ESTIMATED GROWTH OF SURFACE-SCHOOLING SKIPJACK TUNA, *KATSUWONUS PELAMIS*, AND YELLOWFIN TUNA, *THUNNUS ALBACARES*, FROM THE PAPUA NEW GUINEA REGION

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ABSTRACT

The study was undertaken on length-frequency data collected from the Papua New Guinea pole-and-line fishery between June 1977 and December 1979.

Both skipjack and yellowfin tunas are recruited to all areas of the fishery at between 30 and 46 cm fork length. Skipjack tuna remain in the exploited phase up to an average 69 cm fork length and yellowfin tuna up to an average 85 cm fork length. Periods of time during which the greatest range of fork length occurred in the catch correspond with periods of low abundance, as inferred from catch per unit of effort indices. The estimated von Bertalanffy parameters are $k = 0.0429$ and $L_\infty = 74.8$ cm for skipjack tuna; and $k = 0.0243$ and $L_\infty = 180.9$ cm for yellowfin tuna (k on a monthly basis). Estimated growth over the observed range of modal values corresponds closely with that estimated from Papua New Guinea tagging data for skipjack tuna and from studies in other regions for yellowfin tuna.

Modal progressions indicate a 12-month periodicity in mass movement of yellowfin tuna stocks in northerly and southerly directions. The presence of two skipjack tuna spawning groups, one spawning during the northern summer and the other during the northern winter, is indicated by back calculation to date of birth of all length-frequency modes using an estimate of growth derived from the tag and recapture data.

With the recent expansion of surface fisheries for skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, in the Pacific (Bour and Galenon 1979; Kearney[2]) the need for information on this resource is becoming increasingly important for rational management. One method that might provide the quantitative information necessary is that of estimating yield per recruit (Schaefer and Beverton 1963), for which an estimate of growth is necessary.

Three techniques of obtaining growth estimates are in common use: the analysis of tag and recapture data, the analysis of data from the examination of hard parts of the fish for growth marks, and the analysis of modal progressions in length-frequency distributions. All three techniques have been used, with varying success, throughout the world for both yellowfin and skipjack tunas. The results of these studies have recently been reviewed by Le Guen and Sakagawa (1973) and Josse et al. (1979). Both studies recalculated published growth estimates using standardized procedures and indicated that, since the variances of the estimates were so wide, calculated growth rates for each species were not dissimilar among geographical areas.

Studies of growth of tunas in the western Pacific have been few. Yabuta et al. (1960) investigated growth of longline-caught yellowfin tuna, Lewis[3] reported the results of aging studies of skipjack tuna using readings of "daily" growth increments on otoliths, and Josse et al. (1979) analyzed skipjack tuna growth from the results of tagging studies conducted in Papua New Guinea in 1971-74.

This paper presents the results of a program of length-frequency data collection carried out from June 1977 through December 1979 from the pole-and-line (baitboat) fishery operating in Papua New Guinea waters. The results are presented as length-frequency modal progressions from which an estimate of growth is compared with estimates available from published sources. Since the

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[2] Kearney, R. E. 1979. An overview of recent changes in the fisheries for highly migratory species in the western Pacific Ocean and projections on future developments. South Pac. Bur. Econ. Co-op., Fiji, SPEC (79)17, 99 p.

[3] Lewis, A. D. 1976. The relevance of data collected in Papua New Guinea to skipjack studies in the western Pacific. Unpubl. manuscr., 5 p. Kanudi Fisheries Research Laboratory, P.O. Box 2417, Konedobu, Papua New Guinea.

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fishery takes place on several adjacent fishing grounds, and length-frequency data are available separately for each ground, the movements of groups of fish through the fishery are investigated where possible. Finally the availability of an independent estimate of skipjack tuna growth, from the tagging data, makes possible the calculation of probable date of birth of the fish comprising each modal group, the results of which indicate possible stock structure in the Papua New Guinea region.

DATA COLLECTION

Although skipjack and yellowfin tunas are found throughout Papua New Guinea waters, the fishery (Figure 1) is centered on baiting grounds on the north coast of Manus Island, within the extensive lagoon systems around and to the east of the island of New Hanover, and in the barrier reef lagoons on the northwest coast of the large island of New Britain. During the period of the present study, these four areas were effectively separated on both a fishing fleet and geographical basis. Fleet A operated in the eastern Bismarck Sea (area 4, Figure 1), fleet B operated throughout both New Hanover fishing areas (2 and 3), and fleet C also operated from New Hanover, but at any one time fished either north (area 2) or south (area 3) of the baiting grounds. The Manus-based fishery (area 1) was exploited only occasionally and by few vessels.

Fifty-one Okinawan-type vessels (Tomiyama and Hibiya 1976) operated throughout the fishery in 1977, 47 in 1978, and 41 in 1979. Poor fishing conditions caused by the northwest monsoon season from December through February preclude intensive fishing in these areas, resulting in limited data being available for this period each year.

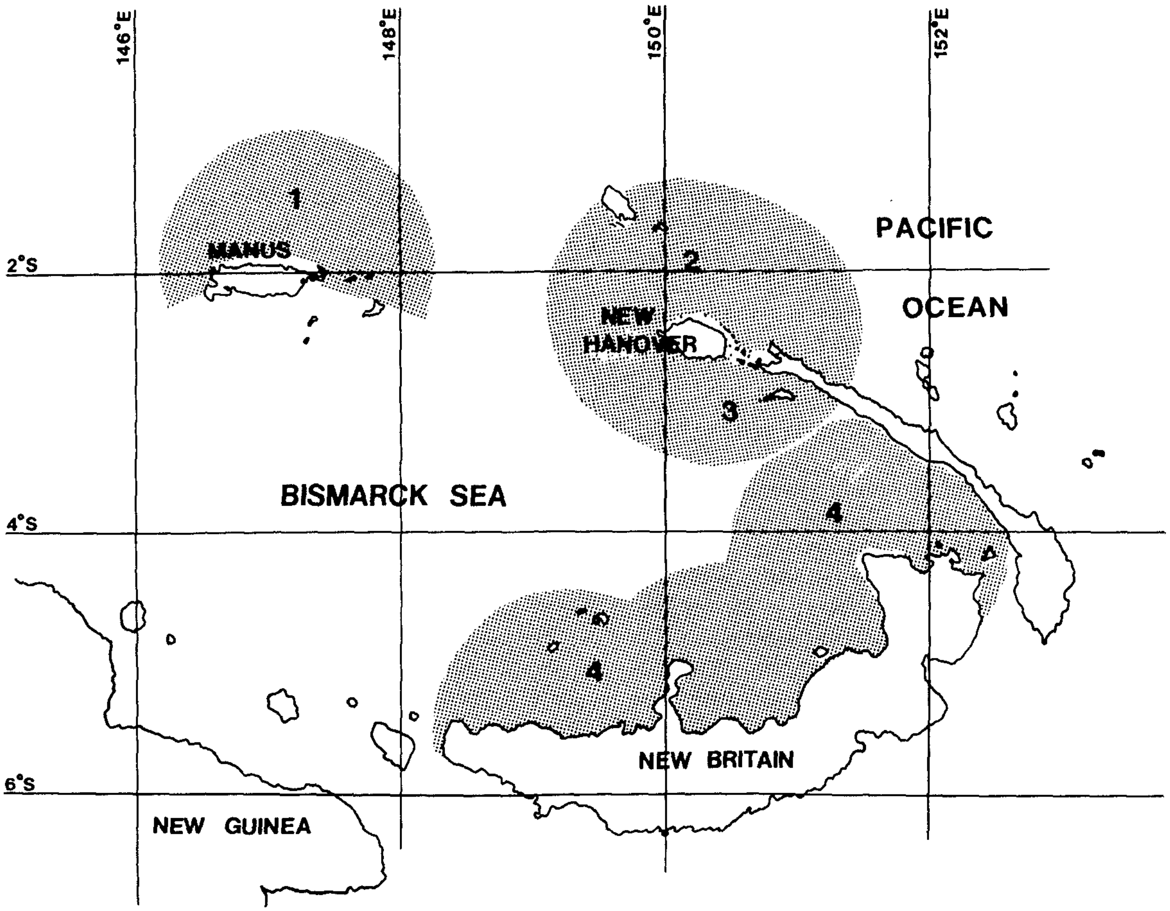

FIGURE 1.—Pole-and-line tuna fishing areas in the Papua New Guinea region (shaded): 1—north of Manus Island, 2—north of New Hanover Island, 3—south of New Hanover Island, 4—eastern Bismarck Sea.

