Asian Fisheries Science 5(1992):25-36.
Asian Fisheries Society, Manila, Philippines

Age and Growth of Three Dominant *Lutjanus* Species of the Great Barrier Reef Inter-Reef Fishery

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Abstract

Whole otoliths were used to age *Lutjanus sebae*, *L. malabaricus* and *L. erythropterus* from Great Barrier Reef waters. Validation of age estimates was incomplete. Significant differences existed between the sexes for some of the von Bertalanffy growth parameters and lengths at age of older fish. In general, males grew faster than females in older size classes, apparently after the attainment of maturity.

Introduction

The component fisheries of the Great Barrier Reef (GBR) demersal fishery are briefly described by McPherson (1989) and McPherson et al. (1992). The reproductive biology of three large lutjanid fishes that dominate the north Queensland inter-reef fishery, the red emperor (*Lutjanus sebae*), scarlet sea perch (*L. malabaricus*) and saddletail sea perch (*L. erythropterus*) all locally referred to as 'redfish' (McPherson 1989), is described by McPherson et al. (1992).

In this paper we estimate the age and growth parameters required to develop recommendations to management for optimal minimum legal sizes for 'redfish' species in GBR waters.

Methods

Sampling was conducted in northern GBR waters offshore of northeastern Queensland between latitudes 15° and 18° (see Fig. 1, McPherson et al. 1992). Specimens of *L. sebae*, *L. malabaricus* and *L. erythropterus* ('redfish') were obtained from handline catches of research, commercial and recreational vessels (McPherson et al. 1992). Juvenile *L. sebae* were sampled from shrimp trawl catches in 1981-83 and maintained at the Northern Fisheries Centre (NFC) mariculture facility. Red emperor taken below the legal size of 35 cm total length (TL) from charter vessel catches in 1988-90 were tagged and released.

Fish were measured to the nearest 0.5 cm (FL = fork length, TL = total length). Details of 'redfish' total weight and gonad weight sampling, and sampling to determine sex by histological analysis are given by McPherson et al. (1992).

Otoliths were removed and stored dry. Whole otoliths were immersed in aniseed oil and examined against a black background. Each otolith was read three times, twice by one of the authors. Otolith radius and annulus measurements were taken from the focus on the concave proximal face to the posterior margin of the otolith. Scales were removed from at least two locations and stored dry, urohyals were separated from connective tissue with sodium perborate.

Results

Age Determination

Determination of age from examination of the hard parts requires two operations, the reliable detection of bands within the hard part, and the determination of the time scale associated with this banding, or validation (Williams and Bedford 1974).

RELIABLE DETECTION OF OTOLITH BANDS

Whole otoliths, scales and urohyals from approximately 75 fish of each 'redfish' species were compared for the suitability of each bony structure for age assessment. A large proportion of scales appeared as either replacements or displayed considerable resorption, especially in *L. sebae*. Discontinuities were readily seen in the urohyals of each species, however regular checks could not be detected.

Initial rejection of otoliths on the first reading was 22 and 13% for *L. sebae* and *L. malabaricus*, respectively, due primarily to many otoliths being completely opaque without showing any signs of check formation. The precision of subsequent age determinations between readings was acceptable with indices of Average Percent Error (APE) (Beamish and Fournier 1981) being less than 1%. The initial rejection rate of *L. erythropterus* otoliths was 39%, while the index of APE of the remaining otoliths was 3.0%.

Chi-square tests between the proportions of otoliths sampled from fish within 5-cm length classes, and those fish aged indicated that older fish were significantly ($P<0.01$) more difficult to age. The relative proportions of otoliths unsuitable for age determination are indicated in Fig. 1. Larger specimens of *L. sebae* appeared to be less successfully aged than other 'redfish' species. However, there was little difference between the L_{max} (maximum FL) of the total otolith sample, and of those successfully aged for all three species (Table 1).

