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APPARENT GROWTH OF YELLOWFIN TUNA FROM THE EASTERN ATLANTIC OCEAN

J. C. Le Guen[1,2] and Gary T. Sakagawa[1,3]

ABSTRACT

Apparent growth of yellowfin tuna from the eastern Atlantic Ocean was estimated from modal progression of length-frequency distributions by two methods. One was to use fish of unknown age, which gave estimates of parameters of the von Bertalanffy growth function of $L_\infty = 194.8$ cm and $K = 0.035$, on a monthly basis. The other was to use fish of apparent known age, which resulted in $L_\infty = 175.2$ cm and $K = 0.044$. Although the parameter estimates were different, estimates of length at ages 1.5-4.5 years were quite similar with both approaches.

A comparison of growth estimates of yellowfin tuna was made. Estimates from analysis of length-frequency distributions appeared to be superior to those from analysis of scales because they were based on a larger range of fish sizes. However, observed lengths at ages 1.5-5 years were similar for both types of analysis and for yellowfin tuna from both the Atlantic and Pacific Oceans.

It is recommended that observed sizes at age rather than the estimated sizes at age from the von Bertalanffy function be used in estimating yield per recruitment of yellowfin tuna.

There have been several studies (e.g., Le Guen, Baudin-Laurencin, and Champagnat, 1969; Yang, Nose, and Hiyama, 1969) on growth of Atlantic yellowfin tuna (*Thunnus albacares*) but little agreement among them. The disagreement can be traced to at least three sources: first, the kinds of data, e.g., length-frequency distributions and scale readings have been different; second, the method of fitting the von Bertalanffy growth function has varied; and third, the range of fish sizes employed has been different. Because an accurate estimate of growth is important for estimating yield per recruitment by the Beverton and Holt approach (Schaefer and Beverton, 1963), one method that can provide information for rational management of the resource, a study was initiated to estimate growth from the best series of data available and, hopefully, to resolve the disagreement. In this report the results of that study on apparent growth of yellowfin tuna from modal progression of length-frequency distributions are presented and compared to growth estimates derived from published data and computed by standardized procedures.

PLAN OF ANALYSIS

Length frequency samples from commercial landings were employed in our study (Table 1). The fish were caught off Africa by baitboats and purse seiners and were sampled by French and Inter-American Tropical Tuna Commission (IATTC) scientists. (Scientists of the IATTC sampled the Atlantic tuna catch of U.S. vessels under a contract from the National Marine Fisheries Service.) The French scientists sampled the French catches, which were from three general regions—Abidjan, Ivory Coast; Dakar, Senegal; and Pointe-Noire, Congo—and the IATTC scientists sampled the American catches, which were from primarily the Gulf of Guinea. The IATTC samples were caught in both the Abidjan and Pointe-Noire regions, but because

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[1] Alphabetical authorship since the paper is based on independent studies of both authors.

[2] Office de la Recherche Scientifique et Technique Outre-Mer, Centre de Pointe-Noire, P.O. Box 1286, Pointe-Noire, Republic of Congo.

[3] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92037.

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TABLE 1.—Sources of length data of Atlantic yellowfin tuna caught in the surface fishery off Africa.

Region	Year	Type of length measurement	Type of vessel sampled			Source
			Bait-boat	Small seiner[1]	Large seiner[2]	
Abidjan	1966	Predorsal		X		O.R.S.T.O.M., 1971
	1966-69	Predorsal	X	X		O.R.S.T.O.M., 1971
	1970	Predorsal	X	X	X	O.R.S.T.O.M., 1971
Dakar	1968	Fork	X			Champagnat and Lhomme, 1970
	1969	Predorsal	X	X		Champagnat and Lhomme, 1970
	1970	Predorsal	X	X	X	O.R.S.T.O.M., 1971
Gulf of Guinea	1968-70	Fork			X	Staff, Tuna Population Dynamics Project, 1971[3]
Pointe-Noire	1965-66	Predorsal	X	X		O.R.S.T.O.M., 1971
	1967-68	Predorsal	X	X		Le Guen et al., 1969
	1969	Predorsal	X	X		O.R.S.T.O.M., 1971
	1970	Predorsal	X	X		O.R.S.T.O.M., 1971
	1971	Predorsal	X	X		Unpublished data (Le Guen)

[1] Small purse seiner = less than 500 metric tons capacity.

[2] Large purse seiner = larger than 500 metric tons capacity.

[3] Staff, Tuna Population Dynamics Project. 1971. Size composition of the yellowfin and skipjack tuna purse seine fishery off the west coast of Africa 1968-1970. Unpublished manuscript, 28 p. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92037.

they could not be separated as such, they were treated separately from the French data.

Two methods were employed in our analysis. One approach ("age unknown") was based on all samples from the four regions, for years 1965-70 and with age of size groups unknown. The second approach ("apparent age known") was slightly different. Only fish that were caught in an area from São Tomé to southern Angola, 1967-71, and with the apparent age of each size group known, were employed.