Over the period of the study, 9.97% of the total catch consisted of yellowfin tuna, 89.83% skipjack tuna, and the remaining 0.20% other tunas and tunalike species. However, it should be noted that the proportion of yellowfin tuna in the catch is quite variable (Wańkowski 1980). The fishery since its inception in 1970 is described by Wańkowski (1980) while the 1978 and 1979 seasons are described in detail in Anonymous.[4, 5]

All vessels catch bait each day and the return to the baiting grounds is almost always accompanied by unloading the day's tuna catch onto one of the five motherships from which the fleets operate. From March 1978, length-frequency data were collected every day from each fishing area during unloading. The fork lengths (FL) of a sample of 10 skipjack and 5 yellowfin tunas from each vessel were measured to the nearest centimeter. This sample size was chosen since it represented an acceptable compromise between statistical and logistic requirements. The measurement of more than 15 fish/vessel proved impossible during busy periods of unloading, and it was considered more important to collect data from as large a number of vessels as possible than to increase sample size. Yellowfin tuna were measured only when sufficient numbers were present in individual catches to enable easy sampling, since the catches are rarely sorted by species.

During 1977, samples were measured on an ad hoc basis by Papua New Guinea Fisheries Division personnel during the course of their normal duties on board fleets operating in the Manus and eastern Bismarck Sea areas. The New Hanover fishery was sampled on a daily basis, but each sample was obtained from a small proportion of the total catch transhipped to a shore-based processing plant. It was therefore not possible in 1977 to differentiate between fish caught north or south of New Hanover.

During the 2½ yr of study, 106,933 skipjack tuna and 47,405 yellowfin tuna were measured.

DATA ANALYSIS

The length-frequency data were analyzed by area on a monthly basis. Individual monthly histograms were plotted by 1.0 cm FL interval for each of the four areas designated in Figure 1 and for the New Hanover area as a whole (areas 2 and 3, Figure 1). The separate data for north and south of New Hanover (areas 2 and 3, respectively) were obtained from fleet C only, while those for the New Hanover area as a whole were obtained only from fleet B. Monthly length-frequency distributions were therefore available separately for the Manus, New Hanover, and eastern Bismarck Sea areas.

Polymodal distributions were divided into successive unimodal distributions, using the method of "successive maxima" (Daget and Le Guen 1975). This method does not require the assumption of normality of distributions, but merely their symmetry in relation to the modal value. For samples with only one prominent mode and for the unimodal distributions resulting from the above analysis, the midpoint of the fork length interval of maximum frequency was taken as the modal length. Examples of length-frequency distributions and the resultant modal fork lengths are shown in Figure 2. Two conditions were attached to mode selection. The first was that model fork lengths were considered separate only if the midpoints of adjacent length intervals of maximum frequency were themselves separated by intervals of 3.0 cm or more. The second was that isolated peaks of only one 1.0 cm interval were not taken to represent modes (e.g., Figure 2: 1979, month 5, 61 cm).

Modal lengths were derived from all monthly samples where $n > 30$ fish (Figures 3, 4). However mean size of these monthly samples was 1,215 skipjack tuna and 578 yellowfin tuna. Only 19 (of 88) monthly skipjack tuna samples contained <400 fish and 1 <99; similarly, 21 (of 82) monthly yellowfin tuna samples contained <200 fish and 2 <49.

Because of the apparent large-scale migration between the relatively closely associated fishing areas, it was not possible to consider the results independently for each area. A serial succession of increasing modal lengths with time was designated a single group of fish distinguishable from other groups on the basis of size and progression with age. The progression which appeared to be most logical was used without taking into account the relative strength of each mode, major and minor modes being treated equally. As can be seen from Figures 3 and 4, the data does not naturally fall into conventional year-class or cohort structure. This absence of structural form, other than

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[4] Anonymous. 1979. Fisheries research annual report for 1978. Dep. Primary Ind., Port Moresby, Papua New Guinea, 98 p.

[5] Anonymous. 1980. Fisheries research annual report for 1979. Dep. Primary Ind., Port Moresby, Papua New Guinea, 103 p.

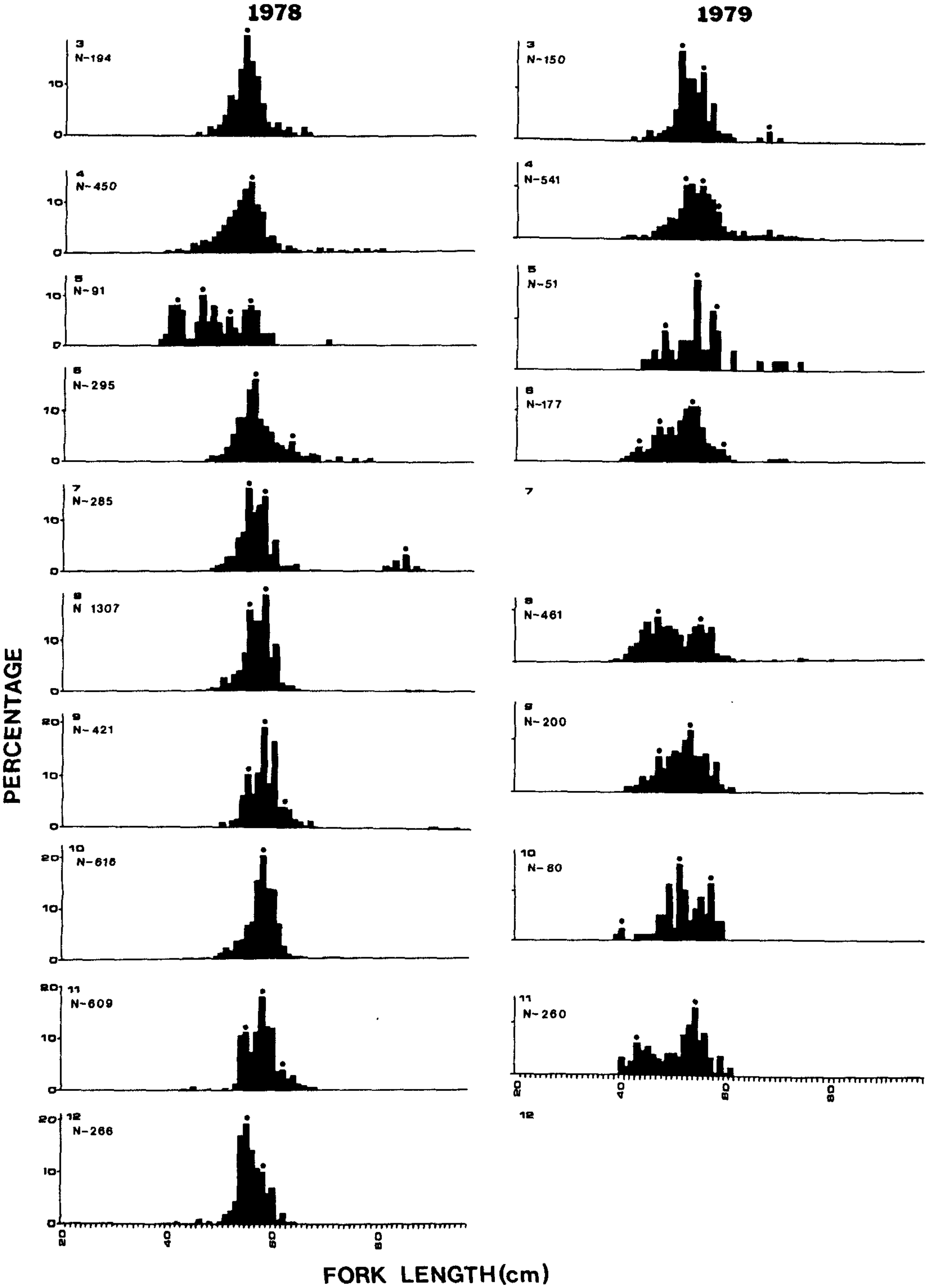

FIGURE 2.—Monthly length-frequency distributions of yellowfin tuna samples from the Papua New Guinea region from north of New Hanover (area 2) during 1978 and 1979. Modal fork lengths are indicated by dots. Note that data for July (month 7) and December (month 12) 1979 were not available.

modal progression, occurs whether the data are analyzed using all the modes as shown, or using the major mode of each monthly distribution only.

