Population Dynamics of *Harengula humeralis* and *Harengula clupeola* (Pisces, Clupeidae) in the Archipiélago de los Roques National Park, Venezuela

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ABSTRACT

Length-frequency data of the red ear herring, *Harengula humeralis* (Cuvier) and the false pilchard, *Harengula clupeola* (Cuvier) caught in the Archipiélago de Los Roques National Park, were used to derive growth and mortality parameters with the ELEFAN methods. The von Bertalanffy growth parameters were estimated as L = 20.1 cm and K = 0.52 year^{-1} for *H. humeralis* and L = 15.9 cm and K = 0.69 year-1 for *H. clupeola*. Results show that seasonal growth is important (*C* = 0.3, WP = 0.2, for both species). The growth parameters estimated are consistent with the assumption that clupeids are a small, fast growing and short lived species and fall within reported growth values for clupeids from other studies. Total mortality was estimated at 3.62 year-1 and 5.25 year^{-1} for *H. humeralis* and *H. clupeola* respectively, using length-converted catch curve analysis. Natural mortality values estimated using Pauly's (1978) relationship were 0.90 year^{-1} for *H. humeralis* and 1.17 for *H. clupeola*. Fishing mortality was 2.74 year^{-1} and 4.08 year^{-1} respectively for both mentioned species. Exploitation ratio, E, of approximately 0.7 for both species indicates that stocks are subject to high fishing pressure at the sampling site.

KEY WORDS: ELEFAN, *Harengula humeralis*, *Harengula clupeola*, length-frequency, population dynamics, Venezuela.

RESUMEN

La distribución de frecuencia de tallas de la manzanillera, *Harengula humeralis* (Cuvier) y la carapachona, *Harengula clupeola* (Cuvier) capturadas en el Parque Nacional Archipiélago de Los Roques, fue utilizada para derivar los parámetros de crecimiento y mortalidad para cada especie siguiendo las especificaciones del método ELEFAN. Los parámetros de la ecuación de crecimiento de von Bertalanffy fueron estimados como L = 20.1 cm y K = 0.52 year^{-1} para *Harengula humeralis* y L = 15.9 cm y K = 0.69 year^{-1} para *Harengula clupeola*. Los resultados muestran que la estacionalidad en el crecimiento es importante (*C* = 0.3, WP = 0.2, para ambas especies). Los parámetros de crecimiento estimados son consistentes con la asunción de que los clupeidos solo alcanzan pequeño tamaño, presentan un crecimiento acelerado y su ciclo de vida es corto, encontrándose correspondencia con lo estimado para otras especies en esta familia. Usando el análisis "length-converted catch curve", la mortalidad total era estimada en 3.62 year^{-1} y 5.25 year^{-1} para *Harengula humeralis* y *Harengula clupeola*, respectivamente. La mortalidad natural era estimada a partir de la ecuación de Pauly (1978) y corregida por un factor de 0.7

como se recomienda para el caso de clupeidos, siendo los valores estimados de 0.90 year^{-1} para *Harengula humeralis* y 1.17 year^{-1} para *Harengula clupeola*. La mortalidad por pesca fue estimada en 2.74 year^{-1} y 4.08 year^{-1} para cada especie mencionada, respectivamente. La razón de explotación, E, estimada en 0,7 para ambas especies indica que las poblaciónes estan sujetas a alta presión de pesca en el sitio de muestreo.

INTRODUCTION

The fishes of the family Clupeidae are an important group of pelagic fish, both in terms of their commercial value and as a food resource for numerous marine mammals, fishes, birds and turtles (Rivas, 1963). The family contains 80 genera and 300 species at the global level. In the Western Central Atlantic Ocean a total of 16 genera and 33 species have been reported (Whitehead, 1978, 1985). In Venezuela there are presently 11 genera and 17 species, of which 3 belong to the genus *Harengula: H. humeralis* (Cuvier)(manzanillera, red ear herring), *H. clupeola* (Cuvier)(carapachona, false pilchard), and *H. jaguana* (Storey)(carapachona, scaled sardine). Descriptions of the habitat and general habits of these species are found in Rivas (1963), Hildebrand (1963), Whitehead (1978), and Cervigón (1991).

Both species, *H. humeralis* and *H. clupeola*, are common at the Archipiélago de Los Roques National Park as well as in other oceanic island and coastal zones of Venezuela. They form large schools over seagrass beds and among coral reefs in shallow waters. While at some Caribbean islands these species are commercially exploited (Grant, 1981; Harvey, 1982), in other areas, such as Venezuela and Antigua, those are considered highly toxic and not suitable for human consumption (Brody, 1972; Cervigón, 1991).

