

Age and Growth Study of the Octopus (*Octopus maya*) from the Continental Shelf of Yucatan, Mexico

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ABSTRACT

Studies on age and growth of the octopus are scarce. The main problems are associated with the absence of hard skeletal parts to measure growth and where changes in size could offer easy and direct measures. The octopus' body is soft and can change in size according to the environmental conditions. In this paper several techniques based on catch-at-length data are comparatively applied to the octopus (*Octopus maya*). The methods tested were: 1) Bhattacharya; 2) ELEFAN; 3) SLCA; 4) Projection Matrix; and 5) MIX. With the exception of methods 1 and 5, growth follows Bertalanffy's equation, and assumed to follow parameters whose estimation is based on different algorithms. Bhattacharya and MIX do not necessarily have this constraint. Results are different, especially those that consider growth rate (K , year⁻¹): with ELEFAN and the SLCA, a $K = 1.1$ was estimated, although the SLCA gives a rough approach. Projection Matrix did not converge to clear values. Bhattacharya and MIX both identify practically the same "modes" or "cohorts" within the sample, usually four. However, estimates following these modes using the Bertalanffy equation indicate values of $K=0.3$. A discussion of these differences is presented based on the biology, life cycle and the algorithms used by each method.

KEY WORDS: Octopus, Mexico, fisheries, cephalopod

INTRODUCTION

Age and growth studies are perhaps the most important aspects of population dynamics that provide an adequate estimation of the biomass available for fishing. Cephalopods are one of the most difficult groups to study, because their lack of hard parts makes age determination difficult. Additionally, most cephalopod populations are heavily influenced by environment changes (Caddy, 1983).

On the other hand, there are a number of methods that use catch-at-length composition data, but their application to the same set of data frequently result in different estimations of growth (Rossenberg and Beddington, 1988),

primarily due to the algorithm used to fit the model, although most of them assume growth follows the von Bertalanffy equation. (Arreguín-Sánchez *et al.*, in press).

For octopus, some laboratory experiments suggest that this species' growth pattern does not fit the von Bertalanffy model (Van heukelem, 1977; Hanlon & Forsythe, 1985; Forsythe & van Heukelem, 1987); Arreguín-Sánchez (1992), however, states that variability in growth pattern is particularly high for *Octopus maya*, and is related to the population biology (*i.e.* recruitment pattern) and environmental conditions, such as temperature and the influence of seasonal upwelling in the northeastern region of the continental shelf of Yucatan (Ruíz and Merino, 1989). In this contribution, it is assumed that the growth of *Octopus maya* is reasonably represented by the von Bertalanffy equation, and several length-based methods are tested for the same set of data to estimate age and growth parameters.

MATERIALS AND METHODS

Octopus maya population presents a reproductive aggregation close to the coast which is exploited by fishermen. The fishing season is four and one-half months long, beginning in August. The artisanal fleet fishes with a large rod (locally named "jimba") with several lines baited with crab. Depending on the fisherman's skill he is able to operate from four to seven "jimbos" as the boat drifts over fishing ground. When the octopus attacks the crab, the fishermen take the octopus by recovering the cord (Solís, 1967; Solís and Arreguín-Sánchez, 1984; Arreguín-Sánchez *et al.*, 1987). The average catch in the last eight fishing seasons was around 8,000 tons/year.

Monthly length composition data during 1980 were obtained from commercial catches landed by the artisanal fleet along the coast of Yucatan. Since the fishing grounds are used by all fishermen and fishing techniques the same, a random sampling design was applied using as weighted factor the amount of catch landed in each port. It is important to note that in recent years (since 1984) larger vessels have begun to catch octopus from shallow and deeper waters. Using the same fishing gear, *Octopus vulgaris* constitutes 30% in volume of the catch in this fishery. In 1980, only the artisanal fleet was operating in this fishery.