The von Bertalanffy growth function (Bertalanffy 1960) was used to describe growth. This function is usually expressed as

$$L_t = L_\infty [1 - \exp - k(t - t_0)]$$

where L_t = length at age t, L_∞ = asymptotic length, k = coefficient describing the rate of growth, and t_0 = theoretical age where L_t is zero. The Fabens' (1965) least squares procedure can be used to fit length data to the von Bertalanffy function, which then takes the form:

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

Although originally devised to fit tag return data, this procedure is equally applicable to length observations of untagged fish, and is especially useful since length at known age is not required. This procedure has been used by Rothschild (1967) and Joseph and Calkins (1969) to estimate growth of skipjack tuna from tagging data, and Le Guen and Sakagawa (1973) to estimate growth of yellowfin tuna from modal progression data.

In the present study, Fabens' (1965) procedure was used with monthly modal length data for individual groups of fish of unknown age. Estimates of L_∞ in centimeters and of k on a monthly basis were derived. Length-at-age information from published sources was used to fix the derived growth functions on a known time scale.

RESULTS

Recruitment and Exploited Size Range

Recruitment in this report refers to first entry into the fishery. Size at recruitment, as inferred from length-frequency samples, and the size range of both skipjack and yellowfin tunas exploited by the fishery varied throughout the duration of the study. The smallest size of fish of either species occurring in monthly samples was between 30 and 46 cm FL (Table 1), with the exception of a few yellowfin tuna <30 cm FL in July 1979. Skipjack tuna <46 cm and yellowfin tuna <54 cm FL were absent in February 1979. The maximum lengths of skipjack and yellowfin tunas were 74 and 96 cm FL, respectively (Table 1, Figure 5). However, few samples contained fish >69 and >85 cm FL, respectively. There were no consistent differences in size at recruitment, or in the size range exploited, among the four fishing areas.

TABLE 1.—Fork length range (centimeters) of skipjack and yellowfin tunas from all areas of the Papua New Guinea region combined, and corresponding catch per unit effort (CPUE) (metric tons per boat fishing day) and effort (number of fishing days). The fishing effort remained fairly constant from April to November of each year.

		Skipjack tuna		Yellowfin tuna		
Year	Month	Size range	CPUE	Size range	CPUE	Effort
1977	June	44-64	2.3		0.3	1,076
	July	43-65	3.0	39-92	.2	1,070
	Aug.	40-67	3.4	36-82	.4	1,093
	Sept.	38-65	1.7	37-80	.4	957
	Oct.	37-68	1.4	42-80	.4	966
	Nov.	36-68	1.7	36-77	.5	945
	Dec.	40-64	1.7	38-80	.6	579
1978	Mar.	31-69	2.2	41-80	1.4	471
	Apr.	33-69	2.4	30-80	.5	820
	May	33-69	4.6	35-81	.2	1,129
	June	40-69	4.4	34-81	.2	1,150
	July	43-69	4.4	41-88	.1	1,166
	Aug.	42-69	5.8	44-90	.3	1,168
	Sept.	40-69	6.1	46-96	.2	1,069
	Oct.	39-69	5.0	40-80	.3	1,271
	Nov.	42-68	5.0	31-80	.4	1,161
	Dec.	40-67	4.2	37-77	.4	423
1979	Feb.	46-59	5.0	54-72	.5	206
	Mar.	40-66	4.3	42-78	.4	351
	Apr.	34-65	5.5	40-78	.2	797
	May	33-68	3.3	35-80	.4	956
	June	40-70	3.5	32-83	.4	1,016
	July	40-74	2.9	24-83	.4	1,041
	Aug.	34-69	2.7	30-87	.2	922
	Sept.	33-69	2.0	31-84	.4	902
	Oct.	30-70	1.0	33-80	.6	719
	Nov.	30-70	1.1	31-90	.2	739
	Dec.	32-67	1.1	31-90	.4	276

Size at recruitment for yellowfin tuna was smaller than has been reported in the past for the eastern Pacific (Hennemuth 1961; Davidoff 1963; Anonymous[6,7]) or eastern Atlantic (Le Guen and Sakagawa 1973), where recruits are reportedly 40-60 cm and 60 cm FL, respectively, but similar to that recently reported for the eastern Pacific (Anonymous footnote 7) and for the western Indian Ocean (Marcille and Stequert 1976a). A similarity between skipjack tuna size at first recruitment in the western Pacific and western Indian Oceans is also apparent from a comparison of the results of the present study with those of Marcille and Stequert (1976b).

Suzuki (1971), Kikawa and Warashina (1972), Le Guen and Sakagawa (1973), Marcille and Stequert (1976b), and others have noted the extreme size-specificity of pole-and-line catches. In

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[6] *Anonymous. 1975. Annual report of the Inter-American* Tropical Tuna Commission, 1974. [In Engl. and Span.] Inter-Am. Trop. Tuna Comm., La Jolla, Calif., 169 p.

[7] Anonymous. 1980. Annual report of the Inter-American Tropical Tuna Commission, 1979. [In Engl. and Span.] Inter-Am. Trop. Tuna Comm., La Jolla, Calif., 227 p.

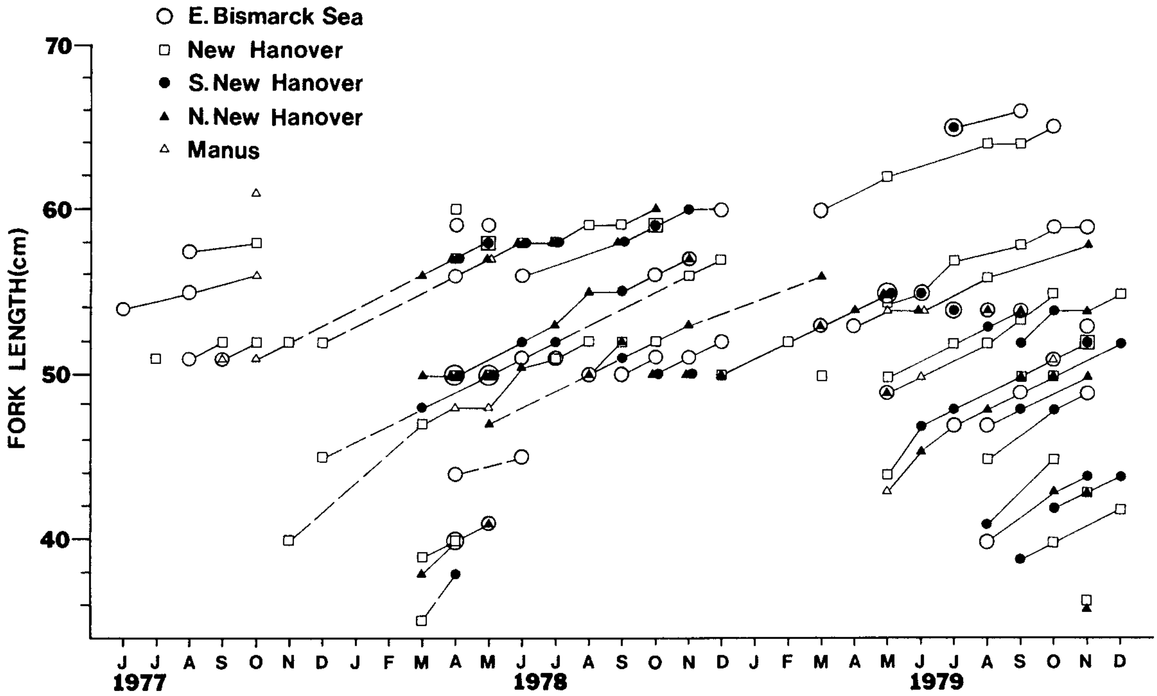

FIGURE 3.—Modal fork lengths of samples of skipjack tuna from all Papua New Guinea areas as a function of time (in months). Modal progressions are indicated by lines.