Several authors have reported on the biology and ecology of both species (Hubold and Mazzetti, 1982; Bustamante *et al.*, 1990; Garcia-Arteaga, 1990; Cervigón, 1991; Posada *et al.*, 1988). Age, growth, and mortality for some members of the genus have been estimated using age-at-length and length-frequency (Petersen) data. However, estimating growth rate of the species by the use of modal progression analysis, specifically the Compleat ELEFAN software package of Gayanilo *et al.* (1989), has not been attempted. The objectives of this study are to estimate growth and mortality parameters by using the Compleat ELEFAN and compare them with those previously obtained using other techniques.

METHODS

Seagrass beds near the keys Dos Mosquises Norte and Sur, in the Archipiélago de Los Roques National Park were chosen as sampling sites for this study (Figure 1). The archipelago is a complex reef system situated 155 km north of the central coast of Venezuela (11°44'/11°58' N and 66°33'/66°57'W).

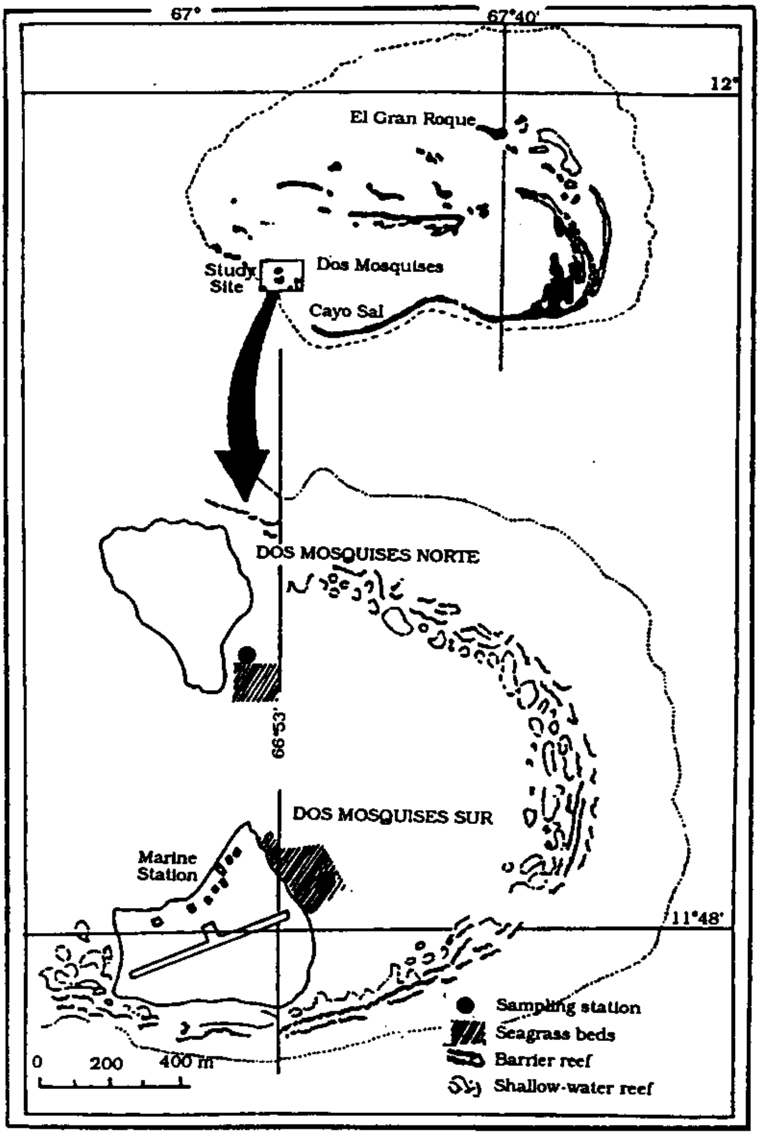

Figure 1. Map of the Archipiélago de Los Roques National Park, showing sampling stations at Dos Mosquises Norte and Sur Keys.

Fishes were caught twice a month between April 1986 and May 1987 with beach seines of 1.5-cm stretched mesh. The maximum sample size was 150 individuals per species, taken randomly from the total catch. When fortnightly samples were not big enough, they were grouped on a monthly basis. Total lengths (TL) of 3717 and 3019 fish of *H. humeralis* and *H. clupeola*, respectively, were measured to the nearest 0.1 centimeter.

Data Preparation

A preliminary analysis was done to estimate the optimum interval width and sample size for length frequency analysis. From those results, Posada (unpubl. ms) recommended a 1.0 cm interval width and fortnightly sampling. Higher or lower interval widths or a monthly sampling basis were rejected based on the greater difficulty in distinguishing modes or peaks in size frequencies. Sampling on a fortnightly basis is more suitable in species of small size, fast growth, short-life, and high mortality such as herrings. The size-frequency distribution of the catch can be expected to change rapidly with time, reflecting the simultaneous impact of both growth and mortality (Caddy, 1986).

