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Growth of alfonsino *Beryx splendens* Lowe 1834 in the South-West Indian Ocean

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Age and growth of alfonsino *Beryx splendens* from South-West Indian Ocean seamounts were studied based on whole otolith readings. Ages of the fish under study ranged between one year and 14 years (15.5–43.5cm fork length). Age distribution was related to depth. The von Bertalanffy growth parameters for males were L_∞ = 49.1cm, K = 0.099 year^{-1} and t_0 = –4.11 years, and L_∞ = 57.1cm, K = 0.081 year^{-1} and t_0 = –4.16 years for females, obtained by length-age pair values. For all individuals the von Bertalanffy growth parameters were L_∞ = 53.5cm, K = 0.085 year^{-1} and t_0 = –4.33 years. There were no differences in the growth parameters between males and females. Also, the growth parameters of the alfonsino under study did not differ between those of alfonsino from New Caledonia and the Izu Islands (Japan), but they differed significantly from those from New Zealand.

Keywords: age, alfonsino, *Beryx splendens*, growth, Indian Ocean

Introduction

The Berycidae *Beryx splendens* Lowe 1834, commonly called alfonsino, is a circumglobal benthopelagic species that inhabits the outer shelf and slope between 25m and 1 300m depth. The species also inhabits seamounts and underwater ridges. It does not, however, occur in the north-eastern Pacific or the Mediterranean Sea. Several studies on this species have been carried out in regions were it is commercially valuable, e.g. the Atlantic Ocean (Galaktionov 1984), Emperor-Hawaiian Ridge (Pacific Ocean; Humphreys *et al*. 1984), Pacific Ocean (Seki and Tagami 1986), Uglovoye-Submarine Rise (North-East Atlantic Ocean; Sherstyukov and Nostov 1986), Australian Trough (Indian Ocean; Ivanin 1987), Azores (Atlantic Ocean; Isidro 1996), New Caledonia (Pacific Ocean; Lehodey *et al.* 1997) and North Atlantic Ocean (Vinnichenko 1997, 1998).

The present study describes, for the first time, the growth of alfonsino from the South-West Indian Ocean. Growth parameters are compared with those found for this species in the Atlantic and Pacific oceans.

Material and Methods

Specimens of *B. splendens* were collected during an experimental trawl fishery carried out in the South-West Indian Ocean by the Spanish vessel *Puente Ladeira* from October to December 2001, in waters ranging between 600m and 1 350m deep. Catches were taken from the Walters Shoals (Madagascar Plateau) and the Sapmer Seamount (South-West Indian Ridge) following normal commercial fishing procedures (Figure 1).

For each fish, the fork length (FL) was measured to the nearest millimetre. In all, 195 alfonsino were sampled for biological analyses; 107 males ranging in size between 15.5cm and 42.5cm FL, 85 females between 17.8cm and 43.5cm FL, and three of indeterminate sex between 17.2cm and 19.3cm. Sagittal otoliths were removed from each individual, cleaned with water and stored in small envelopes for later analysis.

Age was determined by interpreting growth rings on the whole otolith (Figure 2), which were immersed in water and viewed using a stereo microscope with reflected light under 10x magnification. Each otolith was read by two people independently, with no knowledge of the length of the specimen. The readings for a given otolith were accepted if both readers agreed and/or depending on the reliability of the reading. Four levels of readings were established, ranging from reliable to unreliable, for which only the first two levels were accepted.

The lack of continuity in the monthly samples precluded assessment of the evolution of the marginal rings in the otoliths under study. However, work by De León and Malkov (1979) and age validation of *B. splendens* in the Atlantic Ocean (Kotlyar 1987, Isidro 1996, Rico *et al.* 2001) and the Pacific Ocean (Massey and Horn 1990, Lehodey and Grandperrin 1996a, Adachi *et al*. 2000), strongly suggest that rings with one hyaline and one opaque ring are deposited annually.