the Papua New Guinea fishery, observations have shown that vessels continually pursue and fish an individual school during periods of low catch per unit of effort (CPUE), thereby fishing few schools each day. However, during periods of high CPUE, vessels fish a large number of schools, taking fish from each school until they "go off the bite" and then moving on to a fresh school. Size-specificity of the catch, as a consequence of the fishing strategy adopted, would therefore be expected to be greatest during periods of high CPUE, vessels taking only a restricted size range of fish from each school (presumably those size classes most vulnerable to this method of fishing), and lowest during periods of low CPUE, during which a wider range of size classes would be represented in the catch.

Figures 3 and 4 show two periods, November 1977 to May 1978 and May 1979 through to the end of sampling in December 1979, during which a wide range of size classes appeared in the samples. These periods coincide with periods of relatively low skipjack tuna CPUE (Table 1). The situation is less clear for yellowfin tuna. However, since skipjack tuna composed 90% of the total catch on average, it is clear that skipjack tuna abundance would determine the adoption of a particular fishing strategy. This would therefore account for the yellowfin tuna size range, varying synchronously with that of skipjack tuna (Figures 3, 4), but independently of yellowfin tuna abundance (Table 1).

Observations from the fishing vessels during the course of the study confirmed that yellowfin tuna larger than the maximum size taken by the fishery and schools of very small skipjack tuna, both normally comparatively rare, were common throughout the fishery during late 1977 and from August to November 1979. There is therefore some indication that fishing strategy, determined by low apparent abundance, may not alone account for the appearance of small and large fish in the catch during these periods.

The results show that the timing of recruitment cannot be determined from the size composition of the landed catch. However, Ueyanagi (1970), Nishikawa et al. (1978), and Naganuma (1979) have demonstrated that skipjack tuna spawn throughout the year in the western Pacific, although in different geographical areas depending on season: a situation likely to result in continuous recruitment to the equatorial region. The re-

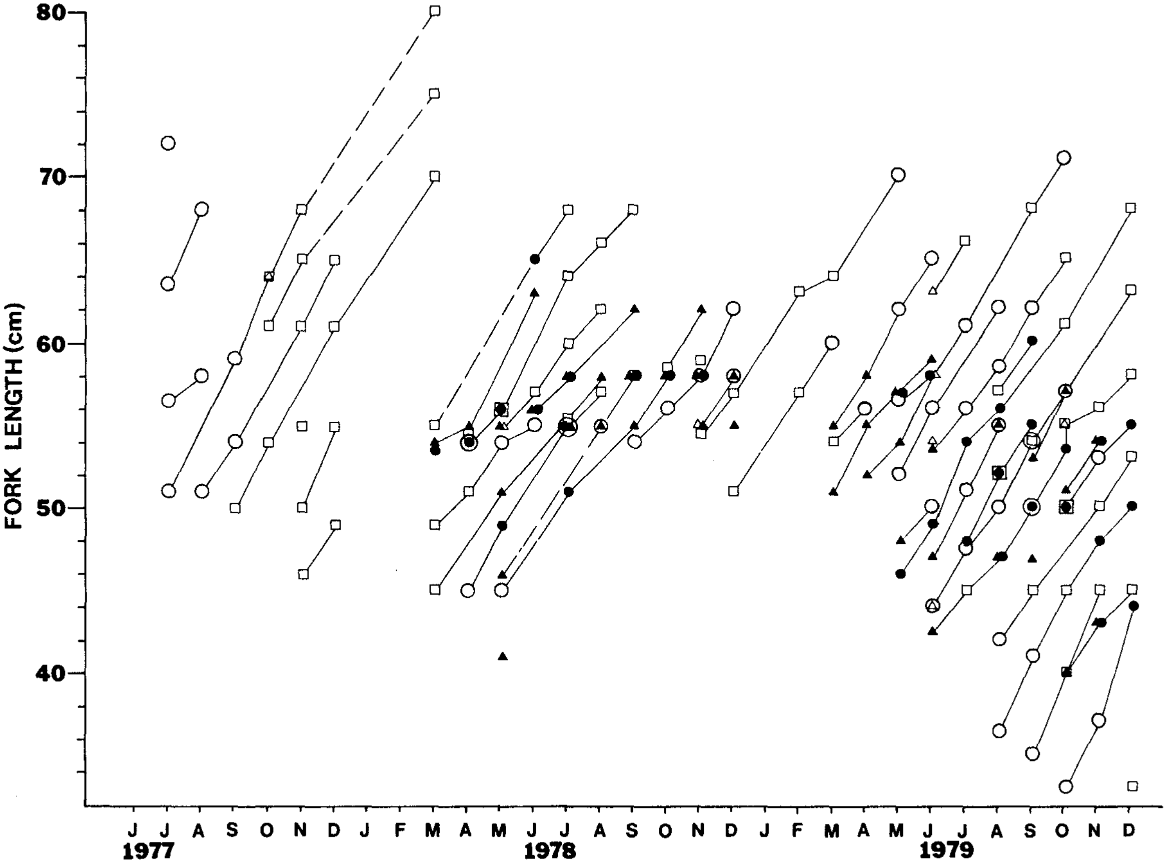

FIGURE 4.—Modal fork lengths of samples of yellowfin tuna from all Papua New Guinea areas as a function of time (in months). Modal progressions are indicated by lines. See Figure 3 for explanation of symbols.

sults of tagging studies in Papua New Guinea (Lewis 1980a, b, see footnote 8) indicate that skipjack tuna recruitment may be intermittent, and possibly dependent on periodic influxes from north and east of the area.

It has been suggested (Lewis 1980a, b, footnote 3; Anonymous[9]) that there are at least three partially mixing components to the skipjack tuna population in the western Pacific: one ranging from Japanese waters to the Equator, one centered on the Bismarck Sea and ranging to lat. 10° N, and the last extending south from the Bismarck Sea; and that these components are composed of separate spawning units, distinguishable on the basis of spawning periodicity with respect to northern and southern summers. The following analysis of data from the present study provides further evidence supporting this view.

Josse et al.'s (1979) estimates of the von Bertalanffy parameters (k = 0.94512 on an annual basis and L_∞ = 65.47 cm) for tagged skipjack tuna in the Papua New Guinea region were applied to the length-frequency modal data to estimate the dates of birth from all modal lengths available for skipjack tuna samples from the four areas. Josse et al.'s estimate is independent of the modal data, being derived from an earlier study using a different technique, and for this reason it is preferable (for present purposes) to the estimate derived in this report.

The frequency distribution of dates of birth is shown in Figure 6. The extremes of the range (pre-1975 and post-1977) are poorly represented; however, a 6-mo periodicity is indicated. Although

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[8] Lewis, A. D. 1977. Tuna tagging in Papua New Guinea. Harvest, Papua New Guinea 4:13-17.