Analysis Procedure

1. Data were entered into the computer using the ELEFAN 0 routine of the Compleat ELEFAN package (Gayanilo *et al.*, 1989).

2. The "curve-fitting-by-eye" routine of ELEFAN I was used to check whether any modal progression of peaks was visible, as indicated by the "restructurated" length-frequency data.

3. The Wetherall *et al.* (1987) routine of ELEFAN II was used to obtain a preliminary estimate of L .

4. A rapid estimate of the growth coefficient, K, was obtained using an empirical relationship proposed by Pauly and Munro (1984), as modified by Appeldoorn (in press):

$$' = \mathrm{Log}_{10}\,K + 0.75\,\mathrm{Log}_{10}\,L$$

where L is the value previously obtained and ' is the growth performance index for interspecific comparisons based on length. A search was made through the literature for data on the growth of populations of *Harengula* spp.

5. The "response-surface" routine of ELEFAN I was used to refine the estimates of L and K. The logic of ELEFAN I implies that one should pick the value of K and L associated with the highest Rn value (best fit parameter); however, some constraints were imposed considering the biology of these species and clupeids in general.

6. The growth parameters originally estimated in part 5 above were then re-estimated by adding in a seasonal growth oscillation (Pauly and Gaschütz,

1979; Somers, 1988) . Seasonality of growth is important to consider in the case of short-lived species such as clupeids. Various studies summarized in Longhurst and Pauly (1987) have demonstrated that the growth of fishes and aquatic invertebrates oscillates seasonally, even in the tropics.

7. An optimization of L , K, *C* and WP estimates were reached through the "automatic search" routine of ELEFAN I, which allow a narrow search around the initial values until one feels confident that the best curve has been identified.

8. The jackknife method was used to estimate the 95% confidence limits for L and K (Pauly, 1984). Computationally, the jackknife involves the successive estimation of L and K values (equal in number to the total number of samples) but omitting each time a different fortnight's sample. The standard deviations of these estimates are used to generate 95% confidence intervals.

9. Length-converted catch curves, based on pooling of percent samples, were used to estimate total mortality (Z) and to derive approximate probabilities of capture by length. An estimate of Z is obtained when the following function is adjusted to the points of the right descending arm of the catch curve:

$$\mathrm{Log}_e\ (Ni\ /\ \ t) = a + b_{ti}$$

where Ni is the number of fish in the i-th length class, t is the time required for the fish to grow through length class i, a is the intercept, ti is the mean (relative) age of the fishes in that length class i, and the slope of the regression line (b) is an estimate of Z with sign changed. The standard deviation of the slope was used to calculate 95% confidence limits around Z.

10. The left arm of the length-converted catch curve, composed of size classes too small to be fully retained by the gear, was used to estimate the probabilities of capture by length (under the assumption of a trawl-type selection fit to the logistic function).

11. Natural mortality (M) was estimated using the Pauly (1980) empirical relationship, with T = 27.5 °C (average water temperature at Los Roques), corrected by a factor of 0.7 as recommended in the case of clupeids (Kiinzel and Löwenberg, 1990). Fishing mortality, F, was computed as F = Z - M, while exploitation rate, i.e., the ratio of fishing mortality to total mortality, was computed from E = F/Z.

12. Using ELEFAN II, an annual recruitment pattern was obtained by projecting the length-frequency data backward onto the time axis using the growth equation to recover the pulsing of annual recruitment (Pauly, 1986). The absolute position of recruitment frequency on the time axis is not known, because the true value of t_0 is unknown. This information could be used to corroborate evidence obtained from data on the reproductive activity of the fish.

13. In order to compare different estimates of growth parameters, the empirical equation of ϕ', as originally described by Pauly and Munro (1984) and

Table 1. Length-frequency data on *Harengula humeralis* collected between April 1986 and May 1987 at Dos Mosquises Key, Archipíelago de Los Roques National Park.