Frequency of distributions of the otolith radius to the last check formed for the three 'redfish' species exhibited single modes for each age group. The combined sex mean annulus measurements for the three 'redfish' species are given in Table 2. There was a consistent increase in modal length for each age, with the frequency

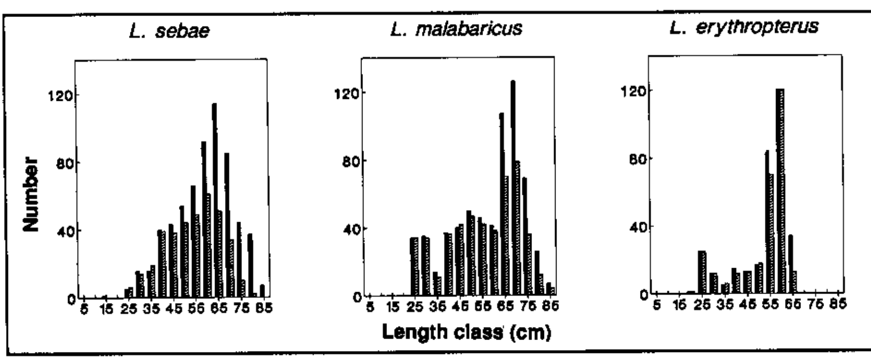

Fig. 1. Sampled (solid bars) and successfully aged (hatched bars) otoliths of 'redfish'.

Table 1. Maximum lengths (FL_{max}) and sample sizes of 'redfish' from samples where otoliths were collected and successfully aged.

	Otoliths sampled		Otoliths aged	
Species	FL_{max}	n	FL_{max}	n
L. sebae	81.0	620	78.5	387
L. malabaricus	83.0	632	81.0	485
L. erythropterus	64.0	496	62.0	359

Table 2. Otolith checks (in ocular eyepiece units) for combined sex-age groups of 'redfish' species.

Age group	*L. sebae* Mean	(s.e.)	n	*L. malabaricus* Mean	(s.e.)	n	*L. erythropterus* Mean	(s.e.)	n
1	25.9	(0.4)	33	23.6	(0.3)	118	33.4	(0.6)	44
2	26.8	(0.3)	65	36.2	(0.4)	64	46.7	(0.8)	27
3	45.3	(0.2)	90	43.4	(0.3)	85	54.7	(0.8)	76
4	52.2	(0.2)	93	49.8	(0.3)	79	61.8	(0.4)	77
5	57.3	(0.2)	94	54.7	(0.3)	104	67.7	(0.4)	106
6	62.8	(0.4)	43	59.7	(0.4)	63	69.9	(0.6)	38
7	66.2	(0.5)	25	63.3	(0.5)	34	75.5	(2.7)	2
8	70.6	(0.7)	12						

distributions overlapping for older age groups. Two-way ANOVA did not detect any significant effect of sex for the otolith annulus measurements of *L. sebae* and *L. erythropterus*. There was a minimal effect of sex for *L. malabaricus* between the first two early year classes although the effect was trivial (MSS = 32.7) compared with that of age group (MSS = 11,484).

VALIDATION

Mean monthly marginal increments of the first two age classes of *L. sebae* and *L. malabaricus* otoliths appeared to reach a maximum during winter. However, significant differences ($P<0.05$) between monthly means could only be demonstrated by ANOVA for age group 1 in *L. malabaricus* (Fig. 2). The annulus for this age group formed between July and October inclusive. Monthly collections of *L. erythropterus* were highly variable; marginal increments were not calculated.

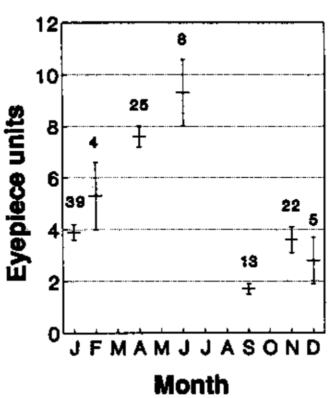

Fig. 2. Otolith marginal increments of *L. malabaricus*. Numbers are sample sizes.

Backcalculation of Lengths-At-Age and Von Bertalanffy Growth Curve

The FL : otolith radius (OR) functional relationships (Kendall and Stuart 1973) for the three species best approached linearity using a transformation between ln (ln(FL)) and ln (OR) in the form

$$FL = \exp \{e^{a} (OR)^{b}\}$$

on the marginal scale. There were no significant differences between the FL : OR relationships between males and females for each species. The parameters of the combined sex FL : OR relationships are given in Table 3.

Table 3. Parameters of the FL : OR functional relationship in the form $FL = \exp\{e^{a} \cdot (OR)^{b}\}$ for 'redfish' species.

	Parameters	
Species	a	b
L. sebae	-0.13	0.37
L. malabaricus	-0.21	0.40
L. erythropterus	-0.52	0.45

With the transformed FL : OR relationship being linear, FLs at the time of annulus formation were back-calculated to the last annulus formed using a proportional back-calculation procedure (Guetreuter 1987). The mean back-calculated lengths-at-age and the results of t-tests between age groups for the 'redfish' species are given in Table 4.