Growth was estimated with the von Bertalanffy growth function. This function is often expressed as,

$$L_t = L_\infty \left[1 - \exp - K\ (t - t_0)\right],$$

where L_t = length at age t, L_∞ = asymptotic length, K = growth rate, and t_0 = theoretical age when $L_t = 0$. It is fitted to growth data by various procedures (e.g., Walford, 1946; Abramson, 1963; Ricklefs, 1967; Gulland, 1969; Knight, 1969), most of them require data on size at known age. A least-squares procedure that does not contain this limitation was described by Fabens (1965). He fitted a von Bertalanffy function of the form

$$L_{t+\Delta} = L_t + (L_\infty - L_t)\ (1 - \exp - K)$$

to tag-return data, but his procedure is equally applicable to length observations of untagged fish made at t and again at a later date, $t + \Delta$, when the age of the fish is unknown. For tuna, Rothschild (1967) and Joseph and Calkins (1969) employed Fabens' procedure to estimate growth of skipjack tuna (*Katsuwonus pelamis*) from tagging data. We used the Fabens' procedure with monthly mean lengths for individual year classes to estimate growth of yellowfin tuna of unknown age. A computer program written by Tomlinson (Abramson, 1971) was employed to estimate L_∞ in centimeters and K, expressed on a monthly basis. For growth estimates based on apparent known age fish, we used a computer program written by Abramson (1963) and modified by Psaropulos (1966) of a least-squares procedure described by Tomlinson and Abramson (1961).

ANALYSIS WITH UNKNOWN AGE FISH

METHODS

Fish landed at Abidjan, Dakar, and Pointe-Noire (Figure 1) were measured for predorsal length (tip of snout to anterior base of the dorsal fin) by French scientists; fish were measured for fork length by IATTC scientists. In order to standardize the length measurements, we em-

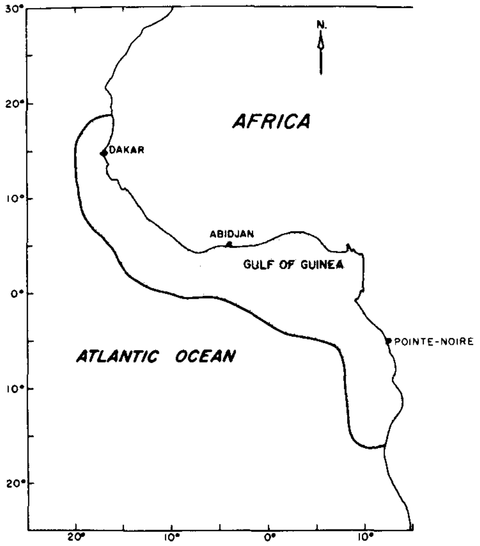

FIGURE 1.—Area off Africa where the surface fishery for yellowfin tuna operates.

ployed the relation, $\log L_f = 0.273 + 1.175 \log L_d$ to convert samples with predorsal length in centimeters (L_d) to fork length in centimeters (L_f). This relation is based on 508 observations and differs from $L_f = (3.624 + 0.212\ L_d)^2$, which was employed by Poinsard (1969). It has a slightly better correlation coefficient ($r = 0.9943$) than Poinsard's equation ($r = 0.9940$) (Lenarz, 1971).[4] Calculated fork lengths based on either equation are accurate only to 1-4 cm.

Monthly length-frequency distributions were tabulated by 4-cm-fork-length groups for samples from each region. Modes were identified and assumed to represent age classes within which lengths were normally distributed. Normal distributions were then fitted to the length frequencies of samples in which two or more modes were present, and the mean length of each age class was estimated (Table 2). A computer program for separating size classes in a mixture that was written and described by Hasselblad (1966) and modified by Tomlinson (1970)[5] was used to separate the age classes and estimate the mean lengths. For samples with only one prominent mode, the modal length, or midpoint of length interval of maximum frequency was considered the "mean length." Representative length-frequency distributions are shown in Figure 2.

Mean lengths for each sample are plotted in Figures 3-6. For each region a serial succession of increasing mean lengths with time was designated a year class, with only one recruited per year although two groups appear to be recruited

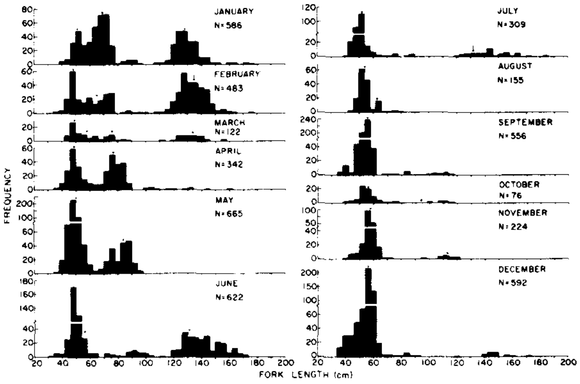

FIGURE 2.—Length-frequency distributions of samples from Pointe-Noire, 1970. Arrows indicate mean lengths of modal groups that were identified by curve fitting.

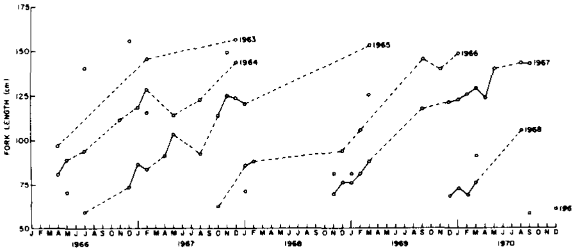

FIGURE 3.—Mean length of size groups of yellowfin tuna as a function of sampling date at Abidjan. Growth of the 1963-69 year classes are indicated

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[4] Lenarz, W. H. 1971. Length-weight relations for five Atlantic scombrids. Unpublished manuscript, 9 p. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92037.

[5] Tomlinson, P. K. 1970. Program for separating mixture of normal distributions. Unpublished manuscript, 2 p. California Department of Fish and Game, Operations Research Branch, Long Beach, CA 90802.

TABLE 2.—Mean lengths (cm) of modal groups identified in samples from Abidjan, Dakar, Gulf of Guinea, and Pointe-Noire. Values that were not used in the analysis of growth are shown in parentheses.