Methods selected for the analysis were: Bhattacharya (1967); ELEFAN (Gayanilo *et al.*, 1988); SLCA (Shepherd, 1987a); Projection Matrix (Rosenberg *et al.*, 1986; Shepherd, 1987b; Rossenberg and Beddington, 1988; Basson *et al.*, 1988); and MIX (MacDonald and Pitcher, 1979); where the Bhattacharya (BHAT) and MIX only separate modes (assuming a normal distribution) as possible age groups; and the ELEFAN, SLCA and Projection Matrix (PROJMAT) assume growth as the von Bertalanffy model (VBGM) which is described by the equation:

$$L = L (1 - \exp^{-K(t-t_0)}) \quad (1)$$

where L is the mean length at age (t). L = the maximum asymptotic length. K = individual growth rate ; and t is the average length of the hypothetical age t=0.

General aspects of the algorithms used by some of the methods, are briefly explained in Appendix I.

RESULTS

The length frequency data set used is shown in Table 1. Initially, the data were grouped in length-class intervals of 5mm. In the case of the ELEFAN, BHAT and MIX, the output gave a low goodness-of-fit; so data were grouped into larger intervals (10 mm). This was not necessary for SLCA and PROJMAT.

BHAT and MIX procedures do not directly estimate growth parameters for the VBGE; rather, they try to separate normal distributions (age groups) from length frequencies, statistically using a chi squared test. Tables 2 and 3 show the number of age groups per month and the statistical parameters obtained by these methods, respectively. Results were similar for both sexes combined. From the mid-length of each group, growth parameters for the VBGE were obtained (Table 4).

As for the ELEFAN, SLCA and PROJMAT, the response surface from which the L and K were selected showed several peaks, or a "region" of the "best" pair of values. In ELEFAN, a free narrow search routine close to the expected values was used. However, with the other methods, a "region" of the best possible values was consistently observed, although the size of the length-intervals increased twice (10 mm). In these cases, the growth parameters corresponding to the lower end of the region were selected.

Estimates of growth rate (K) and the maximum asymptotic length (L) from each method are given in Table 4. In order to compare results directly, the growth pattern index was estimated (Gallucci and Queen, 1979) $w = K * L$. Values obtained with ELEFAN, SLCA and PROJMAT were similar between sexes; but slightly lower for those computed with the last method. This tendency was also observed for w. On the other hand, estimates obtained from the mid lengths of the age groups identified with BHAT and MIX, yield similar values for L to those with previous methods, but the magnitude of growth rate K was always lower than others. It is important to note from Tables 2 and 3, that for most of the months, four modes (or cohorts) were found, but each cohort does not correspond to an annual periodicity. The maximum longevity for *Octopus maya* is around twelve to eighteen months (Forsythe and van Heukelem, 1987; van Heukelem, 1977; Caddy, 1983; Solís, 1988, 1990; Arreguín-Sánchez, 1990).

Table 1. Length frequency distributions for the octopus (*Octopus maya*) from the Campeche Bank. Data from commercial samplings in 1980.

Length mm	Aug	Sep Females	Oct	Nov	Aug	Sep Males	Oct	Nov
65	0	0	0	0	0	1	0	0
70	0	1	2	0	2	1	1	0
75	4	4	2	0	4	5	1	0
80	10	10	5	0	10	10	6	2
85	18	6	7	0	18	12	13	0
90	29	22	19	2	28	33	17	4
95	33	19	19	1	39	26	24	0
100	52	50	44	9	59	73	62	4
105	37	46	47	7	57	66	40	8
110	49	66	74	19	75	85	68	12
115	33	59	51	7	42	52	57	9
120	41	72	77	15	63	73	86	13
125	35	45	51	16	37	44	40	10
130	35	48	50	18	45	58	72	11
135	11	21	19	10	20	19	19	2
140	15	41	50	9	39	49	53	12
145	10	9	12	5	17	14	16	3
150	13	9	20	0	15	20	27	4
155	8	3	7	3	12	6	5	1
160	7	11	6	2	7	12	17	0
165	0	2	1	0	3	3	0	0
170	2	1	5	1	4	6	6	0
175	0	0	0	0	2	0	0	0
180	1	1	0	0	3	1	2	0
185	1	0	1	0	0	0	2	0
190	0	0	0	0				
195	0	1	0	0				
200	0	0	1	0				