The growth study by Kotlyar (1987) in the north-western Indian Ocean was chosen as the one geographically closest to the current study for interpreting the birth date of *B. splendens*. However, this work did not provide the birth date assumed for the species. Therefore, considering the other works by Massey and Horn (1990) and Adachi *et al.* (2000), the 1 August was used as the birth date of the fish under study. In order to validate the age reading technique used here, the position of each ring was measured and compared with successive ring groups and with results from other regions. Measurements of the radii of each otolith, from the focus to the anterior edge of each hyaline zone (r_n; Figure 3), were made using a micrometer eyepiece. In addition, the mean length-at-age evolution for males and females was determined.

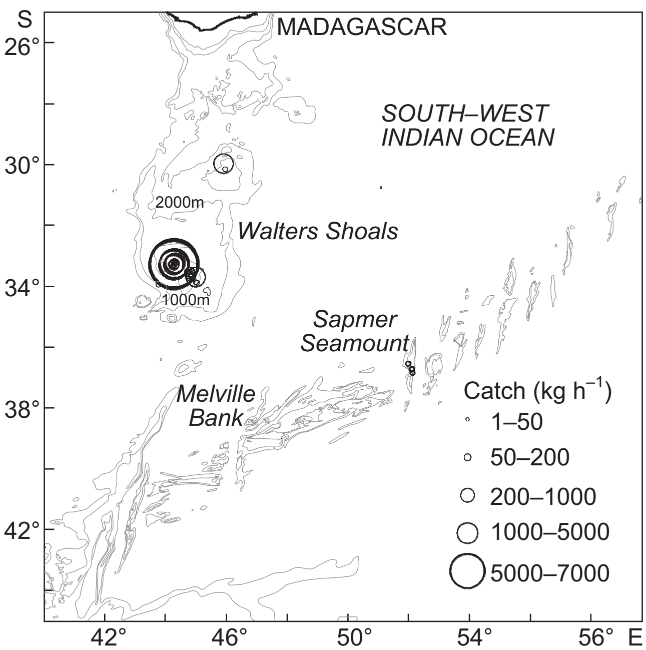

Figure 1: Map of the study area (Walters Shoals and Sapmer Seamount) showing the catch rates of *B. splendens*

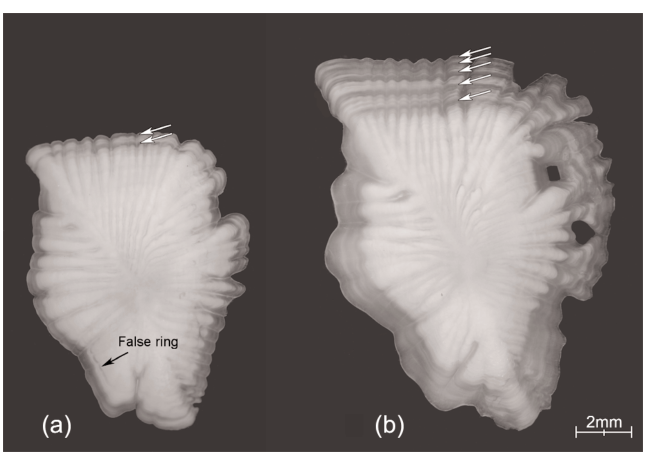

Figure 2: Sagittal otoliths of *B. splendens* assigned an age of (a) 2 years and (b) 5 years. The reading line shows the most common path used to identify annual rings

The age-length relationship was established for males, females and all individuals, using 1-cm size intervals (rounding off to the lower centimetre). The mean size and the standard deviation by age-class were estimated, taking as a reference the mid-point of the size interval. The age-length key for all individuals was applied to the length distribution to obtain the age composition of the catches.

The growth parameters for males, females and for all individuals were estimated by means of a non-linear regression, using the Levenberg-Marquardt algorithm (SPSS Inc.). Length-age pair values were fitted to the von Bertalanffy growth function:

$$L_t = L_\infty (1 - e^{-K(t - t_0)})$$

where L_t is length (FL) at time t (years), L_∞ the asymptotic length, K the growth coefficient and t_0 the hypothetical time when fish length is zero. Differences between growth parameters by sex were tested by the Hotelling's T^2 statistic for unequal variance-covariance matrices (Cerrato 1990, Quinn and Deriso 1999).

An analysis of covariance (ANCOVA; Zar 1984) was used to compare length-at-age values from different locations using a linearised relationship between length and age (ln [age]).