Region	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Abidjan	1966				80.7 97.2	(56.8) (70.8) 89.4		59.2 94.2 (140.9)				112.0	73.5 (155.2)
	1967	87.3 118.2	84.3 (115.4) 129.7 146.6		92.0	(48.5) 103.8 114.9			92.8 122.9	(56.0)	62.9 114.8	65.3 125.3 149.7	124.6 144.5 156.8
	1968	(71.7) 86.2 121.9	88.0									69.4 82.3	76.3 94.8
	1969	76.2 (82.3)	81.9 105.4	87.9 112.2 (125.5) 153.6						118.2 145.6		140.0	(50.1) 67.9 122.4
	1970	(54.8) 73.8 123.0 148.4	69.5 125.3	76.9 (92.1) 129.4	124.0	140.0			(55.6) 105.6 143.7	58.1 143.0		(48.0) (58.4)	(43.1) 60.6
Dakar	1968	(44.0)	(56.3) 117.9	(61.2) 122.3	(63.5) 120.7	72.0	(55.3) 70.1 (118.6)	76.0	(63.0) 81.2	(58.4) 88.4	62.3 89.6	66.9 100.1	64.0
	1969	(70.1) 79.4 102.3	75.3 102.6	75.5 105.0	79.9 113.9	(43.6) (57.4) 85.4 112.2	(49.0) (60.1) 93.7	(49.1) 90.9 107.8	(64.8) 95.7 108.2	(69.4) 102.5 118.5	62.4 (75.7) 123.8	53.2 (78.5) 124.5	(61.9) 74.0 119.9
	1970	64.8 124.8	(49.6) 71.8 (88.9) 126.0	(49.4) 73.5 (101.7) 124.3 145.1	(51.4) 72.5 (106.0) 126.4 147.2	(50.6) 76.2 132.4	(53.4) (70.5)	(55.3) (72.3)	(56.3) (74.3) 90.6 133.7	(39.7) (56.4) 92.4	(42.9) 59.2 (72.3) 100.8 145.2	(30.9) (45.0) 63.0 108.8 146.3	(46.4) (57.4) 69.9
Gulf of Guinea	1968								62.9 136.0 (160.2)	57.8 77.0 135.8	70.0 84.4		
	1969								56.8 112.7 124.7	(52.6) 120.3 132.6 151.3	(59.4) 121.5 153.4	156.0	
	1970						(54.8) 87.1 141.2	(55.5) 82.6 (106.8) 143.3 165.7	(56.0)	66.8 140.6	65.6 (103.9)		
Pointe-Noire	1965							(57.7) (78.1) 113.0	(57.4) (80.2) 116.4	59.1 104.0	60.3 (78.4) 121.1	60.0	
	1966									(64.0) 99.1 145.3		63.0 102.2	
	1967			(50.5) 86.9		(52.9) 90.6 113.8 155.9	(58.0) 88.8	(53.4) 102.1	(53.6) 104.0 113.0	(59.3) 105.1	(61.4) 108.4	112.0	(68.0)
	1968	(60.7) 122.7 (154.6)				(68.0)	(56.4) (73.4) 120.9	59.7 (71.1) (85.4) 134.0 140.0	62.2 (73.6) (90.9) 130.8 152.7	64.6 (75.3) (87.0) 143.8 (156.6)	65.9 (76.2) (91.9) 136.8	(75.0)	72.7 (89.5) (101.5)
	1969	76.0		86.3 (111.1)	49.6 94.3 (117.7) 148.4 164.8	100.0	(56.9) 104.2	(55.7) (112.9) 154.5	(45.8) (56.3) (117.5) 156.0	(57.7) 112.7	(57.4) 114.6	59.9 (127.7)	56.6 127.1
	1970	(51.5) 69.0 129.7	(48.5) 65.5 134.7	(48.8) (57.5) 75.6 134.1	(48.9) 76.8	(49.9) 82.8	(50.7) 131.8	(51.3) 132.2	(53.7) 62.2	(56.0)	(55.3) 93.5	(57.6) 113.5	(56.0)

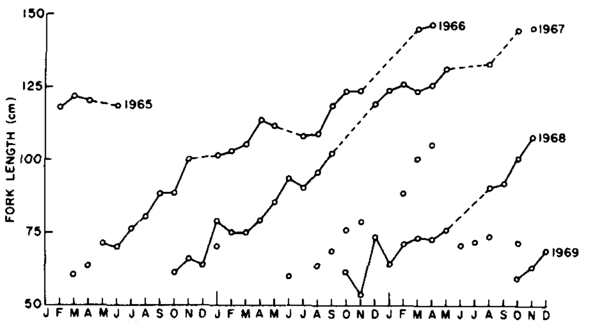

FIGURE 4.—Mean length of size groups of yellowfin tuna as a function of sampling date at Dakar. Growth of the 1965-69 year classes are indicated.

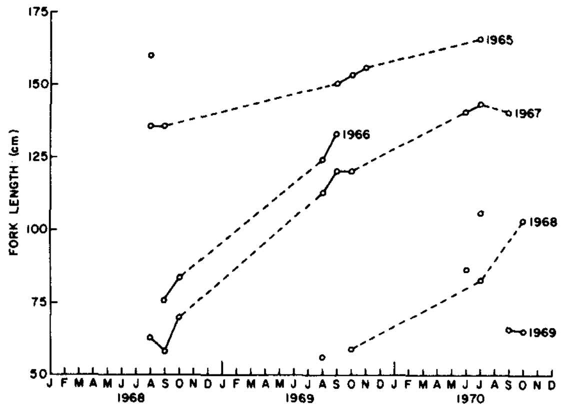

FIGURE 5.—Mean length of size groups of yellowfin tuna from the Gulf of Guinea. Growth of the 1965-69 year classes are indicated.

in some years. Recruitment is assumed to be completed in the second year of life (Le Guen et al., 1969).

