Growth of the oblique-banded grouper (*Epinephelus radiatus*) on the coasts of Reunion Island (SW Indian Ocean)

by

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Abstract. – The oblique-banded grouper, *Epinephelus radiatus* (Day, 1968), occurred within the whole Indo-West Pacific where it is harvested by small-scale coastal fisheries. The aim of this study was to estimate the growth of this species at Reunion Island (South-West Indian Ocean) since no study investigated this topic so far. Fifty-seven individuals were sampled in the landings of the French local artisanal fisheries from March 2014 to March 2015. The relationships between two types of body length (total and standard lengths, cm) and total weight (g) were significant ($p < 0.05$). Total length-weight relationship was described by the following parameters: $a = 0.01$ and $b = 3.098$. For each individual, morphometry of the whole otolith was described with several parameters (O_L: otolith length; O_{WI}: otolith width; O_A: otolith area; Ow: otolith weight). Age was determined on a transversal section of otolith. Among the morphometric parameters of otoliths, only the weight ($p = 0.002$) was significantly correlated with the age of *E. radiatus*, with no difference between left and right otolith ($p = 0.67$). Von Bertalanffy growth equations were $TL_t = 65.99(1 – e^{–0.20(t)})$ and $Wt = 4526.44(1 – e^{–0.20(t)})^3$.

Résumé. – Croissance du mérou zébré (*Epinephelus radiatus*) sur les côtes de l'île de La Réunion, sud-ouest de l'océan Indien.

Le mérou zébré, *Epinephelus radiatus* (Day, 1868), est présent dans l'océan Indien et l'ouest de l'océan Pacifique, où il est capturé par la petite pêche côtière artisanale. Le but de cette étude est d'estimer la croissance du mérou zébré sur les côtes de l'île de la Réunion (sud-ouest de l'océan Indien) pour lequel aucune donnée publiée n'est disponible. Au total, 57 individus ont été échantillonnés à partir des débarquements de la petite pêche artisanale locale, de mars 2014 à mars 2015. Les relations entre les deux types de longueur (longueurs totale et standard, en cm) et la masse totale (en g) sont toutes significatives ($p < 0,05$). La relation entre la longueur totale (LT) et la masse (WT) est décrite par les paramètres suivants : $a = 0,01$ et $b = 3,098$. Pour chaque individu, la morphométrie des otolithes entiers a été décrite par plusieurs paramètres (O_L : longueur ; O_{WI} : largeur ; O_A : surface ; Ow : poids) puis l'âge a été déterminé à partir de coupes fines transversales de l'otolithe sagital. Parmi tous les paramètres morphométriques de l'otolithe, seul le poids ($p = 0,002$) présente une relation significative avec l'âge du mérou zébré, sans effet du côté de la tête où l'otolithe est présent ($p = 0,67$). Les équations de Von Bertalanffy ont été estimées à $LT = 65,99\ (1 – e^{–0.20(t)})$ et $WT = 4526,44\ (1 – e^{–0.20(t)})^3$.

Received: 21 Apr. 2015
Accepted: 18 Aug. 2015
Editor: E. Dufour

Key words
Epinephelidae
Epinephelus radiatus
Otolith
Indian Ocean
Ageing
Otolith weight

The oblique-banded grouper, *Epinephelus radiatus* (Day, 1868), inhabits the Indo-West Pacific (Heemstra and Randall, 1993; Craig *et al*., 2011). This species is present in the tropical and subtropical waters from the Red Sea to Japan and Papua New Guinea (Gloerfelt-Tarp and Kailola, 1984; Baranes and Golani, 1993; Kramer and Newman, 1994) where it is apparently rare (Heemstra and Randall, 1993). Specimens were observed from the Red Sea, Gulf of Aden, Reunion Island, Mauritius Island, Chagos Islands, Gulf of Oman, India, Sri-Lanka, northwestern Australia, Taiwan, Japan and Papua New Guinea (Heemstra and Randall, 1993; Kandula *et al*., 2015). *E. radiatus* is particularly targeted by artisanal fisheries at Reunion Island. This species is appreciated for local consumption and is sold at an expensive price (~35 € per kg). *E. radiatus* is the main species exploited by fisheries off Indian coasts (Kandula *et al*., 2015). This species seems to be regularly confused with three other species: *E. morrhua* (Valenciennes, 1833), *E. poecilonotus* (Temminck & Schlegel, 1842) and *E. tuamotensis* Fourmanoir, 1971. All these four *Epinephelus* species have been classified as endangered. Consequently, *E. radiatus* belongs to the IUCN (International Union for Conservation of Nature) Red List at level "least concern" (Pollard *et al*., 2008). Despite this concern, few data about *E. radiatus* growth are available, and growth parameters have never been documented so far. The aim of the present study was thus to investigate the growth of *E. radiatus* along the coasts of Reunion Island, based on otolith analysis.