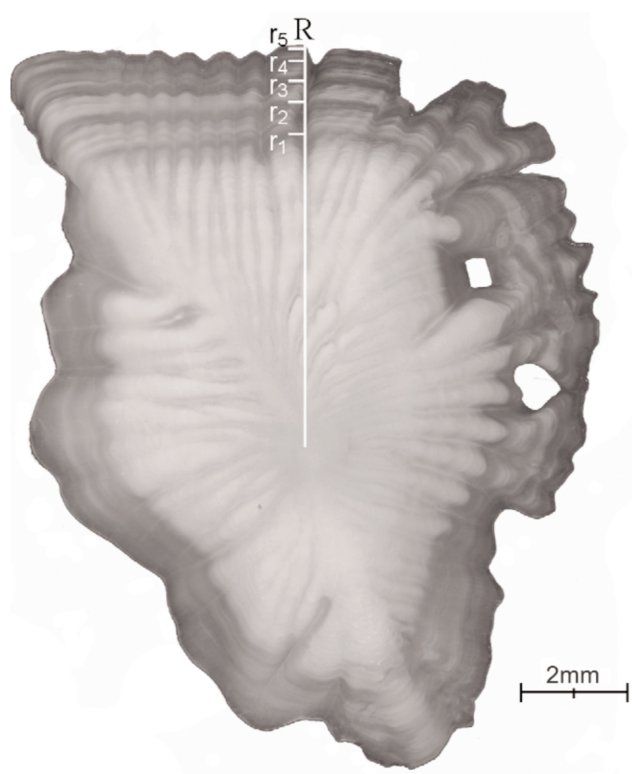

Figure 3: Sagittal otolith of *B. splendens* showing the measurement method used for the radii (r_n) and otolith radius (R)

Results and Discussion

Age interpretation

Otoliths of small *B. splendens* were easy to read, but they generally had false rings. Irregular shapes appeared from about the eighth ring, making reading difficult. Despite these problems, only two readings were rejected and 195 were accepted for analysis. The age assignment and the border shape of an alfonsino otolith are shown in Figure 2. A common feature was the presence of a narrow opaque zone very close to the first ring, which is likely a result of physiological and/or seasonal changes, food availability or environmental fluctuation (Figure 2a). Considering the narrower width of such rings compared with that of the ring following it, it was considered to be a false ring and consequently was included and counted with the ring closest to it. This interpretation was also assumed by De León and Malkov (1979) for *B. splendens* in the West-Central Atlantic. For alfonsino in New Zealand waters, Massey and Horn (1990) referred to such false rings as check rings and not as annual growth rings.

Table 1 lists information on the mean radius of the anterior edge of each hyaline zone of *B. splendens* otoliths from studies in the Pacific, Atlantic and Indian oceans. The locations of the outer ring groups were not analysed in those studies because of the scarcity of information. The analysis of the hyaline zone position in the otoliths of alfonsino from New Zealand (Massey and Horn 1990) indicates that ring counts were accurate for higher ring groups (10–15 rings).