DISCUSSION

Results obtained with ELEFAN and SLCA could be considered, as adequate estimations of the growth parameters of the VBGM. PROJMAT estimates of growth rate were lower than for ELEFAN or SCCA. Arreguín-Sánchez *et al.* (in press) discuss suggests that seasonality in growth is interpreted as mortality by the PROJMAT's algorithm, and that the amount of bias is proportional to the intensity of the seasonality. In the case of *Octopus maya*, seasonal growth was mentioned previously by Arreguín-Sánchez (1992) whose analysed the 1983 to 1988 fishing seasons using ELEFAN method.

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Table 2a. Modes and possible age groups estimated by the BHAT method for the *Octopus maya* of the continental shelf of Yucatan. Data for both sexes mixed (1980).

Month	Group	Popul (N)	Mean mm	St. Dev	Sep. Index	X ²	Deg. Fr.
Aug	1	473	98.4	10.62	-	16.56	12
	2	485	123.3	13.99	2.02		
	3	78	154.3	8.83	2.72		
	4	9	178.6	5.38	3.43		
Sep	1	1060	112.2	16.01	-	18.25	13
	2	110	141.7	5.57	2.73		
	3	43	160.9	8.07	2.82		
	4	4	186.2	4.67	3.37		
Oct	1	816	111.1	14.46	-	20.51	13
	2	320	134.7	12.31	1.76		
	3	64	160.8	10.43	2.29		
	4	4	186.2	4.67	3.37		
Nov	1	166	116.6	13.69	-	2.51	7
	2	45	137.4	9.24	1.81		
	3	7	157.9	6.68	2.57		

Popul = Number of individuals; Mean = mean length of mantle; St. Dev = standard deviation; Sep. Index = Separation index; X² = chi square test; Deg. Fr. = Degrees of freedom.

This author suggested a high variability in growth associated with seasonal recruitment pattern and temperature.

From a computational point of view, the source of the differences between estimates of the ELEFAN, SLCA and PROJMAT with those obtained from BHAT and MIX is clear. However, the real problem is to explain it from the population biology and the life cycle point of view; specially because there are few studies on this species, and information available comes from the four and one-half month (August to December) fishing season. Two hypothesis could be formulated to explain the presence of two cohorts per year and differences in growth rate estimationsbaes on the following assumptions:

- a) *Octopus maya* longevity is around twelve to eighteen months
- b) The amount of adults during aggregation timing suggest that spawning occurs in early spring, and mature to adults by the beginning of the fishing season.
- c) During the fishing season, reproduction occurs and the highest recruitment peak will be present two or three months later (*i. e.*, September).

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Table 2b. Modes and possible age groups estimated by the BHAT method for the *Octopus maya* of the continental shelf of Yucatan. Data for females (1980). Meaning of column's headings is the same that in Table 2a.

Month	Group	Popul (N)	Mean mm	St. Dev	Sep. Index	X ²	Deg. Fr.
Aug	1	217	98.1	10.73	-	3.19	9
	2	195	122.4	12.46	2.09		
	3	28	152.1	7.85	2.93		
	4	3	173.8	11.95	2.19		
Sep	1	83	92.2	10.43	-	8.89	9
	2	389	116.7	12.76	2.13		
	3	56	150.0	5.60	2.62		
Oct	4	17	158.0	6.09	2.91	8.41	9
	1	507	115.4	16.49	-		
	2	56	147.4	7.85	2.65		
	3	5	167.0	6.35	2.72		
Nov	4	2	188.0	4.79	3.77	2.96	3
	1	75	113.7	10.15	-		
	2	44	132.3	9.73	1.86		
	3	4	158.9	6.55	3.27		

Table 2c. Modes and possible age groups estimated by the BHAT method for the *Octopus maya* of the continental shelf of Yucatan. Data for males (1980). Meaning of column's headings is the same that in Table 2a.