There were no significant differences in the mean back-calculated lengths at age for male and female *L. sebae* estimated to be less than six years of age. Males older than five years were significantly larger ($P<0.01$) than females of the same age.

While there was some variability in the differences between length-at-age data for male and female *L. malabaricus*, males older than age group 4 were significantly ($P<0.05$) larger than females. There were no consistent differences between length-at-age data for male and female *L. erythropterus*.

The back-calculated lengths-at-age 5 of *L. sebae* and *L. malabaricus* females of 56.2 and 59.7 cm, respectively, coincided with the L_m (length at 50% maturity) for both species of 54.8 and 57.6 cm (McPherson et al. 1992), respectively. Age at maturity of *L. erythropterus* was estimated to occur at age group 4 as the length-at-age estimate of 50.4 cm coincided with the L_m of 48.6 cm and the minimum observed length at maturity of 50.0 cm (McPherson et al. 1992).

The von Bertalanffy model was fitted to the length-at-age data (weighted for sample size) using the minimization routine LMM (Osborne 1976; program modified by A.J. Miller, CSIRO, and A.T. Lisle, Queensland Department of Primary Industries). Parameters and their standard errors are given in Table 5; variance was estimated from the pooled within-age-group variation.

Table 4. Back-calculated lengths-at-age for male and female 'redfish' species. (Standard errors and sample sizes in parentheses). Significant differences between sexes are shown (*, $P<0.05$; **, $P<0.01$).

Age group	*L. sebae*			*L. malabaricus*			*L. erythropterus*		
	Male	Female	P	Male	Female	P	Male	Female	P
1	19.5 (2.1, 4)	20.5 (1.1,14)		19.5 (1.1,19)	19.6 (0.9,30)		16.6 (1.6, 5)	19.7 (1.0,12)	
2	31.3 (1.1,15)	29.7 (0.7,37)		31.1 (1.1,20)	33.6 (0.8,32)		30.7 (1.1,11)	27.0 (1.2, 8)	*
3	40.1 (0.8,28)	39.5 (0.6,54)		43.8 (0.8,36)	41.4 (0.7,43)	*	39.7 (0.9,16)	43.3 (1.4, 6)	*
4	48.2 (0.8,30)	49.5 (0.6,57)		51.0 (0.8,37)	52.7 (0.8,37)		48.1 (0.6,39)	50.4 (0.3,38)	**
5	56.1 (0.7,36)	56.2 (0.6,55)		62.3 (0.8,38)	59.7 (0.6,62)	**	51.6 (0.5,46)	52.8 (0.5,60)	
6	64.2 (0.8,26)	59.8 (1.03,16)	**	67.3 (0.9,31)	62.7 (0.9,29)	**	54.3 (3.5, 7)	54.3 (0.4,31)	
7	68.1 (1.1,15)	63.3 (1.4, 9)	**	70.5 (1.2,15)	67.1 (1.1,18)	*	(2.5, 2)	57.1	
8	72.7 (1.3,11)	65.9 (4.13, 1)							

Table 5. Parameters (and approximate standard errors) of the von Bertalanffy growth equation and growth performance index φ' for 'redfish' species. Common parameters ($P>0.05$) between sexes are given.

Species	Sex	L_∞	(s.e.)	K	(s.e.)	t_0	(s.e.)	φ'*
L. sebae	M	102.5	(6.1)	0.15	(0.02)	{-0.32	(0.12)	3.20
	F	88.7	(5.5)	0.18	(0.02)	{ common t_0		3.15
L. malabaricus	M	98.7	(5.3)	0.18	(0.02)	{-0.13	(0.08)	3.24
	F	83.8	(3.4)	0.23	(0.02)	{ common t_0		3.21
L. erythropterus	M	{60.0	(1.3)	0.41	(0.03)	{ 0.21	(0.04)	3.17
	F	{ common L_∞		0.44	(0.04)	{ common t_0		3.17

*$\phi' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro 1984).

The von Bertalanffy growth curves between sexes were compared. All possible combinations of common and separate parameter estimates were fitted to the curve starting with the simplest model with all parameters in common; separate parameters for each sex were included on the basis of maximum reduction in residual sums of squares. The reduction in residual SS was tested for statistical significance using a sequential F test.

Results of the comparison of growth curves between the sexes showed that common t_0 parameters were appropriate for all 'redfish' species (Table 5). Significance differences ($P<0.05$) existed with the remaining parameters for *L. sebae* and *L. malabaricus*, the L_∞ of males was larger, and the K of females larger. For *L. erythropterus* L_∞ was common to both sexes, with K larger for females.