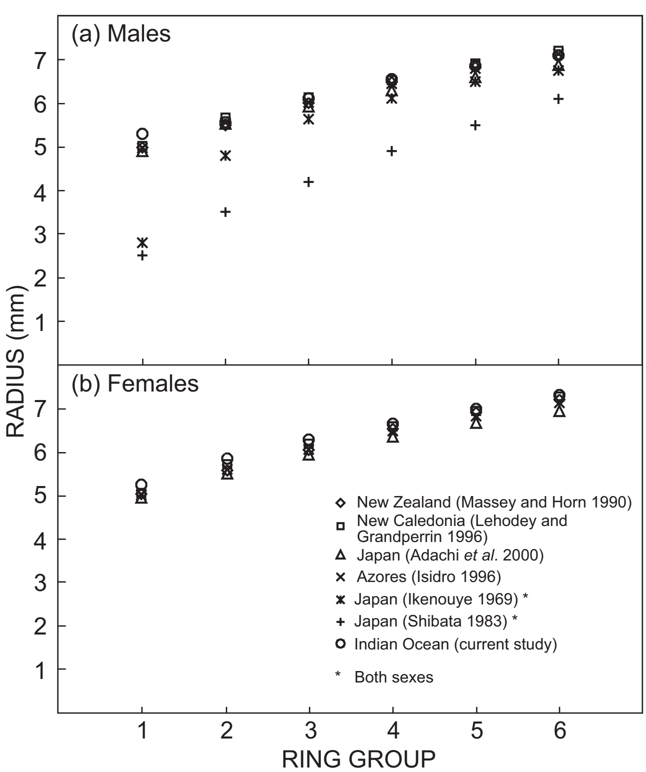

Figure 4: Mean radius of each otolith hyaline zone for (a) male and (b) female *B. splendens* from different geographical regions

Table 1: Information on mean radius measurements of *B. splendens* otoliths from different locations

Reference	Ocean	Region	Sex	Radius (mm)																						
				r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{17}	r_{18}	r_{19}	r_{20}	r_{21}	r_{22}	r_{23}
Massey and Horn (1990)	Pacific	New Zealand (Palliser Bank)	Male	4.99	5.50	6.01	6.48	6.83	7.11	7.21																
			Female	5.04	5.58	6.05	6.54	6.92																		
Ikenouye (1969, in Massey and Horn 1990)	Pacific	Japan (Sagami Bay)	Both sexes	2.80	4.80	5.63	6.11	6.49	6.75	7.02																
Shibata (1983)	Pacific	Japan (Chiba)	Both sexes	2.50	3.50	4.20	4.90	5.50	6.10																	
Lehodey and Grandperrin (1996a)	Pacific	New Caledonia	Male	5.02	5.67	6.13	6.53	6.91	7.20	7.49	7.67	7.83	8.05	8.25	8.43	8.52	8.68		9.19							
			Female	5.06	5.72	6.20	6.59	6.95	7.28	7.58	7.82	8.06	8.31	8.53	8.74	8.85	8.99									
Adachi *et al.* (2000)	Pacific	Japan (Izu Islands)	Male	4.90	5.53	5.92	6.29	6.60	6.87	7.11	7.35	7.52	7.69	7.84	7.98	8.10	8.18	8.26	8.37	8.36	8.50	8.59	8.85	8.95	9.05	9.15
			Female	4.96	5.51	5.95	6.36	6.68	6.95	7.24	7.46	7.68	7.88	8.02	8.14	8.26	8.39	8.56	8.72	8.79	8.93	9.08	9.18	9.35		
Isidro (1996)	Atlantic	Azores	Male	4.97	5.55	6.02	6.45	6.79	7.13	7.42	7.78	8.05														
			Female	5.01	5.60	6.07	6.49	6.83	7.14	7.43	7.74	8.01														
			Both sexes	5.00	5.58	6.04	6.47	6.81	7.13	7.43	7.75	8.02														
Current study	Indian	South-West Indian Ocean	Male	5.30	5.57	6.11	6.55	6.85	7.10	7.29	7.46	7.68	7.95	8.37	8.47	8.55	8.61									
			Female	5.25	5.85	6.29	6.66	7.00	7.31	7.65	7.92	8.06	8.23	8.23	8.00	8.10	8.20									
			Both sexes	5.28	5.69	6.19	6.59	6.91	7.19	7.43	7.64	7.84	8.06	8.30	8.35	8.10	8.20									

Although no data were available to validate that these rings were formed annually, this interpretation was also used in our study.

Figure 4 presents the relationship between radii and ring groups 1–6 for male and female *B. splendens* from different geographical regions. The results from Ikenouye (1969) and Shibata (1983) from Japanese waters were also included in the figure, although those studies did not differentiate between sexes. The first ring placed by Ikenouye (1969) suggests an age misinterpretation, if compared with the other studies. It is likely that the false rings assumed by other authors were considered as true rings by Ikenouye (1969). However, from the third year, the locations of the radii in Ikenouye's study were within or close to the values given for other regions. Although Ikenouye (1969) concluded that two hyaline bands were formed each year in fish older than about three years (see Figure 4), this is not consistent with the pattern of the formation of one ring being laid down annually, which was assumed in the other studies. Shibata (1983) presented a more logical progression of measurements according to the rings, which seems to indicate different growth rate in the Japanese alfonsino off the coast of Chiba compared with other regions, e.g. the Izu Islands (Adachi *et al.* 2000).

