

**Fig. 7.** Relationship between k (year-1) and *L∞* (Total Length, cm) and for grunt species of the genus *Pomadasys*. The auximetric plot for small spotted grunt is indicated by the red triangle, with the k/ *L∞* value of the present study (average value from Table 1) indicated by the unfilled red circle and the k/ *L∞* value estimated from otolith weight indicated by the red asterisk. The 4 data points outlined by the dotted circle indicate outlying species from the general auximetric relationship of decreasing *L∞* with increasing *k*. Data for *P. commersonnii* are presented in Table 2 and data for other *Pomadasys* species are taken from Fishbase (Froese & Pauly, 2017) with the average (minimum - maximum) values presented in Table 2.