Month	Group	Popul (N)	Mean mm	St. Dev	Sep. Index	X ²	Deg. Fr.
Aug	1	407	105.6	13.52	-	4.73	11
	2	167	135.6	12.10	2.34		
	3	23	160.5	9.25	2.32		
	4	4	179.5	5.13	2.64		
Sep	1	525	109.3	14.43	-	9.53	12
	2	137	141.9	11.82	2.48		
	3	5	166.2	5.79	2.75		
Oct	1	82	92.6	8.76	-	17.32	10
	2	419	117.4	13.09	2.26		
	3	110	146.1	8.78	2.62		
	4	19	166.1	9.99	2.14		
Nov	1	82	117.9	13.44	-	1.39	5
	2	13	142.0	8.22	2.22		

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Table 3a. Modes and possible age groups estimated by the MIX method for the *Octopus maya* of the continental shelf of Yucatan. Data for both sexes mixed (1980).

Month	Group	Prop.	Mean mm	St. Dev	Prob.	X ²	Deg. Fr.
Aug	1	0.50108	98.6	11.38	0.9950	3.07	12
	2	0.45151	122.8	13.81			
	3	0.04118	153.6	6.47			
	4	0.00623	178.6	1.31			
Sep	1	0.93783	111.5	16.36	0.9481	5.27	12
	2	0.04406	138.7	8.55			
	3	0.01305	159.3	5.49			
	4	0.00505	178.2	1.73			
Oct	1	0.77361	110.6	14.67	0.9853	1.01	6
	2	0.21790	135.6	14.12			
	3	0.00523	156.9	6.94			
	4	0.00325	187.2	4.03			
Nov	1	0.68920	112.7	13.64	0.9308	5.01	11
	2	0.26293	129.1	7.87			
	3	0.04787	152.1	6.04			

Prop = Proportion of individuals in the population; Mean = mean length of mantle; St. dev. = standard deviation; Prob. = Probability for X (chi square test); Deg. Fr. = Degrees of freedom.

This implies that mature adults could be found any time during the spring of the next year.

With this in mind, two hypotheses could be proposed:

H1: There are two reproductive seasons in the year for the *Octopus maya* population; one during the autumn, and the second during the spring. This reproductive cycle could be governed by regional inter annual changes in temperature and/or certain types of materials in suspension (which produce increments in turbidity).

Explanation: High temperatures during summer initiate the reproduction process (*i. e.*, maturity of gonads). Mature adults aggregation occurs close to coastal waters (relative high and stable temperatures), when turbidity increases (because materials in suspension), and reproduction occurs. Females protect eggs and eclosion occurs one month later. Juveniles reach the adult stage next spring (*i.e.* March/April). Around this time a seasonal upwelling on the northeast border of the continental shelf of Yucatan supply cold water, nutrients, and probably an increment in turbidity. It is possible that octopis move toward

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Table 3b. Modes and possible age groups estimated by the MIX method for the *Octopus maya* of the continental shelf of Yucatan. Data for females (1980). Meaning of column's headings is the same that in Table 3a.