In the current study, with the exception of Ring 1 where the ring widths for males and females were similar, ring width was always greatest in females. This feature is common for alfonsino in other regions. The position of each ring group according to by sex (Figure 4) is similar to that reported for alfonsino from New Zealand, New Caledonia, Japan and the Azores (Figure 4). From these results, it seems likely that one annulus is formed per year in *B. splendens*.

Age-length relationship

In both sexes, the ages of the individuals studied ranged between one year and 14 years. Juveniles (Age 0) were absent in the collections, most likely because of their benthopelagic behaviour (Lehodey and Grandperrin 1996a), which made them unavailable to the bottom trawls. Males aged 11 years and 13 years, and females aged 13 years, were not present in the collections.

Table 2: Age-length key of *B. splendens* for all individuals taken from the South-West Indian Ocean

	Age-class (year)													
Size-class (FL, cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
15	1													
16														
17	5													
18	5	2												
19	12	4												
20	10	11	1											
21	4	11												
22	3	10	2											
23		8	4											
24		11	4											
25		3	7	3										
26		1	6	6	1									
27			5	5	1									
28			1		2	1								
29			1					2						
30					2	1			1					
31						1	1							
32					1	3	1							
33						1	1							
34									1	1				
35							1	2	3	1				
36							2		2	1				
37									1		1			
38								1	1					
39										1		1		
40								1		1				1
41									1					1
42											1	2		
43												1		
44														
45														
46														
47														
Mean length (cm)	19.7	22.3	25.5	26.6	29.2	31.6	34.3	34.8	36.2	37.3	40.0	42.0		41.0
(SD, cm)	1.54	1.90	1.95	0.77	2.06	1.68	2.14	4.55	2.83	2.59	3.54	1.73		0.71
n	40	61	31	14	7	7	6	6	10	5	2	4		2

The age-length key for all alfonsino examined is shown in Table 2. The greatest proportion were age-class 2 (31.3%), followed by age-class 1 (20.5%) and age-class 3 (15.9 %). The mean length-at-age for age-classes 1–10 years did not differ significantly between male and females (two-way ANOVA, p = 0.0621). This trend was particularly apparent for age-classes 1–4 years (Figure 5).

The estimated mean length-at-age of alfonsino differed between regions in the Atlantic Ocean but the difference was not considerable (Table 3). Only one other growth study of alfonsino was carried out in the Indian Ocean, that of Kotlyar (1987), which reported lower estimates of length-at-age than found in the current study.

Size and age distribution

Length frequency distributions of catches per 100m depth stratum (600–1 000m) are shown in Figure 6. Length varied

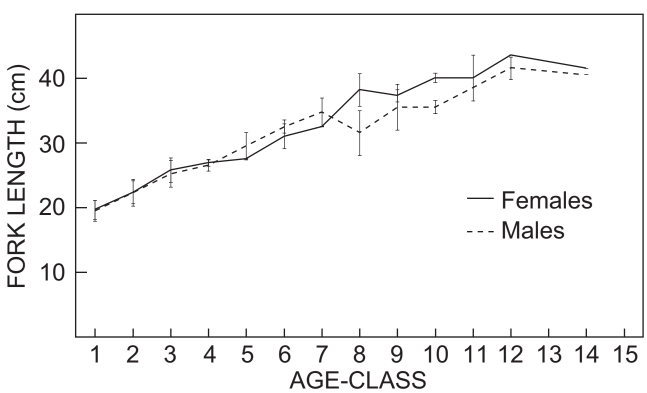

Figure 5: Mean length-at-age for male and female *B. splendens* caught in Walters Shoals and Sapmer Seamount (South-West Indian Ocean)