[9] Anonymous. 1976. Ad-hoc meeting of scientists to discuss skipjack fisheries developments and research requirements. Rep. meet., South Pac. Comm., Noumea, New Caledonia, 6-10 Dec. 1976, 27 p.

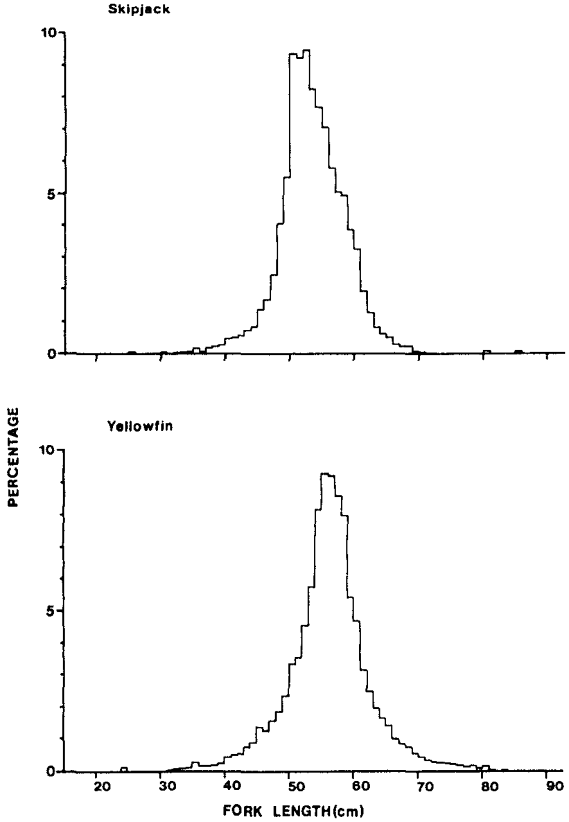

FIGURE 5.—Fork length-frequency distributions for skipjack (top) and yellowfin tunas (bottom) sampled during the study. Individual samples have been pooled for the four study areas in the Papua New Guinea region.

correspondence between 6-mo intervals and calculated peaks is not precise, considering the underlying assumption that all modal groups grew at identical rates, the observed correspondence is fairly good. The results indicate that the skipjack tuna stocks exploited by the Papua New Guinea fishery may exhibit two peaks in spawning activity, 6 mo apart.

Naganuma (1979), using gonad indices of skipjack tuna caught in the western Pacific, demonstrated the existence of two spawning groups: one spawning in southern waters in the southern summer (October-March) and the other in northern waters in the northern summer. Data for larval abundance in Papua New Guinea waters (Nishikawa et al. 1978) indicate almost identical peaks in spawning periodicity, although much continuous spawning in equatorial waters is also indicated. Spawning periodicity as determined from gonad indices and larval distribution therefore corresponds to that determined from the results of the present study.

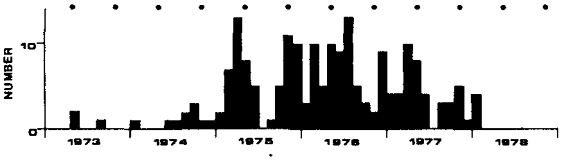

FIGURE 6.—Distribution of month of birth of skipjack tuna from the Papua New Guinea fishery calculated by the von Bertalanffy growth function, using an independent estimate of growth for all modal fork length data. Distribution is shown in one-tenths of 1 yr. Dots indicate 6-mo intervals.

However, as is clear from the skipjack tuna modal data (Figure 3) and abundance (as inferred from skipjack tuna CPUE, Table 1), this possible 6-mo spawning periodicity did not result in semestral recruitment to the fishery in 1977-79. Lewis (1980a), however, reported that there were two groups of skipjack tuna present in the Bismarck Sea in 1972, apparently resulting from two periods of recruitment 6 mo or more apart. As 1972 was a year in which skipjack tuna abundance was exceedingly low, it might be expected that the consequences of possible large-scale periodic recruitment to the fishery would be more obvious then than during periods of relatively high abundance, as during the present study.

Yellowfin tuna show restricted spawning periods and semestral recruitment in many fisheries (Hennemuth 1961; Davidoff 1963; Matsumoto 1966; Le Guen et al. 1969; Richards 1969; Le Guen and Sakagawa 1973). That this is unlikely to have occurred in equatorial western Pacific waters during the period of the study is clear from Figure 4; the fairly continuous production of fish implied by the large number of modal groups passing through the fishery is unlikely to be the result of one or two short spawning periods. Although differential growth between elements resulting from a protracted spawning period might result in the observed spread in recruitment, the youth of the fish, as inferred from rate of growth estimates (Le Guen and Sakagawa 1973; present paper), would necessitate either early separation into groups of fish exhibiting different rates of growth or protracted spawning periods (perhaps continuous spawning activity).

Most identifiable groups of yellowfin tuna disappeared from the pole-and-line catch at between 62 and 71 cm FL (Figure 4). Kikawa and Warashina (1972) pointed out that the Japanese long-range pole-and-line fisheries in the equatorial western Pacific take fish 30-100 cm FL (but mainly <70 cm), harvested well before they enter the deeper water longline fishery that exploits fish mainly >100 cm FL.

However, Wright (1980) indicated that a proportion of Japanese longline catches consist of yellowfin tuna of 70-100 cm FL which are discarded on capture owing to their unsuitability for the sashimi (raw fish) market that this fishery supplies. The equatorial western Pacific purse seine fishery exploits fish from 30 to 100 cm FL (Kikawa and Warashina 1972; Wańkowski and Witcombe[10]), about half the catch consisting of fish <100 cm. The absence of significant numbers of yellowfin tuna >70 cm in the Papua New Guinea pole-and-line catch (Figure 5) therefore indicates selectivity for smaller fish (confirmed by the absence of suitable gear, on Papua New Guinea-based vessels, for poling larger fish on board) and possible recruitment of 70-100 cm size class from the surface fishery into the longline fishery (yellowfin tuna in this region presumably spending less time at the surface with increasing age). However, that this size class of yellowfin tuna does not wholly enter deeper waters is indicated by observations of their presence in surface schools in late 1977 and late 1979, and by the fact that Japanese longliners set shallow lines when their target species is yellowfin tuna (Wright[11]).

A similar point of note is the low incidence of skipjack tuna >65 cm FL (Figure 5) in the catch. This is in contrast to the situation in the central and eastern regions of the Pacific where larger skipjack tuna are common (Rothschild 1965; Doumenge[12]), but is similar to that in the western Indian Ocean (Marcille and Stequert 1976b). Again, gear selectivity in the different regions might account for this difference. However, skipjack tuna >65 cm FL appear to compose a portion (discarded) of the longline catch in the equatorial western Pacific (Wright footnote 11). Barkeley et al. (1978) concluded that skipjack tuna >4.5 kg (about 60 cm FL) would be unable to inhabit the warm surface water of the tropics, unless they were able to make frequent incursions into cooler water, for example below a shallow thermocline.

Stock Movements

A stock is defined as the exploitable group of fish existing in a particular area at a particular time (Anonymous footnote 9). If it is assumed that a serial progression of length-frequency modes with time represents the progress of one group of fish through the fishery, then it should be possible to follow the movements of that group among the four fishing areas. While it is possible to do this, the analysis of skipjack tuna movements indicates only the complexity of the situation: groups of fish apparently moving freely and rapidly (often within 1 mo) between areas. No pattern nor periodic movement can be inferred from the present modal data. However, conclusions from Lewis (1980a, b, footnotes 3, 8) from the Papua New Guinea skipjack tuna tagging program are summarized below.