Month	Group	Prop.	Mean mm	St. Dev	Prob.	X ²	Deg. Fr.
Aug	1	0.54365	97.3	10.58	0.9885	4.23	13
	2	0.36885	121.7	9.35			
	3	0.08040	149.5	5.24			
	4	0.00711	174.2	8.58			
Sep	1	0.18425	94.7	11.68	0.8371	8.10	13
	2	0.77892	116.9	13.61			
	3	0.03500	154.6	7.65			
	4	0.00183	192.9	6.10			
Oct	1	0.96760	114.8	16.49	0.9274	3.74	9
	2	0.02004	149.2	7.85			
	3	0.00840	159.7	6.35			
	4	0.00346	190.3	4.79			
Nov	1	0.42053	106.7	8.84	0.9921	1.96	9
	2	0.51854	126.4	8.17			
	3	0.06094	154.3	5.14			

Table 3c. Modes and possible age groups estimated by the MIX method for the *Octopus maya* of the continental shelf of Yucatan. Data for males (1980). Meaning of column's headings is the same that in Table 3a.

Month	Group	Prop.	Mean mm	St. Dev	Prob.	X ²	Deg. Fr.
Aug	1	0.67516	105.8	12.99	0.9981	1.02	12
	2	0.28126	133.0	12.00			
	3	0.02689	155.6	4.79			
	4	0.01669	172.1	5.13			
Sep	1	0.77199	109.1	14.14	0.9760	1.51	4
	2	0.19187	135.9	9.99			
	3	0.03614	160.6	6.84			
Oct	1	0.05512	95.6	6.49	0.8250	2.15	8
	2	0.82808	116.9	15.05			
	3	0.10175	146.9	10.85			
	4	0.01505	165.5	19.64			
Nov	1	0.92447	118.6	15.44	0.7726	6.49	10
	2	0.07553	140.8	6.14			

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Table 4. Growth parameters of the von Bertalanffy model estimated for the *Octopus maya* from the Campeche Bank.

Parameter	BHAT	MIX	ELEFAN	SLCA	PROJMAT
BOTH SEXES					
L (mm)	230.3	197.1	250	230	260
K year ⁻¹	0.333	0.731	1.0	1.2	0.7
C			0.5	-	-
WP			0.6	-	-
t ₀			-	0.12	0.88
w	77.28	144.1	250	276	200
FEMALES					
L (mm)	226.9	221.8	250	270	260
K year ⁻¹	0.344	0.411	0.9	0.9	0.7
C			0.1	-	-
WP			0.6	-	-
t ₀			-	0.08	0.08
w	78.14	91.24	225	243	182
MALES					
L (mm)	193.3	233.3	250	270	260
K year ⁻¹	0.651	0.380	1.0	1.0	0.8
C			0.9	-	-
WP			0.6	-	-
t ₀			-	0.13	-
w	125.7	88.71	250	270	208

warmer waters (maybe to the northwest continental shelf) for reproduction. This cohort constitutes the adults recruited next fishing season. It is possible that turbidity changes (by winds/rains in autumn, and the upwelling) could be an important variable which contributes to the beginning of the reproduction process of one or more types of nutrients. This hypothesis could imply a second unknown reproductive aggregation. Care must be taken because it could also be suggested as a consequence and is probably strongly influenced by the availability of biomass.

H2: Reproductive timing is longer than the time which is currently considered. The whole period could begin in early spring, and conclude by late autumn. This period would be coincident with the seasonal recruitment pattern estimated by Arreguín- Sánchez (1992).

Explanation: Reproduction could be a continuous process resulting in mature adults (six to eight months old) at the beginning of the autumn. Other

environmental factors may influence reproduction. Under this scenario, the reproductive season could be eight to nine months, and possibly with two maxima (peaks). But aggregative behavior could also be associated with feeding, as well as, reproduction, as has been proposed by several authors. This would explain some upwelling. When this occurs, increments in ecosystem productivity can be expected. Such effects have been proposed for others species such as the red grouper (*Epinephelus morio*) (Arreguín-Sánchez *et al.*, 1990). If reproductive activity and spawning aggregation correlate with upwelling, food supply availability to juvenile octopus is a possible explanation. It also could explain why aggregation occurs (searching for food). Other effects could be the same that in the previous scheme.