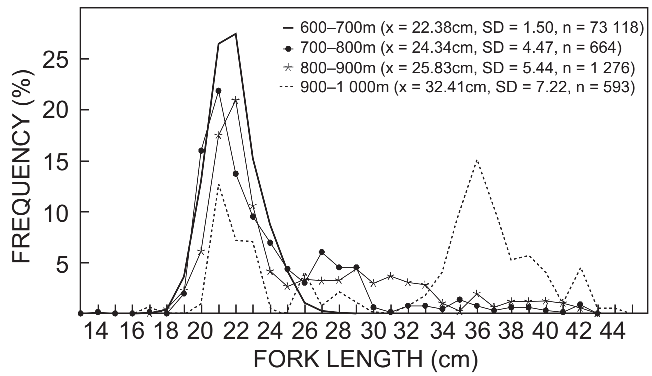

Figure 6: Length composition of *B. splendens* by depth strata of catches from Walters Shoals and Sapmer Seamount

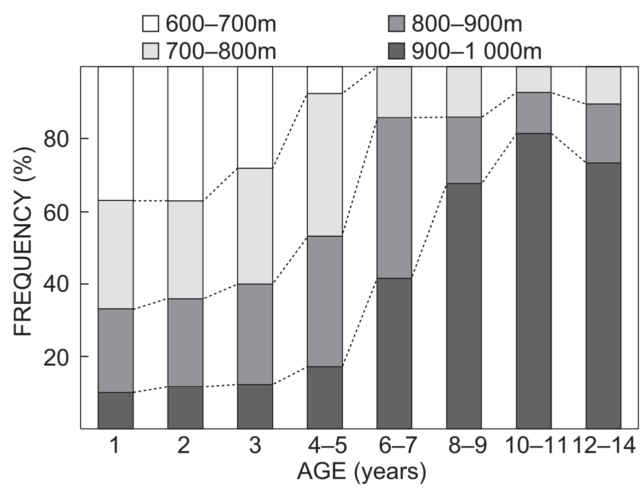

Figure 7: Age distribution of *B. splendens* by depth strata of catches from Walters Shoals and Sapmer Seamount

Table 3: Mean length-at-age of *B. splendens* from different geographical regions (males and females combined)

	Indian Ocean		Atlantic Ocean					
Age-class	Current study (South Madagascar)	Kotlyar (1987) (Error Seamount)	De León and Malkov (1979) (New Year Rise)	De León and Malkov (1979) (Angular Rise)	Isidro (1996) Azores	Rico *et al.* (2001) Canary Islands	Rico *et al.* (2001) Madeira	Rico *et al.* (2001) Azores
0							17.2	18.5
1	19.7	15.2			18.3	19.5	19.7	20.7
2	22.3	17.1	20.5		20.9	25.0	21.6	24.3
3	25.5	20.3	26.1		23.7	27.4	24.3	27.0
4	26.6		28.5	32.7	26.1	30.1	26.5	30.6
5	29.2	28.0	31.0	35.0	28.6	31.6	27.9	32.4
6	31.6		34.4	37.9	31.3	33.6	29.6	32.8
7	34.3		35.5	38.7	33.2	35.3	31.3	35.2
8	34.8		37.7	40.6	34.6	36.5	33.5	36.9
9	36.2		39.6	41.2	36.7	36.3	34.5	35.2
10	37.3			42.5	37.0		33.5	37.5
11	40.0			44.0	38.5		37.5	40.5
12	42.0						40.5	
13								
14	41.0							
15								