Midlength (cm)	4/2/86	5/7	6/1	6/23	7/4	7/21	8/2	8/21	9/15	10/15	11/4	11/18
4.0-4.99												
5.0-5.99												
6.0-6.99							1					
7.0-7.99							0					
8.0-8.99	3		2	1			1			1	3	1
9.0-9.99	54	1	14	4	2	1	19			22	62	3
10.0-10.99	51	30	38	22	11	27	44	13	3	49	57	29
11.0-11.99	22	77	64	65	34	34	47	19	17	64	12	39
12.0-12.99	10	36	24	48	48	35	32	50	32	25	7	54
13.0-13.997	4	5	9	37	37	5	60	45	15			
14.0-14.99	3	2	3	1	17	13	1	7	41	4	1	9
15.0-15.99					1	2		0	31		0	0
16.0-16.99						0		1	6		1	1
17.0-17.99						1						
Total	150	150	150	150	150	150	150	150	175	180	150	150

Midlength (cm)	12/1	12/18	1/5/87	1/17	2/4	2/17	3/5	3/23	4/1	4/19	5/4	5/18
4.0-4.99									2			
5.0-5.99									6			
6.0-6.99									3			
7.0-7.99									1			
8.0-8.99									9	10		
9.0-9.99	1	30	4	6	2	3	1		21	58		1
10.0-10.99	29	102	81	81	10	39	7	19	39	49	6	39
11.0-11.99	51	14	40	43	44	49	44	35	77	25	25	50
12.0-12.99	37	3	16	18	35	34	45	42	41	5	43	30
13.0-13.997	21	1	7	2	37	13	22	26	16	3	35	19
14.0-14.99	10		1		17	7	21	13	5		19	7
15.0-15.99	1		1		3	7	9	14			8	3
16.0-16.99					1		1	1			3	1
17.0-17.99					1						1	
Total	150	150	150	150	150	152	150	150	220	150	140	150

the parameter Φ′, as modified by Appeldoorn (in press) for interspecific comparisons were used.

RESULTS

Length frequency distributions used for the estimation of growth parameters for *H. humeralis* and *H. clupeola* are presented in Table 1 and 2, respectively.

Table 2. Length-frequency data on *Harengula clupeola* collected between April 1986 and May 1987 at Dos Mosquises Key, Archipíelago de Los Roques National Park.

Midlength (cm)	4/2/86	5/7	6/1	6/23	7/15	8/15	9/15	10/15	11/8	11/23
6.0-6.99										
7.0-7.99				1			1		5	
8.0-8.99	23			2	10	1	2	37	31	4
9.0-9.99	79	20	10	14	35	24	13	76	56	118
10.0-10.99	45	109	78	64	91	74	11	71	42	28
11.0-11.99	3	21	61	54	67	75	15	39	15	56
12.0-12.99			1	14	8	1	4	4	1	
13.0-13.99				1						
Total	150	150	150	150	211	175	46	227	150	150

Midlength (cm)	12/15	1/15/87	2/4	2/17	3/15	4/1	4/19	5/4	5/18
6.0-6.99						3			
7.0-7.99		1				24			
8.0-8.99	4	14		7	2	32			
9.0-9.99	38	40	2	45	12	11	10	5	9
10.0-10.99	89	76	68	79	41	54	24	31	17
11.0-11.99	56	46	76	17	39	73	81	82	60
12.0-12.99	3	6	4	2	17	21	30	28	51
13.0-13.99		1			4	3	5	4	13
Total	190	184	150	150	115	221	150	150	150

For *H. humeralis*, the Wetherall *et al.* (1987) plot combined with the mean Φ' value of 0.569 (from *H. jaguana* and *H. humeralis*, Table 3) provide a preliminary estimate of L = 18.3 cm (Figure 2A) and K = 0.42 year^{-1}; subsequent refining using the ELEFAN I program described the growth of this species by the parameters L = 20.1 + 0.5 cm, K = 0.52 + 0.15 year^{-1}, *C* = 0.32 and WP = 0.17 of the seasonally oscillating version of the von Bertalanffy growth equation (Figure 3A). For *H. clupeola* , the Wetherall *et al.* (1987) plot combined with the previously mentioned Φ' value gave L = 17.4 cm (Figure 2B) and K = 0.44 year^{-1}, subsequently refined to L = 15.9 ± 0.3 cm, K = 0.69 ± 0.02 year^{-1}, *C* = 0.3 and WP = 0.2 (Figure 3B).

The length-converted catch curve for *H. humeralis* led to Z = 3.62 ± 0.23 year^{-1} (n=6); the estimate of M obtained was 0.90 year^{-1}, and hence F = 2.71 year^{-1} and E = 0.75 (Figure 4A). For *H. clupeola*, the corresponding values are Z = 5.25 ± 0.26 year^{-1} (n=3), M = 1.17 year^{-1}, F = 4.08 year^{-1} and E = 0.78 (Figure

Table 3. Comparison of growth parameters and growth performance (' and ") in *Harengula* spp. and other clupeids.