Independent Observations of Growth Increments

The growth increments of three *L. sebae* at liberty for 0.3, 0.9 and 1.0 years are given in Fig. 3. The FLs at the time of tag and release was aligned with the von Bertalanffy curve derived from otoliths (Table 5), the observed growth for two of the three recaptures fell below the predicted growth from the growth equation. However, the observed growth was generally supportive of the growth estimates derived from otoliths.

A single *L. sebae* was maintained at the NFC mariculture facility for 1.1 years. The observed growth increments of this fish from 19.5 to 37.5 cm were greater than the predicted growth from the von Bertalanffy growth curve (Fig. 3). However, the otolith of this fish sampled during the summer months showed two growth checks, the last having been recently formed.

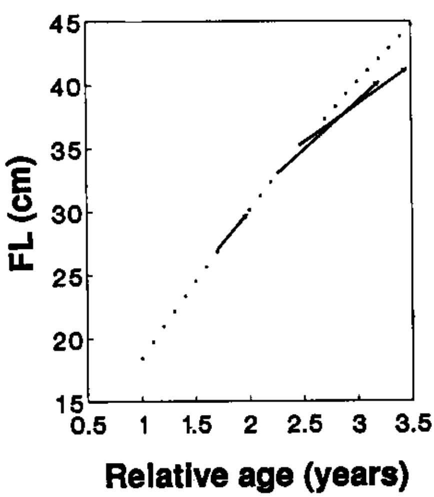

Fig. 3. Observed growth increments of *L. sebae* from tag recaptures (solid lines). Predicted growth is indicated by the von Bertalanffy growth curve (dotted line).

Length Relationships

The parameters of the TL : FL linear regression relationships in the form TL = a + b·FL, for the 'redfish' species (sexes combined) are given in Table 6.

Table 6. Parameters of the regression relationships between total length (TL) and fork length (FL) in the form TL = a + b·FL for 'redfish' species.

	Regression parameters					
Species	a	(s.e.)	b	(s.e.)	R^2	n
L. sebae	-0.21	(0.07)	1.07	(0.001)	0.99	835
L. malabaricus	-0.45	(0.04)	1.04	(0.001)	0.99	1,019
L. erythropterus	-0.06	(0.10)	1.05	(0.002)	0.99	579

Discussion

This study provides the first otolith-based growth estimates for *L. sebae*, *L. malabaricus* and *L. erythropterus* from the GBR. Validation of these growth estimates in general was not possible, but it was considered reasonable to assume that the checks were annual based on: a) unimodal otolith radius distribution; b) the validation of one check for *L. malabaricus*; c) collaborating growth increment data for *L. sebae*; and d) reasonable spacing of growth checks for all 'redfish' species.

The general failure of marginal increment analysis to validate the annual nature of growth checks was noted for tropical lutjanid fishes by Reshetnikov and Claro (1976). Ageing of tropical fishes is complicated by a lower seasonal variability and protracted breeding seasons which reduce the amplitude of the seasonal signal, both in the hard parts and population length/frequency (Brothers 1971; Sainsbury et al. 1989). Protracted spawning seasons of 5-8 months were demonstrated for the three 'redfish' species (McPherson et al. 1992).

Insufficient data were available to indicate the time of annulus formation in 'redfish' species. The formation of a winter growth check on the otoliths of an age group 1 *L. malabaricus* that would mature at five years of age demonstrates that annulus formation for all age classes need not necessarily be related to spawning activity.

Lai and Liu (1979) demonstrated a time of annulus formation in *L. sanguineus* (=*malabaricus* of Allen 1985) from the Australian North-West Shelf in 1973-75 between October and December, while Chen et al. (1984) demonstrated a check formation in May-September for *L. malabaricus* from the same area in 1983-84. No monthly reproductive data were available from the above studies to correlate time of annulus formation with spawning period or other seasonal effects.

Differential Growth Between the Sexes

The growth of male and female *L. sebae* and *L. malabaricus* differs in the older year classes, males being the larger. The present data are at variance with Grimes (1987) who stated that for studies of lutjanid fishes in which a wide range of sizes was sampled, females tended to dominate the larger size classes.

Comparison of the growth curves between sexes of 'redfish' species demonstrated that L_∞ and K were significantly different between the sexes of *L. sebae* and *L. malabaricus*. For *L. erythropterus*, K was significantly different between the sexes.