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MATERIEL AND METHODS

A total of 57 *E. radiatus* were sampled in the landings of the French local artisanal fisheries (basically deep-water handline on electric reel), in eastern part of Reunion Island. Monthly samples were collected between March 2014 and March 2015. All fresh specimens were examined in the laboratory for total length (TL, cm) standard length (SL, cm), total wet weight (W, g).

Preliminary to the characterization of the length-length (L-L) and length-weight (L-W) relationships all pairs of data were plotted in order to identify and delete obvious outliers. In order to estimate the parameters of the allometric L-W relationship, its base-10 logarithm was fitted to data using a least squared linear model:

$W = a\,L^{b}$ (1),

$\log W = \log a + b.\log L$ (2),

where *a* is the intercept or initial growth coefficient and *b* is the slope, *i.e.* the growth coefficient (Le Cren, 1951; Ricker, 1975; Froese, 2006).

In order to estimate the age of fish, sagittal otoliths were removed from left and right head sides of each specimen. Since growth of *E. radiatus* has not been investigated before, calibration of the method for age and growth structure determination was needed. Different techniques were used in order to gain the most precise evaluation of the fish age: observation under both transmitted light and reflected light of the whole otolith and the transverse section before and after burning. Transverse section (width: 0.4 mm) was the only appropriate technique (Fig. 1), providing clearly visible alternating translucent and opaque bands. One growth increment is assumed to consist of one opaque and one translucent band without the prior age validation study. Each sample was analysed using the TNPC software (digital processing of calcified structures, www.tnpc.fr) in two steps, (1) the extraction of morphometric parameters of whole otolith (O_L: otolith length; O_{WI}: otolith width; O_A: otolith area and O_w: otolith weight); and (2) age estimation based on transverse section. Each otolith was examined twice by two readers in order to limit observer bias.

Variations of the relationship between age and morphometric parameters of otolith, according to the explanatory variable head side (S), were investigated with a complete Generalized Linear Model. The model was built considering that individual age depends on otolith shape parameters (continuous effect) and head side (factor):

$\text{Age} \sim O_L + O_{WI} + O_A + O_W + S + O_L \times S + O_{WI} \times S + O_A \times S + O_W \times S$ (3)

Age and total length data were used to describe *E. radiatus* growth using the Von Bertalanffy (1938) model for the length:

$TL_t = TL_\infty\,(1 - e^{-K(t - t_0)})$ (4)

and for the weight:

$W_t = W_\infty\,(1 - e^{-K(t - t_0)})^3$ (5)

with:

$W_\infty = a\,TL_\infty^{\ b}$ (6),

where TL_t and W_t = total length and weight at age t; TL_∞ and W_∞ = asymptotic length and weight; K = rate at which the asymptote is reached and t_0 = theoretical age (in years) at zero length (scaling factor). The adjustment of the growth model was carried out under constraints ($t_0 = 0$).

The fish growth was estimated using the growth performance index (ϕ') (Pauly and Munro, 1984):

$\phi' = \log K + 2 \log TL_\infty$

Comparison of growth was based on growth performance index rather than from a comparison of TL_∞ and K individually, since these two parameters are correlated (Sparre *et al.*, 1987).

There is uncertainty to determine the sex of each fish by macroscopic observation of the gonads, and thus the growth of this species was considered regardless of sex. Moreover, some species of the genus *Epinephelus* are protogynous hermaphrodite, which is first female and then male (Shapiro, 1987; Pothin *et al.*, 2004). This could also be the case for *E. radiatus*.

All statistical analyses were carried out using the open-source statistical package "R" (R Core Team, 2015). Differences were considered significant at $p < 0.05$.

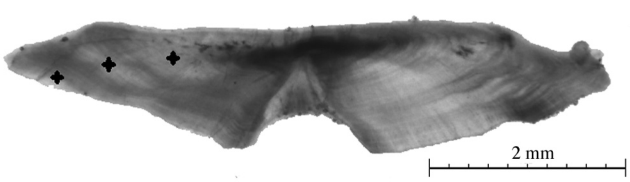

Figure 1. - Otolith transverse section of *Epinephelus radiatus* (TL = 31.4 cm; 3 years old) using transmitted light. Growth increments were identified by black crosses.