Table 4: Growth parameters of *B. splendens* from different geographical regions

Area	Sex	K	L_∞	t_0	Reference
	Atlantic Ocean				
New Year Rise	Both sexes	0.209	44.8	−0.89	De León and Malkov (1979)
Angular Rise	Both Sexes	0.170	48.5	−2.63	De León and Malkov (1979)
Vavilov Ridge	Both Sexes	0.112	48.6	−2.63	Isarev (1991)
Azores	Both Sexes	0.083	56.7	−3.51	Isidro (1996)
Azores	Both Sexes	0.111	50.0	−2.81	Isidro (1996) *
Azores	Males	0.085	53.7	−4.02	Anibal *et al.* (1998)
Azores	Females	0.133	45.3	−2.74	Anibal *et al.* (1998)
Azores	Both Sexes	0.120	46.1	−3.18	Anibal *et al.* (1998)
Azores	Both Sexes	0.170	43.1	−2.80	Rico *et al*. (2001)
Madeira	Both Sexes	0.060	58.7	−5.71	Rico *et al*. (2001)
Canary Islands	Both Sexes	0.150	44.5	−3.41	Rico *et al*. (2001)
	Pacific Ocean				
Japan (Sagami Bay)	Both Sexes	0.505	33.7	–	Ikenouye and Masuzawa (1968)
Japan (Sagami Bay)	Both Sexes	0.225	42.9	–	Ikenouye and Masuzawa (1968)
Japan (Sagami Bay)	Both Sexes	0.457	34.8	–	Ikenouye and Masuzawa (1968)
Japan (Sagami Bay)	Both Sexes	0.439	37.8	0.40	Ikenouye (1969)
Japan (Sagami Bay)	Both Sexes	0.323	45.8	−0.22	Masuzawa *et al.* (1975)
Japan (Zunan Sea)	Both Sexes	0.181	54.4	−0.08	Masuzawa *et al.* (1975)
Japan (Chiba)	Both Sexes	0.137	65.6	−1.05	Shibata (1983)
Japan (Izu Islands)	Males	0.132	44.4	−3.45	Adachi *et al.* (2000)
Japan (Izu Islands)	Females	0.150	45.0	−2.08	Adachi *et al.* (2000)
New Zealand (Palliser Bank)	Males	0.110	51.1	−3.56	Massey and Horn (1990)
New Zealand (Palliser Bank)	Males	0.116	49.6	−3.67	Massey and Horn (1990) *
New Zealand (Palliser Bank)	Females	0.088	57.5	−4.10	Massey and Horn (1990)
New Zealand (Palliser Bank)	Females	0.087	57.9	−4.17	Massey and Horn (1990) *
New Zealand (Tuaheni High)	Males	0.093	54.9	−4.30	Massey and Horn (1990)
New Zealand (Tuaheni High)	Females	0.042	76.3	−8.25	Massey and Horn (1990)
New Zealand (Paoanui Ridge)	Males	0.144	49.1	−1.81	Massey and Horn (1990)
New Caledonia (Norfolk-Loyalty)	Males	0.146	45.2	−2.34	Lehodey and Grandperrin (1996a)
New Caledonia (Norfolk-Loyalty)	Females	0.134	50.8	−2.00	Lehodey and Grandperrin (1996a)
New Caledonia (Norfolk-Loyalty)	Both Sexes	0.119	51.3	−2.51	Lehodey and Grandperrin (1996a)
	Indian Ocean				
South-West Indian Ocean (Walters Shoals and Sapmer Seamount)	Males	0.099	49.1	−4.11	Current study
South-West Indian Ocean (Walters Shoals and Sapmer Seamount)	Females	0.081	57.1	−4.16	Current study
South-West Indian Ocean (Walters Shoals and Sapmer Seamount)	Both Sexes	0.085	53.5	−4.33	Current study

* Back-calculation

between 14cm and 44cm FL. In the shallow stratum (600–700m), there was a unimodal distribution ranging between 18cm and 28cm. The length distribution of fish in the 700–800m stratum was similar to that of fish in the 800–900m stratum. In the deepest stratum (900–1 000m), alfonsino had a bimodal length distribution: one at 17–29cm and the other at 32–44cm. Mean fish length increased with depth, from 22.38cm in the 600–700m stratum to 32.41cm in the 900–1 000m stratum. Lehodey *et al.* (1994) also found an increase in the mean length of alfonsino with depth over the seamounts off New Caledonia.

In the catches, 68% of alfonsino were 1–3-year-olds and 32% were 4–14-year-olds. No fish younger than 5 years was found deeper than 700m and the oldest fish (8–14-year-olds) were mainly found deeper than 900m (Figure 7). The age composition was similar in fish caught between 700m and 900m deep. This finding suggests that fish migrate to deeper water as they get older (ontogenetic migration), which concurs with observations on alfonsino by Massey and Horn (1990) in New Zealand. Larvae and juvenile alfonsino appear to be pelagic for several months before they settle on the bottom (Lehodey and Grandperrin 1996a).