RESULTS

Recruitment

Yellowfin tuna are recruited into the surface fishery when about 60 cm long. Recruitment is year-round but most pronounced during June to December. Two groups of yellowfin tuna appear to be recruited in some years. For example, in 1968 at Pointe-Noire (Figure 6) one group entered in January and another in August-September. The January group was of low relative abundance and persisted up to a length of about 90 cm, while the August-September group was of high relative abundance and discernible up to a length of about 140 cm. A similar phenomenon was described by Hennemuth (1961) and later verified by Davidoff (1963) for yellowfin tuna of the eastern Pacific Ocean. Hennemuth suggested that sampling bias, differential growth in a year class, and multiple spawning were some possible causes of the phenomenon. Variation in the seasonal distribution of fishing effort can be added as another possible cause.

Year Class Difference in Apparent Growth

Estimates of apparent growth for individual year classes for each region are shown in Table 3.

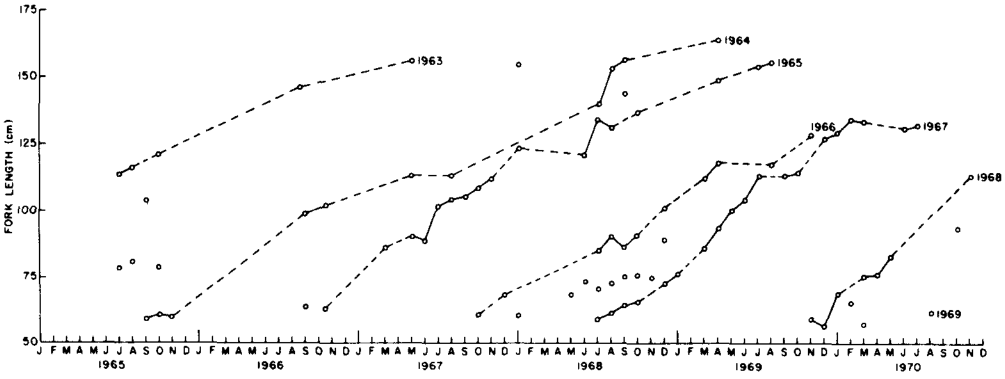

FIGURE 6.—Mean length of size groups of yellowfin tuna as a function of sampling date at Pointe-Noire. Growth of the 1963-69 year classes are indicated.

TABLE 3.—Estimates of parameters of the von Bertalanffy growth function for yellowfin tuna of unknown age from the eastern Atlantic Ocean.

Region	Year class	L_∞	K	No. of observations	Range of lengths (cm)
Abidjan	1963	Linear		2	97.2-156.6
	1964	138.6	0.137	9	80.7-149.7
	1965	275.2	0.016	11	59.2-153.6
	1966	Linear		9	62.9-148.4
	1967	155.1	0.086	13	69.4-143.7
	1968	Linear		4	67.9-105.6
	All years	185.0	0.043	48	59.2-156.6
Dakar	1965	Linear		2	117.9-122.3
	1966	Linear		18	70.1-147.2
	1967	201.5	0.038	20	62.3-146.3
	1968	557.2	0.008	11	53.2-108.8
	All years	307.9	0.017	51	53.2-147.2
Gulf of Guinea	1965	677.4	0.002	5	135.8-165.7
	1966	497.5	0.009	3	77.0-132.6
	1967	174.4	0.052	8	57.8-143.3
	1968	Linear		2	56.8- 87.1
	All years	185.0	0.041	18	56.8-165.7
Pointe-Noire	1963	168.3	0.067	5	104.0-155.9
	1964	273.9	0.017	10	59.1-164.8
	1965	162.9	0.059	16	63.0-156.0
	1966	191.9	0.024	11	61.4-127.7
	1967	160.2	0.051	17	59.7-134.7
	1968	177.8	0.033	8	56.6-113.5
	All years	210.1	0.027	67	56.6-164.8
All regions	1963	158.5	0.136	7	97.2-156.6
	1964	237.4	0.023	19	59.1-164.8
	1965	191.0	0.034	34	59.2-165.7
	1966	895.7	0.003	41	61.4-148.4
	1967	172.6	0.054	58	57.8-146.3
	1968	502.4	0.009	25	53.2-113.5
	All years	194.8	0.035	184	53.2-165.7

In some instances, the estimates of K and L_∞ are unexpectedly too high or too low, indicating that the estimates are inappropriate for the entire life span of the species. According to Knight (1968) and Le Guen (1971), a possible cause of variation in K and L_∞ is lack of size measurements for the entire life span of the species. This appears to be the case in some instances for our data. Length measurements for Dakar, for example, were from catches made predominantly by pole-and-line, or baitboats that generally catch small fish, a characteristic that is well documented (Pianet and Le Hir, 1971). Consequently, large fish were underrepresented in the samples, resulting in heavier weight on the lower size groups. Estimates of L_∞ were therefore unreasonably high, while those of K were unreasonably low. It should be noted that generally L_∞ and K are inversely correlated (Beverton and Holt, 1959).

For some year classes, apparent growth appears to be exceptionally faster than for others. Apparent growth of yellowfin tuna from Pointe-Noire can best illustrate this point (Figure 6). The 1965 and 1967 year classes grew at a faster rate than the 1964 or 1966 year class. The result was an apparent convergence of the growth curve for the 1964 year class with that for the 1965 year class, and the 1966 year class with the 1967 year class. In each case, there appears to be no relation between the time of recruitment and the rate of growth.