RESULTS

The sizes of 57 *E. radiatus* ranged from 12 to 65 cm TL (Fig. 2). Significant L-L and L-W relationships were detected:

$SL = 0.89 * TL - 8.69$; $r^2 = 0.99$; $p < 2.10^{-16}$

$W = 0.01 * TL^{3.098}$; $r^2 = 0.99$; $p < 2.010^{-16}$

The observed ages of *E. radiatus* ranged from 2 to 13 years (Fig. 2). In the present study, multiple regression models were used to investigate the potential relationship between age and simple parameters describing otolith morphometry, such as O_L, O_W, O_A, O_{WI} and head side of fish. Among the morphometric parameters of otolith, only the weight ($p = 0.002$; Tab. I) was significantly correlated with the age of *E. radiatus*. The Von Bertalanffy growth function was fitted to age and length data for all the samples (Fig. 2).

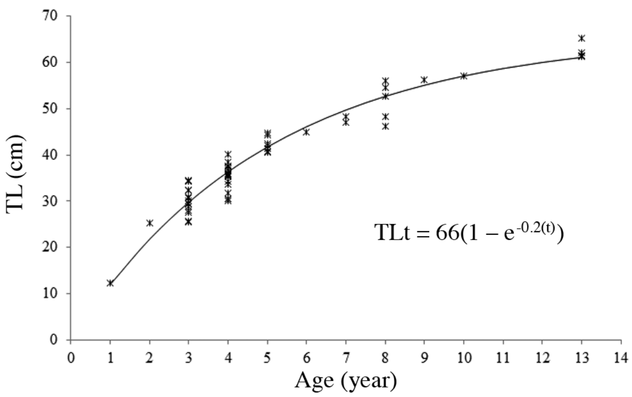

Figure 2. - Von Bertalanffy growth curves of *Epinephelus radiatus* from Reunion Island fitted to all data (n = 57).

The estimated growth parameters were: TL_∞ = 65.99 cm; W_∞ = 4526.44 g; K = 0.2 year^{-1}. Maximum size reported for this species was 70 cm TL (Randall and Heemstra, 1991).

DISCUSSION

All body measure types of this species are correlated, as for another *Epinephelus* species (*E. merra* Bloch, 1793) studied in Reunion Island (Pothin *et al*., 2004). The growth coefficient "b" is close to 3, confirming the isometric growth previously observed for other species of the genus *Epinephelus,* such as *E. marginatus* (Lowe, 1834) along the Brazilian coasts (b = 3.09; Condini *et al*., 2014), *E. merra* from Reunion Island (b = 3.01; Pothin *et al.,* 2004), *Hyporthodus quernus* (Seale, 1901) from north-western of the Hawaiian Islands (b = 2.99; Nichols and DeMartini, 2008) and *E. areolatus* (Forsskål, 1775) (b = 2.95), *E. chlorostigma* (Valenciennes, 1828) (b = 3.04), *E. tauvina* (Forsskål, 1775) (b = 3.07), *E. coioides* (Hamilton, 1822) (b = 3.00) and *E. malabaricus* (Bloch & Schneider, 1801) (b = 3.06) off eastern Indian coasts (Kandula *et al*., 2015).

The significant relationship between TL and O_w was observed in previous studies on several species, such as red snapper [*Lutjanus campechanus* (Poey, 1860); Beyer and Szedlmayer, 2010], yellowfin bream [*Acanthopagrus australis* (Günther, 1859); Ochwada *et al*., 2008], sand whiting [*Sillago ciliata* Cuvier, 1829; Ochwada *et al*., 2008], Chilean jack mackerel [*Trachurus murphyi* Nichols, 1920; Araya *et al*., 2001], cod [*Gadus morhua* Linnaeus, 1758; Cardinale *et al*., 2000]; European plaice [*Pleuronectes platessa* Linnaeus, 1758; Cardinale *et al*., 2000), haddock (*Melanogrammus aeglefinus* (Linnaeus, 1758); Cardinale and Arrhenius, 2004], Macrouridae species [*Nezumia sclerorhynchus* (Valenciennes, 1838) and *Coelorinchus caelorhincus* (Risso, 1810); Labropoulou and Papaconstantinou, 2000] and grey angelfish [*Pomacanthus arcuatus* (Linnaeus, 1758); Steward

Table I. - Summary of statistics for of *Epinephelus radiatus*. The table gives F and P values of a completed Generalized Linear Model between age and morphometric parameters of otolith according to the head side (S).

Factors	F	P
O_L	0.41	0.525
O_{WI}	2.71	0.106
O_A	3.54	0.066
O_W	10.38	0.002
$O_L \times S$	0.08	0.782
$O_{WI} \times S$	0.18	0.671
$O_A \times S$	0.23	0.636
$O_W \times S$	0.04	0.848

et al., 2009]. Conversely, the absence of significant relationship between age and other otolith morphometric features could be explained by the fact that O_w is the only parameter considering the growth of the otolith in the three dimensions, whereas the others take only two dimensions into account. The same results between otolith morphometric features have been previously observed in two studies about roundfish (Labropoulou and Papaconstantinou, 2000; Ochwada *et al*., 2008). Inversely, a significant relationship between otolith *radius* and fish age was observed only for a flatfish species [long rough dab, *Hippoglossoides platessoides* (Fabricius, 1780); Fossen *et al*., 2003] and was explained by the small thickness of the otolith. No differences were detected between left and right otoliths for age reading and morphometric parameters (Tab. I). The otolith weight could be used as age predictor for *E. radiatus* as a faster alternative to the traditional annulus count method, considering similarly left or right otolith, since no difference between them was detected.