Skipjack tuna appear to be recruited from east of Papua New Guinea and from north of the Equator, and to move clockwise around the eastern and southern parts of the Bismarck Sea. Some fish appear to retrace this route up to 2 yr later, while others emigrate northward out of this area soon after recruitment. At least part of the stock, however, undergoes little translocation, remaining in one area for a considerable period of time. Most entries and exits appear to be through the northern Bismarck Sea between New Hanover and Manus. Some fish do not penetrate as far south as the eastern Bismarck Sea fishery, remaining in the New Hanover area only. While these results indicate extensive emigration and immigration, the skipjack tuna stocks cannot be considered purely transient since only a small portion of the tagged fish was recovered outside the Papua New Guinea region (although the variable distribution of fishing effort outside Papua New Guinea waters precludes definitive conclusions).

The present modal progressions indicate two types of movement of the yellowfin tuna: one commencing in the eastern Bismarck Sea, entering the area south of New Hanover and sometimes progressing to north of New Hanover (Figure 7, which shows those portions of the data in Figure 4, indicating movement of fish in the directions under discussion), and the reverse movement, indicated by the first appearance of a modal group to

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[10] Wańkowski, J. W. J., and D. W. Witcombe. 1979. Fish associated with floating debris in the equatorial western Pacific purse-seine fishery. Unpubl. manuscr., 13 p. Kanudi Fisheries Research Laboratory, P.O. Box 2417, Konedobu, Papua New Guinea.

[11] Wright, A., Fisheries Biologist, Kavieng Fisheries Research Laboratory, P.O. Box 101, Kavieng, Papua New Guinea, pers. commun. 1979.

[12] Doumenge, F. 1973. The development of tuna and skipjack fisheries in French Polynesia and experience in live-bait technique. South Pac. Comm. Fish. Newsl. 10:27-30.

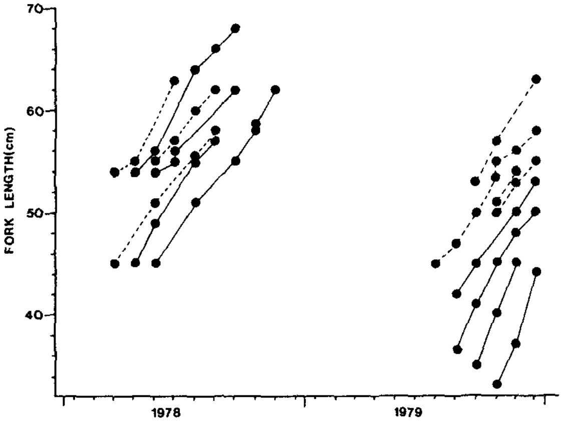

FIGURE 7.—Monthly modal progressions for yellowfin tuna in 1978 and 1979, showing apparent movement through the Papua New Guinea region from the eastern Bismarck Sea in a north and northwest direction through the New Hanover areas (line), and no apparent movement out of the area north of New Hanover (dashed line).

the north of New Hanover, or sometimes in the New Hanover area in general, and terminating in the eastern Bismarck Sea (Figure 8, which shows those portions of data in Figure 4, indicating the reverse movement of fish). A possible northward movement of yellowfin tuna recruited into the eastern Bismarck Sea in July and August 1977 is also indicated from the 1977 data (Figure 4).

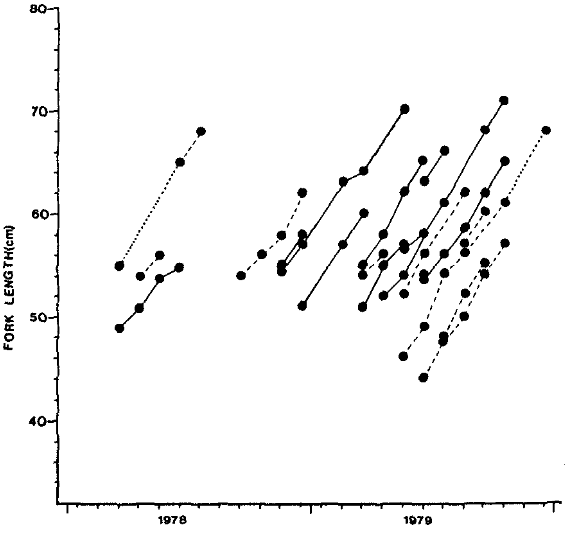

FIGURE 8.—Monthly modal progressions for yellowfin tuna in 1978 and 1979 showing apparent movement through the Papua New Guinea region from the New Hanover north area, south and southeast into the eastern Bismarck Sea area (line), and no apparent movement out of the Bismarck Sea (dashed line).

The periods of northward movement (of yellowfin tuna recruited to the eastern Bismarck Sea fishery in April and May 1978 and between August and October 1979) coincide with the appearance of small fish in the catch. However, since groups of fish of similar size appeared to move both north and south during 1978 and the first half of 1979, the direction of movement cannot be explained on the basis of size or age alone. During these periods of northward movement, all other groups of fish recruited to the fishery were restricted to the New Hanover area, almost exclusively to the north (Figure 4). These observations imply either a situation similar to that occurring in skipjack tuna where some fish penetrate no farther south than the New Hanover fishery or the northward movement of groups of fish that for some reason are not apparent in the Bismarck Sea catch. Groups of fish recruited at the same time as those moving in a southward direction (November 1978-June 1979) appeared to be restricted to the Bismarck Sea (Figure 4).

The results indicate extensive emigration and immigration of some of the yellowfin tuna stock, while other parts of the stock show little movement during their brief period of persistence in the fishery. The path taken appears similar to that shown by skipjack tuna stocks, and that proposed by Inoue (1969) for yellowfin tuna, not a surprising result in view of the geographical constraints of the region and the distribution of fishing effort. There is no evidence for emigration soon after recruitment, nor of source of recruitment, and groups of yellowfin tuna show mass movement either clockwise or anticlockwise through the Bismarck Sea with no indication of any retracing of their route.

Fundamental differences between the skipjack and yellowfin tuna stocks seem to lie in the long-term persistence of groups of skipjack tuna in the fishery (Figures 3, 4), probably an important function of their slower growth rate (Josse et al. 1979; present paper), while, in contrast, yellowfin tuna stocks remain in the exploitable size range for a few months only, since their faster growth rate (Le Guen and Sakagawa 1973; present paper) soon takes them out of the exploitable size range.

Estimated Length-At-Age

The von Bertalanffy parameters estimated from all data and all areas combined were $k = 0.0429$ and $L_\infty = 74.8$ cm for skipjack tuna, and $k = 0.0243$

and L_∞ = 180.9 cm for yellowfin tuna (k in both cases is estimated on a monthly basis). The calculated length-at-age curves are shown in Figures 9 and 10, which also include modal progression data fitted to the curve. Tables 2 and 3 list modal progressions used in the estimations. The mean square error was calculated from the formula:

$$\frac{\sqrt{\Sigma r^2}}{N}$$

where N is the number of pairs of observations and r a coefficient which is minimized in the curve fit.

$$r = \sqrt{\Sigma(\hat{L} - Li)^2}$$

where $\hat{L}$ is the length predicted by the particular curve and Li the observed length value. Since age at length data are unknown, r is not, strictly speaking, a true correlation coefficient. The mean square error was found to be 0.74 for the estimate of skipjack tuna growth and 2.01 for that of yellowfin tuna growth.