Growth

The growth parameters estimated for *B. splendens* in the South-West Indian Ocean are within the range of those obtained for this species in the Atlantic and the Pacific oceans (Table 4). For males, females and all individuals examined the coefficient of determination (r^2) was high at 0.89, 0.92 and 0.90 respectively.

The fitted growth curves, their confidence limits and the length range for males, females and all individuals combined are presented in Figure 8. There were no significant differences in growth between sexes (Hotelling T^2 = 4.839;

Table 5: Comparing of linearised growth curves of *B. splendens* from different geographical regions with those of the current study

Ocean	Area	F-values	p	Significance	Reference
			Males		
Pacific	New Zealand (Palliser Bank)	10.980	$p < 0.0005$	***	Massey and Horn (1990)
	New Zealand (Tuaheni High)	17.545	$p < 0.0005$	***	Massey and Horn (1990)
	New Zealand (Paoanui Ridge)	16.556	$p < 0.0005$	***	Massey and Horn (1990)
	New Caledonia (Norfolk-Loyalty)	1.138	$p > 0.25$	ns	Lehodey and Grandperrin (1996a)
	Japan (Izu Islands)	0.513	$p > 0.25$	ns	Adachi *et al.* (2000)
			Females		
Pacific	New Zealand (Palliser Bank)	3.853	$0.025 < p < 0.05$	*	Massey and Horn (1990)
	New Zealand (Tuaheni High)	7.753	$0.001 < p < 0.0025$	**	Massey and Horn (1990)
	New Caledonia (Norfolk-Loyalty)	2.494	$0.10 < p < 0.25$	ns	Lehodey and Grandperrin (1996a)
	Japan (Izu Islands)	4.846	$0.01 < p < 0.025$	*	Adachi *et al.* (2000)

ns Not significant
* Significant
** Very significant
*** Highly significant

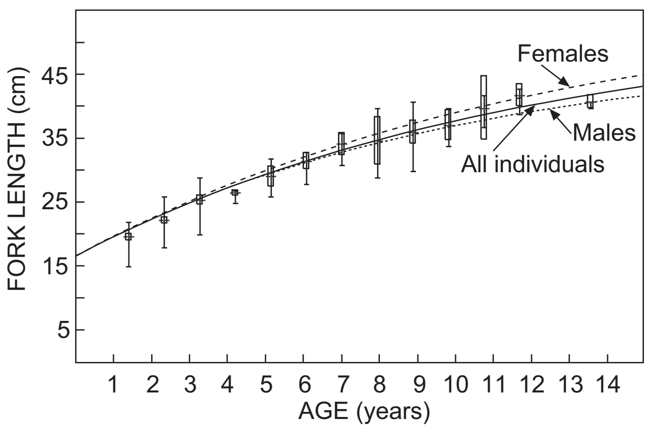

Figure 8: Von Bertalanffy growth curve for males, females and all individuals of *B. splendens* combined. Vertical lines represent length range and bars indicate mean ± 2SE

$0.10 < p < 0.25$ <; $\chi^2_{0.05,3} = 7.815$). This finding concurs with the results reported by Kotlyar (1987), Isidro (1996), Anibal *et al.* (1998) and Rico *et al.* 2001) for alfonsino from the Atlantic Ocean. However, off New Zealand, Massey and Horn (1990) found that female alfonsino were significantly larger than males at a given age. Significant differences in growth between sexes were also observed in alfonsino off New Caledonia (Lehodey and Grandperrin 1996a) and off Japan (Adachi *et al.* 2000).

An ANCOVA was used to test for differences in alfonsino growth from different geographical regions (Table 5). Only length-at-age values obtained from growth parameters that were estimated using a similar method as the current study were considered in the comparison. No significant differences in growth were found in either male or female alfonsino between New Caledonian and South-West Indian oceans, and growth in males was similar between alfonsino in Izu Islands, Japan and those in the current study. Growth in stocks from New Zealand differed considerably, particularly in males, from the South-West Indian Ocean stocks. Differences in growth among regions could be related to hydrographic conditions (Rico *et al.* 2001, Lehodey and Grandperrin 1996b) as well as food availability (Lehodey and Grandperrin 1996a) and feeding behaviour (Kakora 2005).

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