The present study is the first to document the Von Bertalanffy growth function for *E. radiatus*. Only two other growth studies were performed on *E. morrhua*, one of the species mixed up with *E. radiatus*, in Papua New Guinea (Fry *et al*., 2006) and in the Tonga Island (Langi, 1988). Several other studies reported only maximal total lengths. Off Indian coasts, maximal total length (70 cm TL; Kandula *et al*., 2015) for *E. radiatus* was slightly higher than the value calculated in this present study. For *E. poecilonotus* and *E. tuamotensis*, no growth parameters are available, but Craig *et al*. (2011) observed maximal total lengths of 65 and 66 cm, respectively. These values are quite similar to TL_∞ (66 cm) observed in this study at Reunion Island. The TL_∞ obtained in this study was smaller than values observed for other groupers in the southern hemisphere (Fig. 3) except *E. merra* at Reunion Island (Pothin *et al*., 2004). Nevertheless, this study was performed on a low sample size (31 individuals) of small individuals (19-28 cm TL), which might prevent from a formal conclusion. However, the growth performance

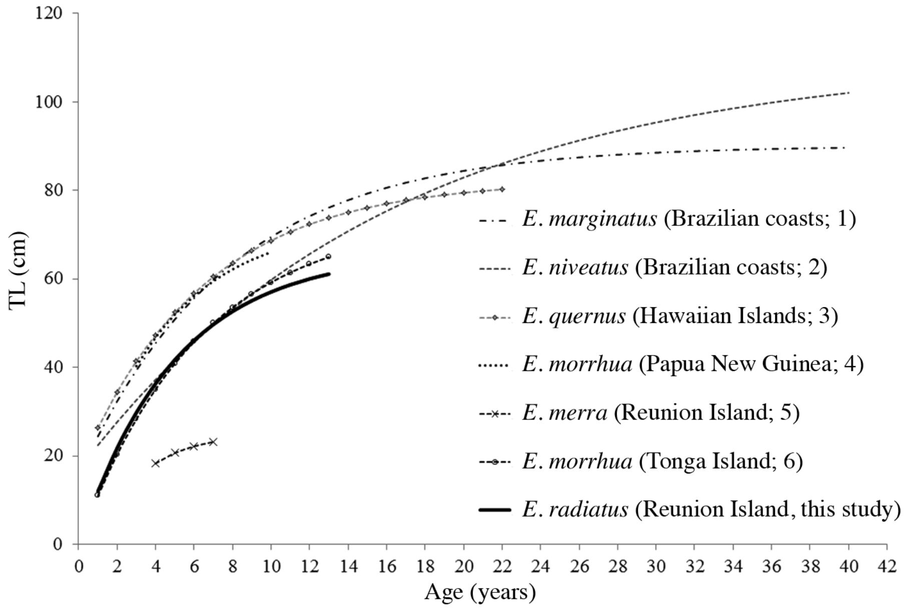

Figure 3. - Growth curves of different species of the genus *Epinephalus* in the southern hemisphere (1: Condini *et al*., 2014; 2: Costa *et al*., 2011; 3: Nichols and DeMartini, 2008; 4: Fry *et al*., 2006; 5: Pothin *et al*., 2004; 6: Langi, 1988).

index (ϕ') calculated for *E. radiatus* at Reunion Island (2.94; this study) is comparable with the value for *E. morrhua* at Tonga Island (2.94, Langi, 1988). Moreover, for the same species (*E. morrhua*), the growth performance is much contrasted between Tonga Island (ϕ' = 2.94; Langi, 1988) and Papua New Guinea (ϕ' = 3.07; Fry *et al*., 2006). Differences among all the estimated parameters could result from several factors: (1) species-specific differences; (2) variations in environmental conditions among sampled areas; (3) different size distributions (probably caused by different types of sampling gear and the catchability size); and (4) different analysis methods. This lack of data stresses for a better assessment of the growth parameters of these highly targeted species.

Acknowledgements. – This study was carried out with the financial support of the European project "ANCRE-DMX2" ("Indicateurs biologiques et écologiques pour une gestion durable des stocks de poissons démersaux profonds d'intérêt halieutique à La Réunion"). We also thank all fishermen and colleagues who helped us on the field, and anonymous reviewers for their comments and suggestions.

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