Species	L (cm)	K(year^{-1})	Z	M	F	E	F	f	Locality	Methods	Source
Harengula jaguana	20.6[a]	0.62					0.78	2.42	Brazil	Lengh-freq. (Petersen)	Hubold & Mazetti (1982)
Harengula humeralis	23.5[b]	0.22	2.62	1.08	1.54	0.59	0.36	2.00	Cuba	Age/Length	Garcia-Arteaga (1990)
	20.1	0.52	3.62	0.90	2.71	0.75	0.69	2.32	Venezuela	Lengh-freq. (ELEFAN)	This study
Harengula clupeola	15.9	0.69	5.25	1.17	4.08	0.78	0.69	2.35	Venezuela	Lengh-freq. (ELEFAN)	This study
Sardinella maderensis								2.75[c]	Africa[d]	various	Djama *et al.* (1989)
Sardinella pilchardus	16.6	0.57						2.19	España	Age/Length	Andreu *et al.* (1950)
	19.6	0.31						2.07	España	Age/Length	Larrañeta & Lopez (1958)

[a] Original data converted to total length from fork length using: TL = [(FL - 0.5) / 1.07 • 1.23] - 1

[b] In absence of a better alternative, original data (FL) converted to total length using the above equation of Hubold & Mazetti (1982)

[c] mean value

[d] from Nigeria, Senegal, Congo and Cameroom

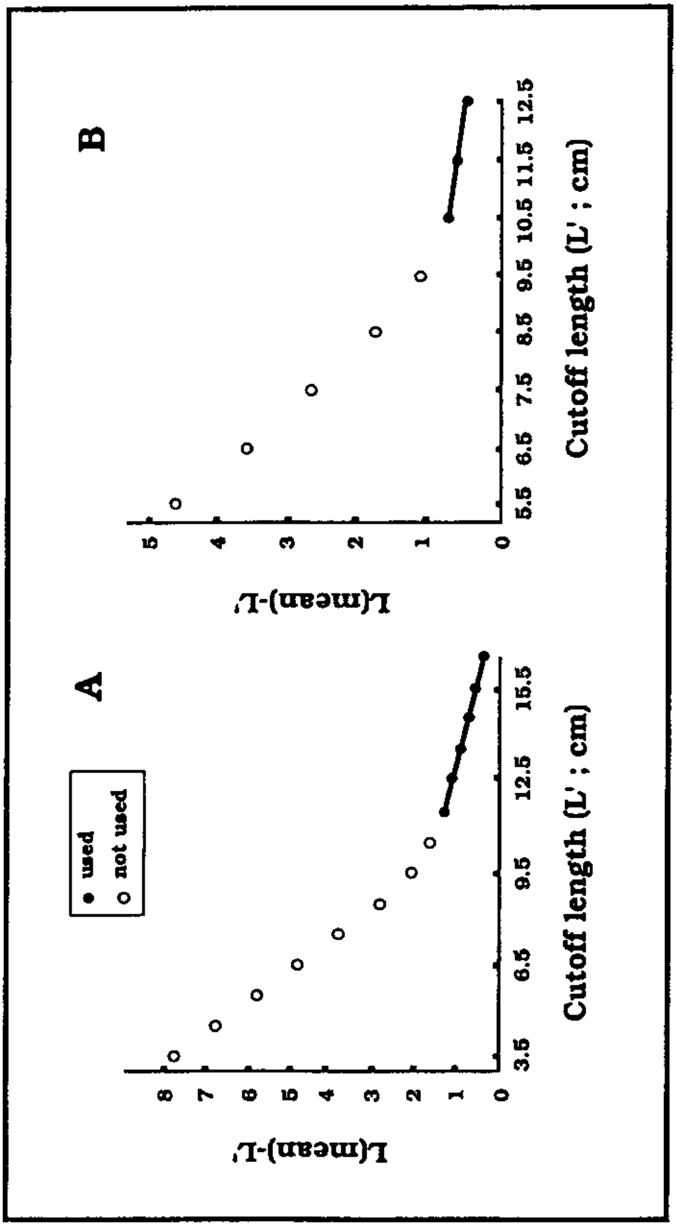

Figure 2. Wetherall plots used to estimate L in *Harengula humeralis* (A) and *Harengula clupeola* (B) from Archipiélago de Los Roques National Park.