Regional Differences in Apparent Growth

For each region, the von Bertalanffy equation was fitted to data for all year classes combined. Apparent growth of yellowfin tuna from Abidjan, Gulf of Guinea, and Pointe-Noire was quite similar for sizes (ranged from about 60 to 160 cm long) observed in the samples (Figure 7). Apparent growth of Dakar fish, on the other hand, seemed exceptionally faster, which is at-

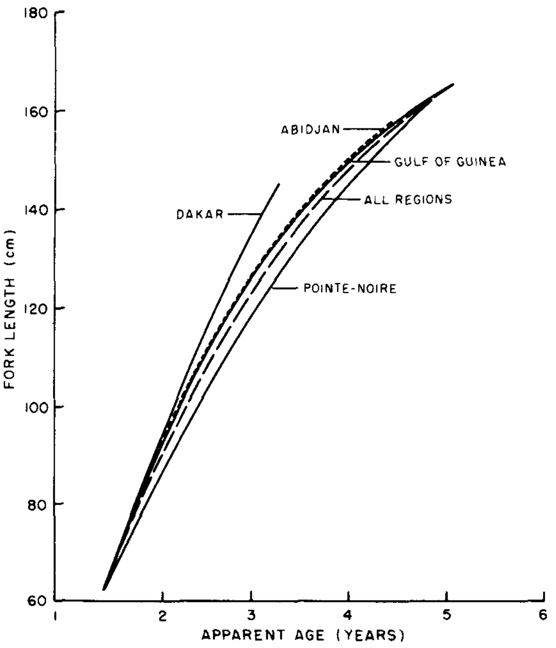

FIGURE 7.—Growth of yellowfin tuna from the eastern Atlantic Ocean.

tributed to lack of data on older fish as was discussed earlier. The range of mean length is 50 to 150 cm.

Estimated Length at Age

An estimate of $L_\infty = 194.8$ cm, and $K = 0.035$, on a monthly basis, was derived from data for all year classes and regions combined (Table 3). We believe these estimates are the "best," on the average, for yellowfin tuna of the eastern Atlantic Ocean, because they were based on data from a broad geographic area off Africa and a wide range of sizes. The estimated growth curve is quite similar to that for Abidjan, Gulf of Guinea, and Pointe-Noire (Figure 7). For individual year classes, however, estimates of L_∞ and K can be expected to deviate from the average, since there is an apparent difference in apparent growth among year classes (Table 3) and considerable scatter of observed mean lengths around the average curve (Figure 8).

Data on growth of tagged yellowfin tuna in the eastern Pacific and on the time of spawning in the Atlantic were used to estimate t_0 in months. The above best estimates of parameters of the von Bertalanffy equation were then used to estimate the length of yellowfin tuna at particular ages. A tacit assumption of this method of estimating length at age is that the von Bertalanffy function is a valid growth model for yellowfin tuna, and the date of birth is constant.

Schaefer, Chatwin, and Broadhead (1961) reported that yellowfin tuna of 40-49 cm long at tagging grew at a rate of 33 cm/year. They indicated that growth was probably adversely affected by tagging, implying that their estimate was too low.

Le Guen et al. (1969) reviewed the literature on time of spawning of yellowfin tuna in the Atlantic Ocean. They concluded that spawning occurred primarily at temperatures greater than 26°C and salinity of about 33.5‰. From seasonal distributions of temperature, salinity, and tuna larvae captured off Africa, they estimated that spawning peaked on about March 1 off Pointe-Noire and on about July 1 off Dakar.

From the above information together with the fact that recruitment into the surface fishery is generally from June to December, we estimated that yellowfin tuna were, on the average, 18 months old at recruitment, about 60 cm long, and $t_0 = 7.48$. Estimates of length at age were calculated with $L_\infty = 194.8$, $K = 0.035$, and $t_0 = 7.48$, employed in the von Bertalanffy function (Table 4). The estimates are graphed in Figure 8, together with monthly mean lengths of individual year classes of each region. There is considerable scatter of the data about the line and an indication that lengths at age 50 months and older are overestimated.

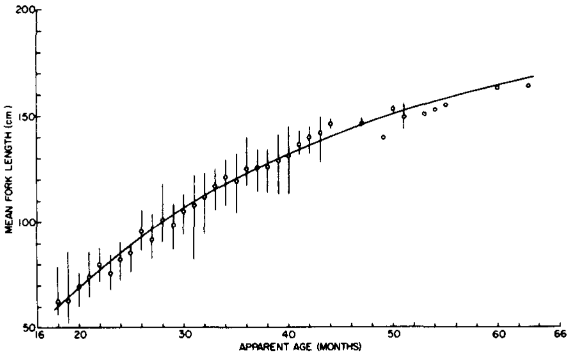

FIGURE 8.—Mean length of year classes of yellowfin tuna as a function of age. The curve is for all year classes and regions combined and is estimated by a von Bertalanffy growth function. Average of observed mean lengths (circles) and the range of mean lengths (vertical line) at various estimated ages are shown.

Estimated Weight at Age

Length can be converted to weight with a weight-length relation. Lenarz (see footnote 4) reported that the weight-length relation for yellowfin tuna from the eastern Atlantic is $W = 0.0000214\ L_f^{2.9736}$, where W = weight in kilograms and L_f = fork length in centimeters. This equation was employed to convert estimates of length at age to weight at age (Table 4).

ANALYSIS WITH APPARENT KNOWN AGE FISH

METHODS

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TABLE 4.—Observed and estimated size at various ages of yellowfin tuna from the Atlantic and Pacific Oceans. Length (cm) is shown for most ages, and weight (kg) in parentheses for a few ages. Estimated length is based on the von Bertalanffy growth function.