CONCLUSIONS

Growth parameters of the VBGM, values selected as adequate estimations were: $L = 250$ mm; $K = 1.1$ year; and $t_0 = 0.13$ years. ELEFAN and SLCA are considered to give adequate results for *Octopus maya*. MIX and BHAT separate two modes per year, but they are not annual cohorts. PROJMAT produces bias, especially when growth is seasonal. Despite results obtained, methods have different sensitivity to seasonal growth magnitude, and it is recommended at least two should be applied in a comparable scheme. It is also recommended to BHAT and MIX, because modes identified by them quite similar.

It is heavily recommended to develop an important scientific effort to test hypotheses proposed above because they could have very serious consequences for management purposes.

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APPENDIX I.

The three methods applied assume that growth follows the VBGE:

$$L_t = L [1 - e^{-K(t - t_0)}]$$

where:

- L_t = length at age t
- L = maximum asymptotic length
- K = growth curvature parameter
- t = computed age at length zero

In its seasonally oscillating version (Hoenig and Choudaryhanumara, 1982; Sommers, 1988), the VBGE has the form:

$$L_t = L [1 - e^{-K(t - t_0)} + (KC / 2) \sin 2 (t - t_s) - (KC / 2) \sin 2 (t_0 - t_s)]$$

where:

- C = parameter reflecting the intensity of seasonal growth oscillation
- t = start of a sinusoid growth oscillation with respect to t₀ = 0.

The parameter Winter Point (WP) is another output of the ELEFAN Program, defined as:

$$WP = t_s + 0.5$$

or the time of the year (expressed as a decimal fraction) where growth is slowest (Pauly and Gaschötz, 1979; Pauly *et al.*, 1984).

The ELEFAN Program identifies peaks and troughs in the length frequency distributions and fits the growth curve which passes through a maximum number of peaks (see Pauly *et al.*, 1984 for comprehensive details). A measure of goodness of fit called R_n (Gayanilo *et al.*, 1988) is determined by the exponential form of the ESP/ASP ratio, where ESP stands for the "Explained Sum of Peaks" and ASP for "Available Sum of Peaks" as:

$$R_n = (10^{ESP/ASP})/10$$

The SLCA method (Shepherd, 1987a; Basson *et al.*, 1988) is based on a cosine function which does not require specifications concerning the number and position of the modes. This function is expressed by:

$$T(1) = [(\sin (t_{\max} - t_{\min})) / (t_{\max} - t_{\min})] \cdot \cos 2 (t - t_s)$$

where:

t_{max} and t_{min} are the ages-at-length corresponding to the upper and lower bounds

of a given length interval, t is the average, and t_s is the fraction of the year in which the sample was taken (Shepherd, 1987a).

The test function, which is positive for modes and negative between modes, calculates a score derived from the sum over all length categories, being maximized by the most appropriate estimates of growth parameters. The form of the score function is given by:

$$S = \sum_i |l_i| N^{0.5}(l_i)$$

where l indexes the length groups, i indexes the various distributions available and N is the observed frequencies.

The PROJMAT is based on the Leslie population projection matrix (Leslie, 1945). Shepherd (1987b) showed that the transition matrix could directly be solved as:

$$N_{(t+1)} = AN_{(t)}$$

where the vectors $N_{(t)}$ and $N_{(t+1)}$ describe the population structure at time t and $t+1$ respectively, and A is the transition matrix, which can be decomposed as:

$$A_{(i,j)} = G_{(i,j)} S_{(j)}$$

where $G_{(i,j)}$ is a growth matrix whose specific elements are the proportions of each initial length group i which contribute to each final length group j by assuming the VBGE, and $S_{(j)}$ is an average survival estimate of the j -th length interval. The PROJMAT projects the sample from time t to time $t+1$, considering seed values of K and L . The projected length frequency distribution is then compared with the observed one through the sum of the differences squared (SSQ). This procedure is repeated over all comparisons between n samples for a range of K and L values, being the best growth parameters those which minimize the SSQ (Basson *et al.*, 1988).