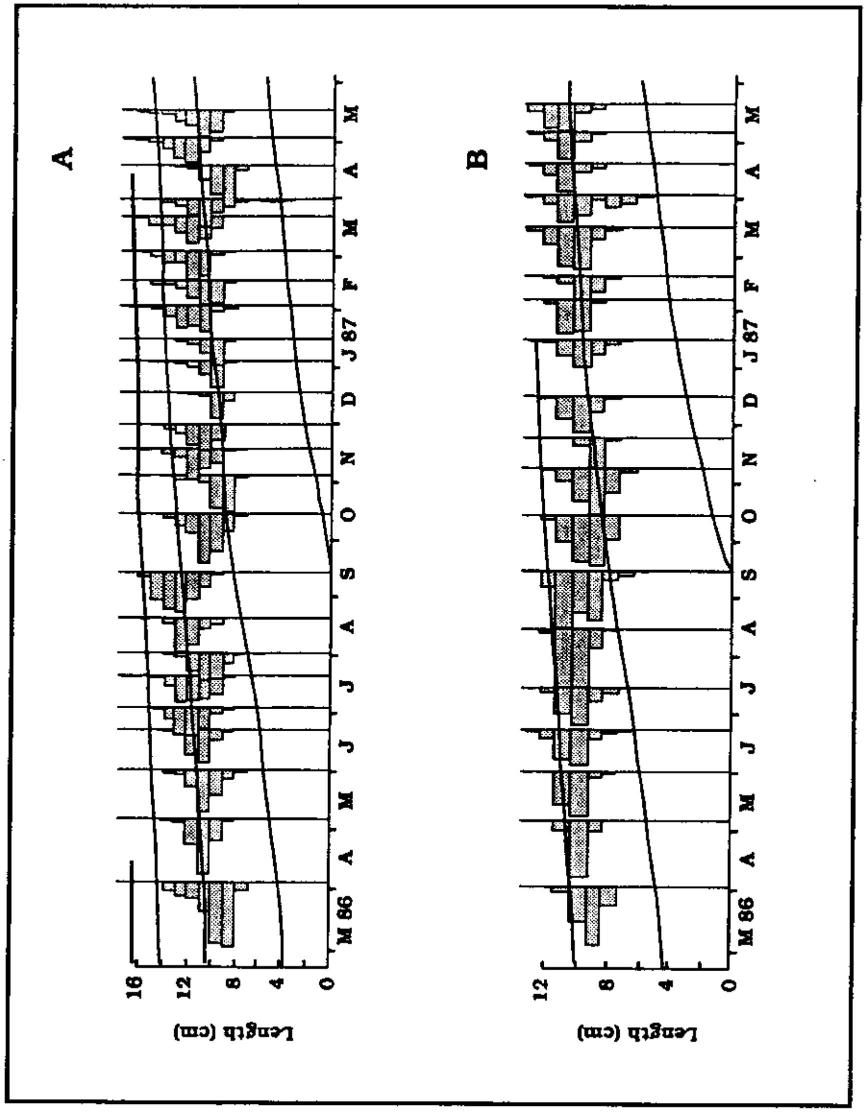

Figure 3. Growth curves of *Harengula humeralis* (A) and *Harengula clupeola* (B) caught at Dos Mosquises Keys, Archipiélago de Los Roques National Park, superimposed on length-frequency data using the ELEFAN I program.

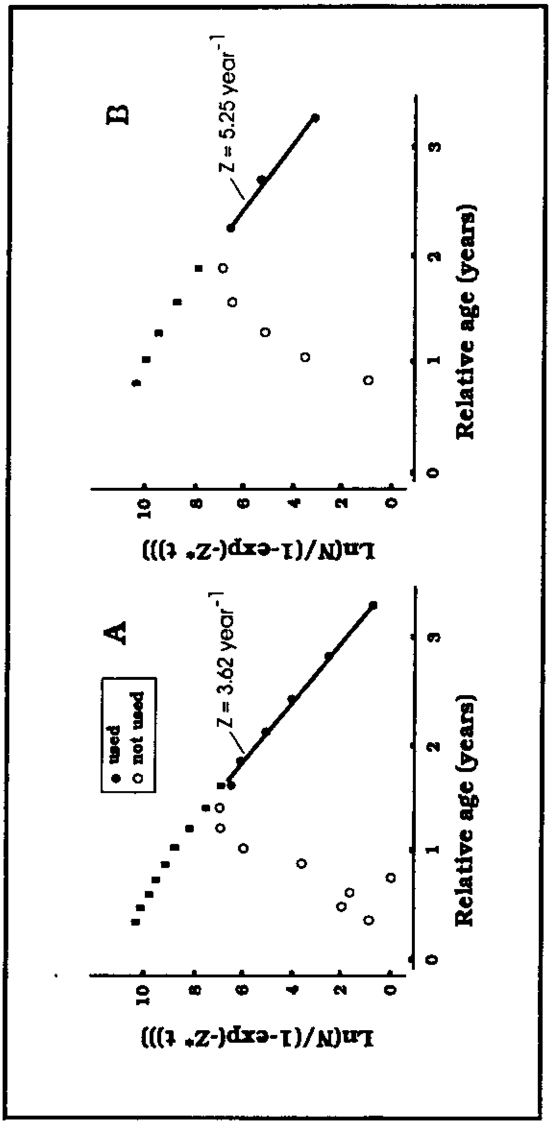

Figure 4. Length-converted catch curve of *Harengula humeralis* (A) and *Harengula clupeola* (B) in Archipiélago de Los Roques National Park.