Age (years)	Source of data											
	Yang et al., 1969		Le Guen et al., 1969				Present study				Davidoff, 1963	
	Atlantic Ocean		Eastern Atlantic				Eastern Atlantic				Eastern Pacific	
			Pointe-Noire		All regions		São Tomé-Angola		All regions			
	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
1.0	--	54.0	--	33.2	--	32.2	--	17.3 (0.1)	--	28.5 (0.4)	--	34.6
1.5	66.1	75.8	64.6	62.9	63.8	60.0	61.5	53.9 (3.0)	62.2	60.0 (4.2)	--	61.9
2.0	86.1	94.9	84.6	86.6	79.5	83.1	77.6	82.0(10.5)	82.3	85.5(11.9)	83.0	84.7
2.5	104.1	111.5	108.3	105.6	103.9	102.0	111.0	103.6(21.1)	105.0	106.2(22.7)	105.0	103.8
3.0	120.0	125.9	--	120.9	124.0	117.7	116.1	120.2(32.8)	125.0	123.0(35.1)	122.0	119.7
3.5	132.9	138.5	132.2	133.1	132.2	130.6	132.2	133.0(44.3)	140.6	136.6(48.0)	136.0	132.9
4.0	--	149.4	--	142.9	--	141.3	135.6	142.8(54.7)	--	147.6(60.5)	141.0	144.0
4.5	--	158.9	147.0	150.7	143.6	150.1	147.0	150.3(63.8)	153.4	156.6(72.0)	--	153.3
5.0	--	167.2	152.0	157.0	152.0	157.4	153.7	156.1(71.3)	164.8	163.8(82.4)	--	161.0

age fish were similar to those described by Le Guen et al. (1969) and are briefly described as follows. Predorsal length-frequency distributions were tabulated for monthly samples collected in 1967-71 off Pointe-Noire in an area from São Tomé to southern Angola. Modes were selected by comparison of successive maxima in the length-frequency distributions and mean predorsal length estimated for each size group by a method described by Gheno and Le Guen (1968). Mean dorsal lengths were then converted to fork lengths with the aid of Table 5, which was based on fish measured for both predorsal and fork lengths at Pointe-Noire. The data in Table 5 give a fork length-predorsal length relation of $\log L_f = 0.299 + 1.162 \log L_d$ that is not significantly different from the equation used earlier.

TABLE 5.—Predorsal length and fork length measurements of yellowfin tuna landed at Pointe-Noire, 1967-71.

Predorsal length (cm)	Mean fork length (cm)	Number of observations	Predorsal length (cm)	Mean fork length (cm)	Number of observations
12	39.0	11	31	109.5	46
13	40.9	21	32	111.3	33
14	45.0	18	33	116.1	27
15	47.3	37	34	118.8	19
16	50.0	36	35	122.9	26
17	53.9	33	36	132.3	24
18	57.2	58	37	134.7	35
19	59.8	83	38	138.4	25
20	63.1	66	39	143.7	28
21	66.3	43	40	145.7	29
22	71.0	20	41	149.7	29
23	74.6	23	42	152.3	14
24	76.0	18	43	158.8	5
25	81.1	16	44	164.0	5
26	84.2	16	45	166.3	10
27	89.0	9	46	172.0	6
28	92.8	21	47	175.4	8
29	99.1	28	48	177.8	7
30	104.9	27	49	179.8	2

An estimated age was assigned to each size group (Table 6) based on: (1) date of birth of yellowfin tuna caught off Point-Noire is on the average March 1 and (2) recruitment occurs in the second year of life (Le Guen et al,. 1969). Estimates of parameters of the von Bertalanffy function were then calculated with Psaropolos' (1966) computer program.

Length at age estimates were converted to weight at age with the weight-length relation of Lenarz (see footnote 4), which was mentioned earlier.

RESULTS

Estimates of parameters of the von Bertalanffy function were $L_\infty = 175.17$ cm (SE = 3.67), $K = 0.044$ per month (SE = 0.003), and $t_0 = 9.643$ months (SE = 0.815). These estimates are quite similar to those derived by Le Guen et al. (1969) for the Pointe-Noire region based on only data from 1967-68 (Table 7); but L_∞ is significantly lower and K significantly higher than our best estimates for yellowfin tuna from a larger area of the eastern Atlantic, even when the difference in range of lengths in the data is taken into account. On the other hand, length at age and weight at age estimates for ages 1-5 years are quite similar to those for the entire eastern Atlantic (Table 4). Thus, we conclude

TABLE 6.—Size classes (cm) of yellowfin tuna identified in samples from São Tomé to southern Angola. Year classes are separated by horizontal lines.

Age (months)	1967-68[1]	1969	1970	1971
18	64.5		58.5	
19			59.8	
20			61.4	
21	70.3			
22	85.0	75.3	68.6	58.5
23	85.1		71.0	63.1
24	84.6	82.6	74.6	68.6
25	89.0	90.9	81.1	72.8
26	90.6	104.9	82.6	74.6
27	91.0	107.2	92.8	76.0
28	95.5	107.2		86.6
29	102.6			
30	108.3	113.7		
31	107.7	116.1		
32	109.4	127.5		
33	114.5	127.5		
34	124.0			
35	120.0	111.3		
36		116.1		
37	122.0	118.8		
38	126.7			
39	123.5			
40	134.7			
41	136.8			
42	132.2			
43	139.0			
46			133.5	
47	138.6			
48			136.5	134.7
52	147.0		141.0	138.4
53	151.3		143.7	
54	147.0			
55	150.5			
60	152.0			155.5
61		149.7		156.0
64				158.8
65	163.4			160.0
66	161.9			
73		166.3		
74		168.1		
75		168.0		170.1
76				170.1
77				170.1

[1] Data from Le Guen et al. (1969).

that there is no appreciable difference in the estimate of apparent growth of yellowfin tuna from the region of the eastern Atlantic, illustrated in Figure 1 or from a smaller region within that part such as off Pointe-Noire.