Tarbit (1980) and Druzhinin and Filatova (1980) stated that adult female *L. sebae* were substantially larger than females in waters of the Seychelles and Gulf of Aden, respectively. Allen (1985) gives the approximate maximum TL of *L. sebae* and *L. malabaricus* as 100 cm, with a maximum age of 10-12 years. From the present data, these observations would be appropriate for males only.

Comparison of 'Redfish' Growth in Other Areas

Comparisons of growth data from the present study with *L. sebae* from Seychelles waters, and with *L. malabaricus* from North-West Shelf waters, are given in Table 7. While the L_∞ of male *L. sebae* from the present otolith-based study and that for combined sexes from the length-frequency-based Seychelles study were comparable, the K parameters were not similar.

The maximum reported weight of *L. sebae* from deep waters (180 m) adjacent to the GBR was 32.7 kg in gutted weight (authors' observations). Extrapolation from limited length-weight data

Table 7. Comparison of age and growth parameters for *L. sebae* and *L. malabaricus*.

			Parameters					
Species	Location	Method	Sex	FL_{max}	L_∞	K	t_0	ϕ'**
L. sebae Present study	Queensland	Ot	M	81	102.5	0.15	-0.32	3.20
			F	72	88.7	0.18	-0.32	3.15
L. sebae Lablache and Carrarra (1988)	Seychelles	Lf	C		100.0	0.25		3.40
L. malabaricus Present study	Queensland	Ot	M	83	98.7	0.18	-0.13	3.24
			F	81	83.8	0.23	-0.13	3.21
L. sanguineus (=*malabaricus*) Lai and Liu (1979)	N-W Shelf	V	M	78				
			F	65				
			C		93.7	0.13	-1.34	3.06
L. malabaricus Chen et al. (1984)	N-W Shelf	V	M	82				
			F	79				
			C		86.1	0.25	-0.08	3.27
L. malabaricus Edwards (1985)	N-W Shelf	V	C	71*	83.5	0.17	0.42	3.07

Sex = M-male, F-female and C-combined
Method= Ot-otolith, V-vertebrae, Lf-length frequency
*= FL estimated from the TL:FL relationship from Table 6.
** $\phi' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro 1984).

(McPherson et al. 1992; unpubl. data) indicated an FL of 116 cm for this fish. This length is within the upper 95% confidence interval of L_∞ for male *L. sebae*. Talbot (1957) reported that this species grew to at least 27.2 kg in eastern African waters.

The FL_{max} data for males and females from the present and other studies of *L. malabaricus* in Australian waters were comparable (Table 7). The L_∞ estimates for combined sex data in North-West Shelf waters were between the estimates for males and females in Queensland waters. However, the K estimates did not show the same tendency.

Marshall (1964) reported a maximum weight of 13.6 kg for *L. malabaricus* in GBR waters. An FL of 102 cm was estimated from the available length-weight data (McPherson et al. 1992). This estimate fell well within the upper 95% confidence interval of L_∞ for males.

Chen et al. (1984) did not find growth differences in length between sexes of *L. malabaricus* off the North-West Shelf, although significant differences were found between the total weight : FL relationships. Males attained heavier weights at a given age than females. No significant differences in length-weight relationships were found between sexes for 'redfish' species in GBR waters.

Significant differences in lengths-at-age were detectable after age group 5 for *L. sebae* and *L. malabaricus*. As the L_m for these species coincided with the length-at-age of age group 5 females, differential growth appeared to begin after attainment of maturity.

Chen et al. (1984) considered that the differential growth in weight of *L. malabaricus* was due to the reproductive burden imposed on females. Ralston and Miyamoto (1983) observed a significant effect of maturation on the growth of male and female *Pristopomoides filamentosus* (Lutjanidae). Growth rate of both sexes declined after the length at maturation.

No comparative age and reproductive data are available for *L. erythropterus*. The present data do not support differential growth in length between the sexes although the K parameter of females was higher. A maximum FL of 64 cm was reported from this study while Allen (1985) gave the maximum TL as approximately 60 cm.

Acknowledgements

Mr. J. O'Brien assisted in the sampling for this program. We thank Captains P. Todd, N. Ridley and A. Williams, and M. Woodley for the provision of additional 'redfish' samples. The statistical assistance of A. Lisle is gratefully acknowledged. Drs. D. Die and K. Sainsbury provided editorial comment.

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Manuscript received 6 March 1991; accepted 30 August 1991.