4B). The Z values estimated from Wetherall *et al.*'s (1987) method were 2.27 $year^{-1}$ (K = 0.52) for *H. humeralis* and 5.77 $year^{-1}$ (K = 0.69) for *H. clupeola.*

Figures 5A and 5B show the recruitment pattern for both species. The graph suggests that there is spawning throughout the year with two uneven seasonal pulses.

DISCUSSION

The estimates of L and K are consistent with the general assumption that clupeids are small sized, fast growing, short-lived and high mortality species. Table 3 presents growth parameters for some clupeids reported from other studies. Growth coefficients are highly variable, ranging from 0.215 to 0.694. Ursin (1984) suggested a mean value of K = O.72 (L = 26 cm) for clupeids living in tropical waters (=26 °C). The present estimation of K for *Harengula* spp. are closely related with the knowledge of a high metabolic rate of clupeids (Ursin, 1984).

The largest fish ever recorded for the stocks of *H. humeralis* and *H. clupeola* in question were 17.3 cm and 13.6 cm (TL), respectively, values that are close to the present estimates of L. Cervigón (1991) reports for *H. humeralis* occurring in Cubagua Isl. (Venezuela) an L_{max} value of 19.2 cm TL, and 15.0 cm TL for *H. clupeola*. The only other estimate of L for *H. humeralis* was in southwest Cuba reported in terms of fork length (Garcia-Arteaga, 1990). The Hubold and Mazzetti's (1982) relationship between total length and fork length for *H. jaguana* in the south Brazilian waters,

$$TL = [\{(FL-0.5)/1.07\} \times 1.23] - 1,$$

was used to standardize the results of Garcia-Arteaga (1990): L was 23.5 cm TL, with the largest fish recorded being 17.9 cm TL.

The values of *C* greater than 0.3 suggest that seasonal growth is important. This is consistent with the known biology of *Harengula* species. In the Los Roques archipelago, annual temperature fluctuation is 2.8°C, sufficient to generate the observed values of *C* (Pauly, 1985). Pauly and Ingles (1981) stated that, in general, winter-summer temperature differences as small as 2 °C are sufficient to induce detectable seasonal growth oscillations. For *H. humeralis* specifically, Bustamante *et al.* (1990) indicated that biological processes and physiological characteristics were highly affected by water temperature in spite of low annual variation. Winter point (WP), which ranged from 0.17 to 0.2, refers to a period of slowest growth around February, coincident with the month of lowest temperature at the sampling area (25.9 °C).

Length-converted catch curves tend to overestimate Z when growth is seasonal, especially in small short-lived fishes (Sparre, 1990). The effect is higher when fishes exhibit strong seasonal changes in growth. Considering the

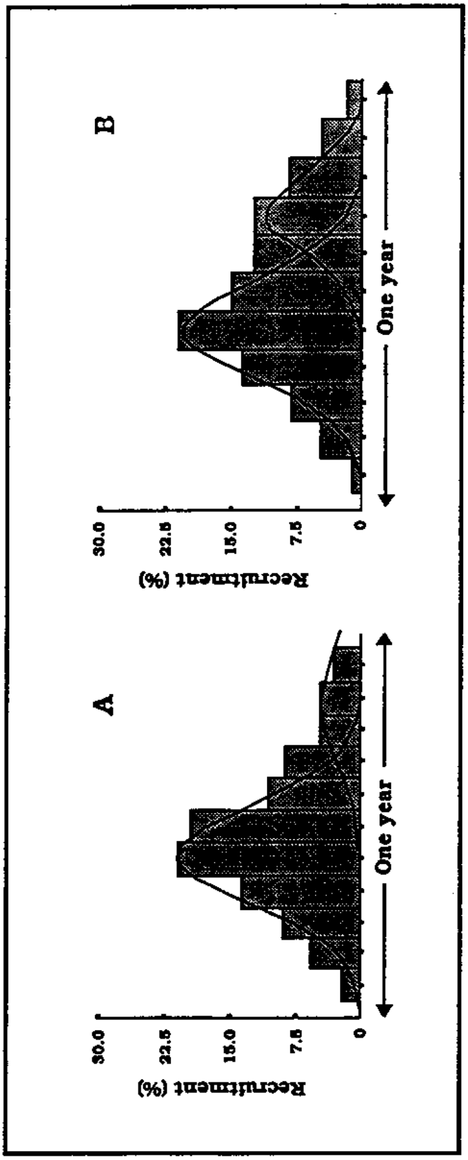

Figure 5. Annual recruitment pattern for *Harengula humeralis* (A) and *Harengula clupeola* (B) as generated by ELEFAN II.

low amplitude of the seasonal growth oscillation observed for both species, it was assumed the estimated values of Z in this study (3.62 $year^{-1}$ for *H. humeralis* and 5.25 $year^{-1}$ for *H. clupeola*) were not too affected by seasonal growth. Garcia-Arteaga (1990) reports a value of Z = 2.62 $year^{-1}$. Values of M reported as 0.90 $year^{-1}$ and 1.17 $year^{-1}$ for *H. humeralis* and *H. clupeola*, respectively, at Los Roques Archipelago are quite similar to that reported for *H. humeralis* in Cuba of 1.08 (Garcia-Arteaga, 1990).