COMPARISON OE GROWTH ESTIMATES

Studies on growth of yellowfin tuna have largely been based on two types of data: length-frequency distributions and scale readings. For comparative purposes we chose two studies that were based on scale readings—one each from the Pacific (Yabuta, Yukinawa, and Warashina, 1960) and Atlantic (Yang et al., 1969)—and three studies that were based on modal progression of length-frequency distributions—two from the Pacific (Davidoff, 1963; Moore, 1951) and one from the Atlantic (Le Guen et al., 1969)—for comparison with our best estimates for the eastern Atlantic. The procedure of estimating the parameters of the von Bertalanffy function was standardized with the use of the Fabens' (1965) procedure whenever appropriate data were available.

ESTIMATES FROM SCALE READINGS

Lengths at mark formation from interpretation of marks on scales were reported by Yabuta et al. (1960). They indicated that mark formation occurs twice a year, in March-April and in September-October, or 6 months apart in the western Pacific. An estimate of growth was calculated from their data with 6 months between marks (Table 7). Growth appears to be substantially slower in the western Pacific than in the eastern Atlantic (Figure 9). Either growth is indeed slower in the western Pacific or the interpretation of scale marks by Yabuta et al. is in error. The latter possibility is suggested by the absence in their data of fish greater than 119 cm long with a designated mark, although fish as large as 161 cm long were reportedly sampled. Moreover, only about 42% of their scales were readable. Other studies made in the western Pacific (see Shomura, 1966; Suzuki, 1971) suggest that growth was underestimated by Yabuta et al.

$L_\infty = 222.8$ cm and $K = 0.023$, on a monthly basis, were estimated by Yang et al. (1969). Their estimates were based on scale readings of 296 yellowfin tuna caught by the Atlantic longline fishery. Since Yang et al. used the Walford (1946) procedure to estimate growth, we recalculated growth with the Fabens' procedure using the data of Yang et al. and the assumption that the scale marks formed every 6 months. The results (Table 7) were not markedly different from the estimates by Yang et al. Compared to our best estimate of growth rate (K), on the other hand, their estimate is substantially

TABLE 7.—Estimates of parameters of the von Bertalanffy growth function for yellowfin tuna from the Atlantic and Pacific Oceans. Estimates are based on data reported in various studies, and were calculated by Fabens' (1965) procedure, except those of Le Guen et al. (1969).

Region	L_∞	K	Range of length (cm)	Source of data	Data
Atlantic Ocean	223.0	0.023	66-133	Yang et al., 1969	Scale readings; Table 6
Eastern Atlantic				Le Guen et al., 1969	Length frequencies; estimates reported by authors
Dakar	206.6	0.026	63-162		
Pointe-Noire	182.4	0.037	64-162		
All areas	191.7	0.032	63-162		
Eastern Atlantic				Present study	Length frequencies (Age unknown)
Abidjan	185.0	0.043	59-157		
Dakar	307.9	0.017	53-147		
Gulf of Guinea	185.0	0.041	57-166		
Pointe-Noire	210.1	0.027	57-165		
All areas	194.8	0.035	53-166		
Eastern Atlantic				Present study	Length frequencies (Age known)
São Tomé-Angola	175.2	0.044	58-170		
Central Pacific	191.9	0.036	47-168	Moore, 1951	Length frequencies; Table H
Eastern Pacific	200.3	0.030	69-148	Davidoff, 1963	Length frequencies; Table 6
Western Pacific				Yabuta et al., 1960	Scale readings; Table 5
Males	202.1	0.023	58-119		
Females	174.9	0.031	57-119		
All sexes[1]	188.4	0.027	57-119		

[1] Estimates were based on weighed average length for each scale mark reported by Yabuta et al. (1960). Sample size of each sex was used as the weighing factor.

smaller. Possibly this smaller K is caused by error in the interpretation of scale marks and the paucity of large fish in their data. The maximum number of marks observed by Yang et al. was five, with a corresponding mean length of 132.9 cm at time of fifth mark formation, but fish as large as 180 cm long were reportedly sampled. For our study, fish as large as mean length 166 cm were used in the calculations.

ESTIMATES FROM MODAL PROGRESSION

Davidoff (1963) examined modal progressions of length-frequency distributions of eastern Pacific yellowfin tuna caught by baitboats and purse seiners and calculated with the Walford procedure $L_\infty = 167$ cm and $K = 0.05$, on a monthly basis, which he noted were similar to earlier estimates reported by Hennemuth (1961). Davidoff's estimates were based on average modal length at each age of all year classes combined. Equal weight was therefore given to each datum point in his calculation.

Using the Fabens' procedure and data for each year class reported by Davidoff (his Table 6), we recalculated the growth estimates. The results, $L_\infty = 200.3$ and $K = 0.030$, are considerably larger for L_∞ and smaller for K than Davidoff's estimates but similar to our estimates for Atlantic yellowfin tuna (Table 7).

Hennemuth (1961) reported that fish 70 cm long in the eastern Pacific were about 20 months old. Entered into the von Bertalanffy equation, this gives a t_0 of 5.67 months with $L_\infty = 200.3$ and $K = 0.030$, and a means of estimating length at age for eastern Pacific yellowfin tuna. The results are shown in Table 4. They compared favorably with our estimates for Atlantic yellowfin tuna, although apparent growth in the eastern Atlantic is 0.9 to 2.8% faster than that in the eastern Pacific for ages 2 through 5 years.