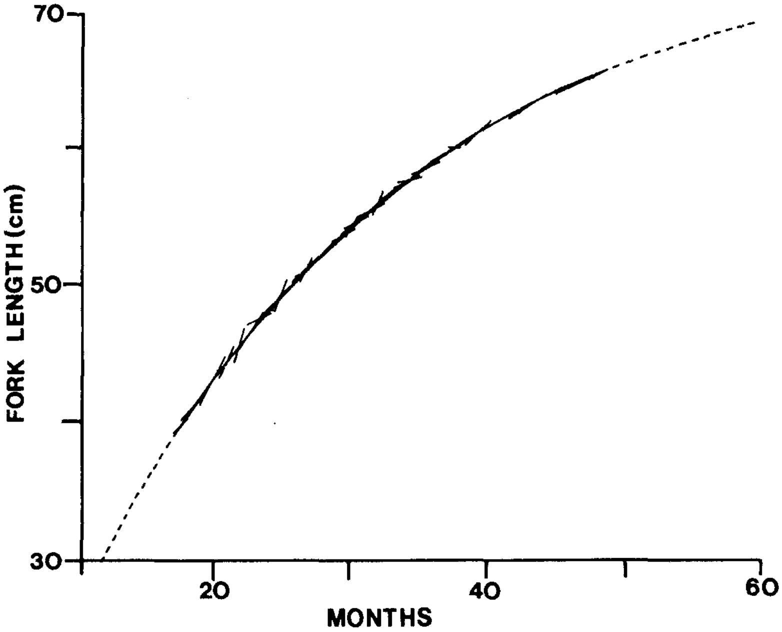

FIGURE 9.—Plot of length at age for skipjack tuna derived from all modal progressions for all Papua New Guinea areas combined, fitting the von Bertalanffy function by Fabens' (1965) procedure. Original modal data are shown fitted to the curve. The time scale is in elapsed months and does not indicate apparent age. Dashed line shows extrapolation beyond the range of observations.

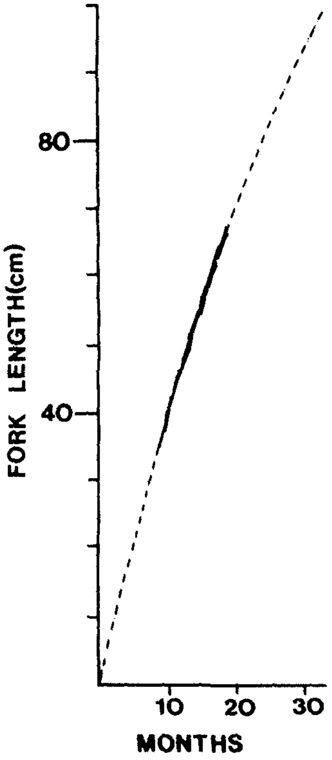

FIGURE 10.—Plot of length at age for yellowfin tuna derived from all modal progressions for all Papua New Guinea areas combined, fitting the von Bertalanffy function by Fabens' (1965) procedure. Original modal data are shown fitted to the curve. The time scale is in elapsed months and does not indicate apparent age. Dashed line shows extrapolation beyond the range of observations.

TABLE 2.—Modal progressions for skipjack tuna used to estimate fork length (centimers) at age. Modal progressions indicated by solid lines; $n = 83$.

Year	Month																		
1977	June		54																
	July		|																
	Aug.	57.5	55	51															
	Sept.	|	|	52	51														
	Oct.	58	56		52	51													
	Nov.					52													
1978	Mar.	56				48	47						38	39					
	Apr.	57	56		50	|	|						40	40					
	May	58	57		|	50	48						41						
	June		58	56	52	51	50.5												
	July		|	|	53	52	51												
	Aug.		59	|	|		52	50	50										
	Sept.		|	58	55			51	52	50									
	Oct.		60	59	56			52		51	50								
	Nov.			60	57	56		53			51								
	Dec.			60		57					52	50							
1979	Jan.											|							
	Feb.											52							
	Mar.				60							53							
	Apr.				|							54		53					
	May				62							55	54.5	|	50	49	44	43	
	June				|								55	54	|	50	47	45.5	
	July			65	|								57	|	52	|	48	47	
	Aug.			|	64		47	41	40				|	56	53	52	|	48	45
	Sept.			66	|	52	48	|	|		39		58	|	54	53.5	50	49	|
	Oct.				65	|	|	45	43	42	40		59	|		55	51	50	48
	Nov.					54	50		44	43	|			58			52	|	49
	Dec.					55				44	42							52	

TABLE 3.—Modal progressions for yellowfin tuna used to estimate fork length (centimeters) at age. Modal progressions indicated by solid lines; $n = 105$.

Year	Month																		
1977	July	63.5	56.5	51															
	Aug.	68	58	|	51														
	Sept.			59	54	50													
	Oct.			64	|	54	61												
	Nov.			68	61	|	65	50	46										
	Dec.				65	61		55	49										
1978	Jan.					|													
	Feb.					|													
	Mar.	54	49	45		70													
	Apr.	55	51	|	54		45												
	May	|	54	51	56		49	45	55										
	June	63	56	|	|		|	|	57	65									
	July		58	55.5	64		55	51	60	68									
	Aug.		|	58	66		57	|	62		55								
	Sept.		62		68			55			58	54							
	Oct.							58				56	58.5						
	Nov.											58	62	54.5	55				
	Dec.											62		57	58	51			
1979	Jan.													|		|			
	Feb.													63		57			
	Mar.	55	54	51										64		60			
	Apr.	58	56	55	52									|					
	May	62		57	54	46	48	52	56.5					70					
	June	65			58	49	50	56	58	44	47	53.5	63						
	July				61	54		|		46.5	51	56	66	45	48				
	Aug.				|	56		62		50	55	58.5		47	52	36.5	42	57	
	Sept.	53			68	|				54		62		50	55	41	45	60	35
	Oct.	57	33	50	71	61	51			57		65		53.4		45	|		40
	Nov.		37	53		|	54	43		|				56		48	50		45
	Dec.		44	55		68		45		63				58		50	53		

DISCUSSION

The use of the von Bertalanffy function for estimating length-at-age implies that this function is a valid description of growth of skipjack and yellowfin tunas and that growth of all groups of each species is identical. Kearney (1978) has speculated that growth of skipjack tuna may be better represented by a number of linear stanzas, and an examination of the modal progression data indicates a disparity in growth rates among groups of fish. It should be noted that Knight

(1968), and others since, have pointed out the dangers of extrapolating the results beyond the range of observations on which they are based. However, provided that these limitations are recognized, and the results considered as representative of average growth of the stock, the length-at-age data are reasonable estimates of growth during the period of the study.

However, several qualifying comments must be made regarding these estimates. Length-frequency samples are subject to errors from two main sources: 1) Suzuki (1971) showed that samples obtained using a size-specific fishing technique are unlikely to be representative of the size class sampled. Fish at either extreme of the size range would be underrepresented: the mean length of modal groups is likely to be overestimated at the lower extreme and underestimated at the upper. 2) Josse et al. (1979) demonstrated that the modal progression method is sensitive to inadequate sampling: estimated growth rates vary widely if few landings are sampled. However, since daily landings from virtually every operating vessel were sampled, possible problems arising from the second source of error were minimized, if not eliminated entirely. The modal progression method itself is considered to be subjective (e.g., Joseph and Calkins 1969), both in view of the methods used to determine modal lengths and in connecting modal values to form serial progressions. However this technique has proved effective provided that the derived growth functions are considered estimates only.

Various studies on the growth of skipjack and yellowfin tunas have been conducted throughout the world, but few have been carried out in the western Pacific. Good estimates for the growth of medium-sized skipjack tuna are available from the Papua New Guinea tagging study. As Le Guen and Sakagawa (1973) pointed out, a comparison of the von Bertalanffy parameters k, L_∞, and t_0 often gives the misleading impression that growth is different in different regions. Two recent studies on yellowfin and skipjack tuna growth (Le Guen and Sakagawa 1973; Marcille and Stequert 1976b) compare these parameters from various regions and studies. In this paper, calculated growth curves from various studies in the Pacific Ocean are compared with those obtained by the present study. Such comparison requires the use of a common time base, in the form of apparent or estimated age, which may be achieved by fixing one common age at length for each species. In the absence of a reliable method for aging skipjack or yellowfin tuna it is necessary to estimate likely age at length by combining results obtained using several techniques.