Estimated fishing mortality rates of 4.08 $year^{-1}$, 2.71 $year^{-1}$ and 1.54 $year^{-1}$ for *H. clupeola* and *H. humeralis* at Los Roques Archipelago and *H. humeralis* in southwest Cuba reflect an exploitation ratios of 0.78, 0.75 and 0.59, respectively, indicating that stocks are subject to high fishing pressure. At the archipelago, these clupeids are constantly used to feed turtles and other marine organisms kept in captivity at Dos Mosquises Marine Station and the stocks in the sampling area have been subjected to continuous fishing pressure for many years. Migration may cause relatively high derived values of total mortality, therefore, a careful study of migration within the Archipelago areas is highly recommended. In Cuban waters, these clupeids are caught for human consumption (Rivas, 1963; Martinez and Houde, 1975); however, the fishing status of the population sampled by Garcia-Arteaga (1990) remains unknown.

The recruitment pattern obtained using ELEFAN II matches the seasonal pattern of gonad maturity reported by Posada *et al.* (in press) from simultaneous sampling of the same stocks. They reported year-round spawning for *H. humeralis* and *H. clupeola* with two peaks, a dominant one from March to June and a secondary one from October to December. Two spawning peaks or waves of recruitment were observed in Cuba for both *H. humeralis* and *H. clupeola* (Mester *et al.*, 1974), and for *H. jaguana* in Texas (Gunter, 1945, 1958), Florida (Springer and Woodburn, 1960), and the Gulf of Mexico (Modde, 1980).

The parameter ϕ', as originally described by Pauly and Munro (1984) can be used for intraspecific comparison (Appeldoorn, in press). Since the index is normally distributed, variation, in most cases, can be explained by random fluctuation. The parameter Φ' was defined for size-independent interspecific comparisons (Appeldoorn, in press). Results in Table 3 are quite similar even comparing ϕ' or Φ' values indicating a similar growth performance and that both indexes are useful tools in growth parameter estimations or comparisons if used appropriately.

Results reflect good agreement between length-frequency derived growth parameters, but the L_{∞} and K parameters diverge somewhat compared to scale-based methods. For a substantially higher L_{∞} for a Cuban data set (Garcia-Arteaga, 1990) a corresponding lower value of K may be expected. Differences in K could be due to the different methods used to estimate the growth parameters, different population structure, or simply colder waters in Cuba. The use of hard-part ageing results to validate the length-frequency based method is highly recommended, assuming the hard-part ageing method is most accurate; however, many tropical fish species do not form annular marks on hard parts or may form more than one mark per year, so ageing of tropical fish is not without problems (Dennis, 1991). Garcia-Arteaga (1990) found two marks per year on scales of *H. humeralis*. Use of scales for ageing have some additional problems, *i.e.*, it is necessary to work with original scales because some fish regenerate more that 75% of scales in 2 years and *Harengula* species typically lose scales easily.

Data available were limited due to poor representation of small-sized individuals. Because most schooling fish segregate by size and certain sizes are more available than others, special measures must be taken in order to sample smaller sizes, using a small mesh gear or visiting different localities. Hubold and Mazzetti (1982) indicate that the young *H. jaguana* invade the coastal areas and bays in Guanabara Bay (Brazil) as nursery grounds, while adults were caught outside of the bay.

The length-converted catch curve allows correction of length-frequency data for a gear selection effects and/or incomplete recruitment and an improvement on growth parameter estimation can be obtained. The method assumes that the smaller fish caught are fully recruited to the fishery (Isaac, 1990). The present data set violates that assumption producing a biased estimation of growth parameters (probability of capture put too much weight on the poorly represented small sample size). Therefore, the uncorrected length-frequency data set was considered to offer the most accurate results.

While results reflect clupeids' growth and mortality characteristics, these should be viewed with care, and an improvement in sampling collection is recommended for future research. As many fish as possible should be sampled. For *Harengula* spp., which are schooling fishes, it is relatively easy to sample over 300 individuals per sampling event. A careful sampling program must be conducted simultaneously at the nursery grounds to obtain a representative sample of the whole population.

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