Moore (1951) based his estimates of growth on length-frequency distributions of yellowfin tuna caught primarily by longline gear in the central Pacific. He used the Walford procedure and calculated $L_\infty = 190.0$ cm and $K = 0.037$ per month. Because of a limitation of Walford's

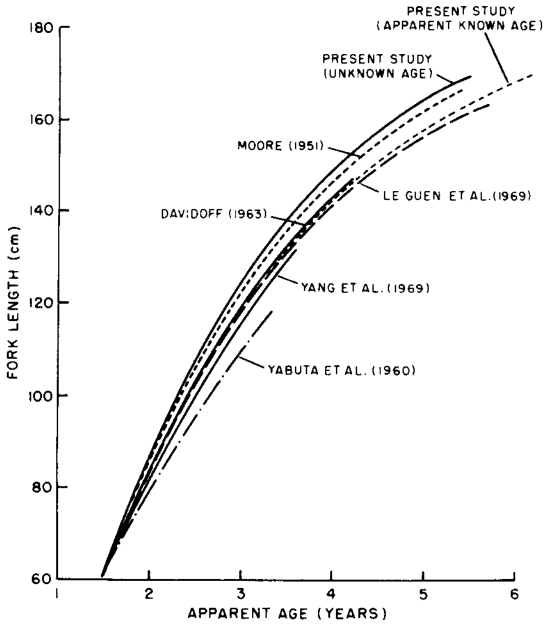

FIGURE 9.—Comparison of growth of yellowfin tuna from the Pacific and Atlantic Oceans. Curves were adjusted to a common base of age 1.5 years = 60 cm long and were estimated, except for that of Le Guen et al. (1969), from data reported in various studies.

method—requiring length measurements at equal time intervals—Moore was able to use only 16 out of his 25 observations. We recalculated L_∞ and K, using the Fabens' procedure and the 25 observations reported by Moore (his Table H). The estimates, $L_\infty = 191.9$ and $K = 0.036$, differ slightly from those of Moore and are very similar to our estimates for Atlantic yellowfin tuna.

Le Guen et al. (1969) estimated growth of yellowfin tuna from Dakar, Pointe-Noire, and both regions combined, based on modal progression of length-frequency samples (Table 7). Their samples were identical to some used in our study, but their estimate of growth for combined regions is slightly lower than ours; the difference in estimated lengths for ages 2 through 5 years is 2.8 to 4.3% less (Table 4). Part of the difference is in the method of analysis. The estimates by Le Guen et al. were based on mode selection from predorsal length distributions, and the lengths of size groups were not assumed to be normally distributed. Predorsal lengths were then converted to fork length; whereas in our best estimate predorsal length was converted to fork length by a log function before frequency distributions were analyzed, and the lengths of size groups were assumed to be normally distributed. Furthermore, Le Guen et al. assumed that the date of birth of fish of each year class of a region was the same and accordingly ages were assigned to size classes; such an assumption was not made for our estimate of K and L_∞; but for obtaining t_0 we assumed that yellowfin tuna of 60 cm long are 18 months old. Nevertheless, the difference is insignificant in view of the fact that there is considerable variability in observed mean lengths at age (Figure 7).

DISCUSSION

It is obvious from the results that estimates of growth of yellowfin tuna are quite variable and largely dependent on the method of analysis. Both the length-frequency and scale methods are based on various assumptions that are not always satisfied. For example, the assumption in the length-frequency method that size groups represent age groups, and the age groups are formed once a year, i.e., hatching within a short period, or season, is not completely satisfied for yellowfin tuna, since spawning occurs over several months (Matsumoto, 1966; Le Guen et al., 1969; Richards, 1969). Nevertheless, in many areas, as in the eastern Atlantic, there is generally a peak month of spawning (Le Guen et al., 1969) that can create a size group discernible in size-frequency distributions in later dates.

The scale method assumes that the scale marks are formed at regular intervals. So far, this assumption has not been satisfactorily verified for yellowfin tuna, although Yabuta et al. (1960) and Yang et al. (1969) have indicated that the marks formed every 6 months. Furthermore, because yellowfin tuna generally spawn over an extended season, the age at first annulus formation is not the same for all individuals of a year class. The back-calculated length at age I may therefore be questionable. It is surprising, however, that the observed lengths at age are remarkably similar for studies based on the scale and length-frequency methods (Table 4). This suggests that the marks on scales of Atlantic yellowfin tuna are indeed layed down at regular intervals and that observed lengths at age rather than estimates of parameters of the von Bertalanffy function are more meaningful in comparison of growth of yellowfin tuna. For such a comparison, the average growth rate of Atlantic yellowfin tuna is 17 cm/6 months, based on the scale method, and 18 cm/6 months, based on the length-frequency method for ages 1.5-3.5 years.

The comparison of observed lengths at age also indicates that there is little difference between growth of Atlantic and Pacific yellowfin tuna (Table 4). Yang et al. (1969), on the other hand, suggested that growth is faster in the Atlantic than in the Pacific. We analyzed their data with analysis of covariance and found that their Walford curves for the Atlantic and Pacific yellowfin tuna were not significantly different from a common line ($F_{2,5} = 0.474$) nor from parallel lines ($F_{1,5} = 0.904$). Thus the suggestion by Yang et al. was not demonstrated by their data, but in fact, growth of yellowfin tuna appears to be similar in the two oceans.

Finally, since the parameters of the von Bertalanffy growth function are sensitive to the method of analysis and range of sizes used to estimate them, we recommend that the observed size at age rather than the estimated size at age from the von Bertalanffy growth function be used in estimating yield per recruitment. The Ricker (1958) model of yield per recruitment, for example, is appropriate for observed values.

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