Estimates of fork length of skipjack tuna at age 12 mo agree very closely. Batts (1972) and Cayre[13] used dorsal spine readings to obtain lengths of 40.6 and 40.7 cm for the western and eastern Atlantic. Yoshida (1971), using modal progression data from juveniles recovered from the stomachs of billfish, and Uchiyama and Struhsaker[14] from readings of sagittae, estimated lengths of 35.0 and 42.6 cm for the central Pacific. Finally Lewis (footnote 3), also reported in Josse et al. 1979) reported estimates from Papua New Guinea waters of between 40.0 and 45.0 cm, again from sagittal readings. In the present study an approximate average of these quoted figures was used: 40.0 cm at 12-mo age.

In comparing growth curves for skipjack tuna from different regions, only those from the Pacific have been used (Figure 11), since Josse et al. (1979) showed that, due to sample variability, no significant difference was detectable in growth among regions, nor between growth in the eastern and western Pacific as calculated from tagging studies. Underestimation (Josse et al. 1979) of growth of larger fish and their low L_∞ (65.47 cm) may account for the difference in slope of the two curves derived for Papua New Guinea skipjack tuna, and for the difference in the two values of k (Josse et al. 1979: $k = 0.9451$; present paper: $k = 0.5148$, both estimated on an annual basis).

Age at length estimates for yellowfin tuna obtained from scale readings and modal progression data show good agreement over the range of observed values only (Suzuki 1971; Le Guen and Sakagawa 1973), with the exception of the study by Yabuta et al. (1960) which appears to have underestimated growth rate. Estimates for age at length have been obtained for yellowfin tuna from the Atlantic from scale readings by Yang et al. (1969), whose observed fork lengths averaged 66.1 cm at 18-mo age, and by calculation from spawning and recruitment data (Le Guen et al. 1969). The latter study estimated fork length at 18 mo to

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[14] Uchiyama, J. H., and P. Struhsaker. 1975. Age and growth of skipjack tuna, *Katsuwonus pelamis*, yellowfin tuna, *Thunnus albacares*, and albacore, *Thunnus alalunga*, as indicated by daily growth increments of sagittae. Int. Comm. Conserv. Atl. Tuna, SCRS 75/57.

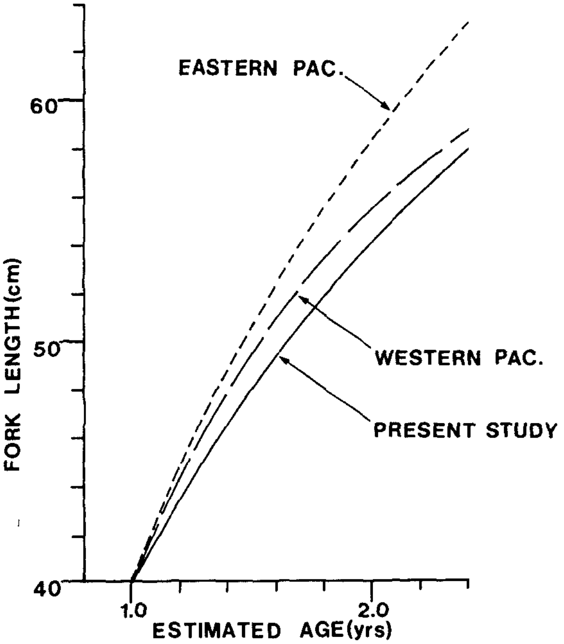

FIGURE 11.—Comparison of growth curves for skipjack tuna from the Pacific. Growth in the eastern Pacific (dashed line) was recalculated from various tagging studies by Josse et al. (1979); in the western Pacific from tagging (Josse et al. 1979, broken line) and modal progressions (present study, line). All are adjusted to a common base age of 12 mo at 40.0 cm FL. Data from Josse et al. (1979) were calculated by them using Tomlinson's (1971) least squares procedure.

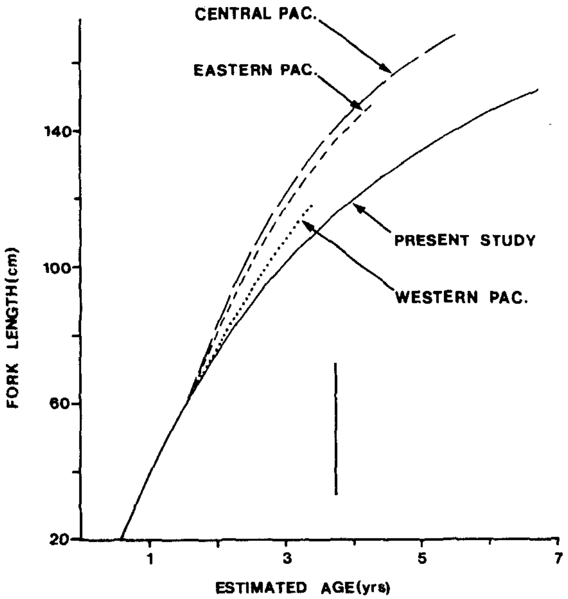

FIGURE 12.—Comparison of growth curves for yellowfin tuna from the Pacific. Eastern Pacific (Davidoff 1963, dashed line); central Pacific (Moore 1951, broken line); western Pacific (Yabuta et al. 1960, dotted line); and present study (line). All were recalculated using Fabens' (1965) least squares procedure. Vertical bar indicates limits of data used to derive the present curve; extrapolation beyond this range is for comparison purposes only.

be 60.0 cm, the value used in the present comparison.

Growth estimates of yellowfin tuna from the eastern Pacific (Davidoff 1963), central Pacific (Moore 1951), and western Pacific (Yabuta et al. 1960) were recalculated by Le Guen and Sakagawa (1973) using Fabens' (1965) method and are compared with the results of the present study (Figure 12). The recalculated lengths-at-age were in all cases similar to those obtained by the original authors. Although the above studies were carried out on large fish within the 47-170 cm FL range, their L_∞ values were only slightly higher (188.4-200.3 cm) than that obtained in the present study. The major difference lies in rate of growth, and, although extrapolation of the present results beyond 71 cm is dangerous, these results and those of Yabuta et al. (1960) imply that growth of yellowfin tuna in the western Pacific may be substantially slower than in the central and eastern Pacific. Marcille and Stequert (1976a) studied growth of pole-and-line caught yellowfin tuna of a similar length range (45-75 cm FL) in the equatorial western Indian Ocean. Their reported growth rate of 17-19 cm/6 mo for this size range of fish is similar to the results of the present study. A further possible explanation for this apparent disparity between growth in large and small yellowfin tuna may be simply that the von Bertalanffy function does not adequately describe yellowfin tuna growth, and that yellowfin tuna may undergo changes in growth pattern, due to movement into deeper water, for example.

A point of ecological importance is the great difference in growth rate between skipjack and yellowfin tunas of the same size. Yellowfin tuna grow to over 180 cm FL, over twice the length of skipjack tuna and almost 20 times the body weight. Studies on skipjack and yellowfin tunas' bioenergetics (Kitchell et al. 1978), although indicating a qualitative similarity between the two species, demonstrated that the metabolic rate of adult skipjack tuna, unlike that of yellowfin tuna and most other fishes, is independent of body weight. This may reflect the apparently less efficient hydrodynamics of skipjack tuna, a consequence of the absence of a swim bladder and relatively small surface area of the pectoral fins, in comparison with yellowfin tuna.

Although over half of the tuna schools in Papua New Guinea waters are pure skipjack tuna (West and Wilson[15]), about 40% contain a mixture of yellowfin and skipjack tunas, and only about 5% are pure yellowfin tuna. Length-frequency sampling has demonstrated that yellowfin and skipjack tunas taken from any single mixed school comprise a similar size range, although observations indicate that larger yellowfin tuna (estimated to be in the 70-130 cm size range) are frequently present. Since yellowfin tuna grow so much faster than skipjack tuna, the yellowfin tuna members of a mixed school must, within a matter of a few weeks, outgrow their skipjack tuna counterparts. Such a situation would lead either to the break-up of the school as a consequence of divergence in size, or persistence of large-size yellowfin tuna in a school comprising mainly smaller skipjack tuna. Observations have indicated that the latter situation occurs during certain periods.

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