

Elsevier, N.Y.

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MORPHOLOGY AND POSSIBLE SWIMMING MODE OF A YELLOWFIN TUNA, *THUNNUS ALBACARES*, LACKING ONE PECTORAL FIN

In September of 1982, the Mexican bait boat, *Paesa*, fishing off Baja California, captured a 36.5 cm fork length (861.2 g wet weight) yellowfin tuna, *Thunnus albacares*, that lacked a left pectoral fin (Fig. 1). The fish was frozen and was brought to the Inter-American Tropical Tuna Commission, La Jolla, CA, for study by W. H. Bayliff.

Pectoral fins provide virtually all hydrodynamic lift in scombrids and are essential for stable and efficient swimming at sustained speeds (Magnuson 1973, 1978). A specimen with only one pectoral fin raises questions on what ways the fish might have compensated for an asymmetrical decrease in hydrodynamic lift and how the presence of only one pectoral fin might have affected its locomotion. We examined the fish to determine what may have caused fin loss and whether morphology was noticeably altered in a manner suggesting some compensation.

Skin in the area where the left pectoral fin should have been was thin, smooth, and silvery in appearance (Fig. 1). There was neither a trace of pectoral fin remnants nor a skin groove for it, suggesting the fin had never formed. On the other hand, the appearance of the skin and the presence of variably sized scales in the area around the normal fin position is compatible with a healed wound, and we thus

could not rule out the possibility that the fin had been bitten off cleanly.

Methods

The specimen was X-rayed and maximum body height and width measured. We measured and traced its median fins, caudal keel, pectoral fin, and both pelvic fins, and estimated their surface areas with a planimeter. The same body and fin measurements were made on similarly sized, preserved yellowfin tuna in the Scripps Institution of Oceanography Fish Collection (SIO). Morphometric data were compared with values derived from the literature (Gibbs and Collette 1967; Fierstine and Walters 1968; Magnuson 1973, 1978; Magnuson and Weinger 1978, app. II). Although some of the specimen's caudal rays were bent (Fig. 1), all rays were present, and the fin was extended to a more natural position before its span was measured and area (which was well defined) traced. Also, to avoid measurement errors noted by Fierstine and Walters (1968) and Magnuson (1978), care was taken not to overextend caudal fins during span measurement.

Density of the thawed fish was determined by water displacement (density = wet weight/displacement volume). The right and left pectoral girdles were then removed and the gas bladder was inspected. Transverse sections were cut (see Graham et al. 1983), concentric myotomal rings on the right and left sides were counted, and red and white muscle were weighed for each section.

Results

The abundance of comparative morphometric and anatomical data for the yellowfin tuna permits a nearly complete assessment of the morphologic and hydrodynamic status of the one-finned specimen. The length (L; 36.5 cm)/weight (861.2 g) relationship and the density ($1.080 \text{ g} \cdot \text{mL}^{-1}$) agree with values published for yellowfin tuna by Magnuson (1973, tables 1, 4). Also, the maximum thickness value (i.e., max. height + max. width/2 = 21.6% L) is within the range (20.5-23.0% L) measured for four SIO specimens (L from 28.5 to 42.5 cm) and near the value given by Magnuson (1973, table 7, 22.3% L). Finally, the point of maximum body thickness in the study fish (39.7% L) and that of SIO fish (36-40% L) are near Magnuson's value of 41.2% L (for fish from 28 to 45 cm L).

The dorsal fin of this fish is normal in shape, with 13 spinous rays, a maximum height of 3.5 cm and a surface area of 9.5 cm^2 . The second dorsal fin is

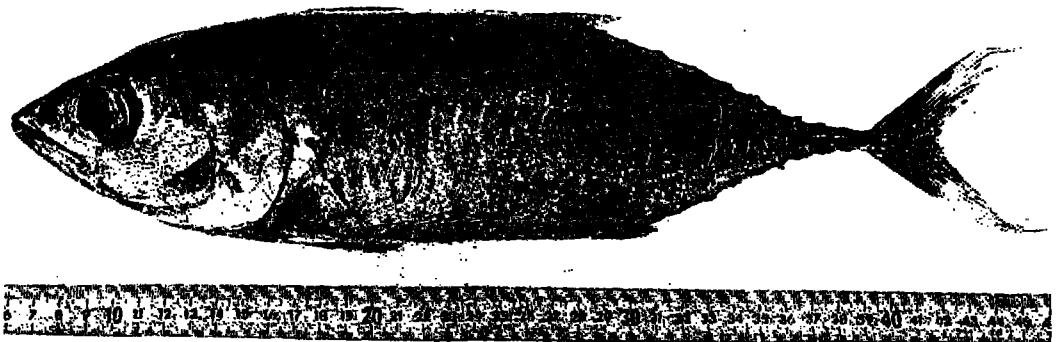
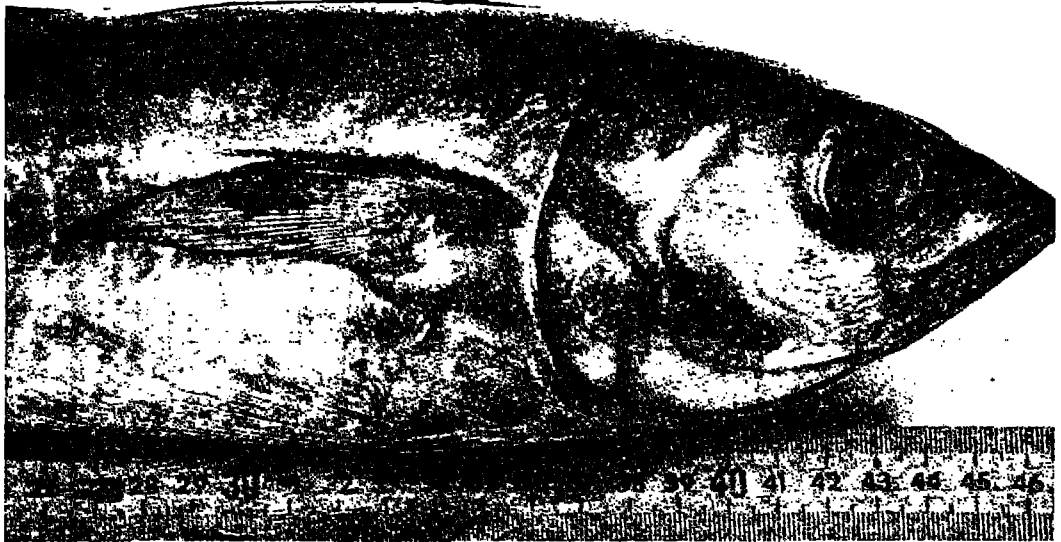
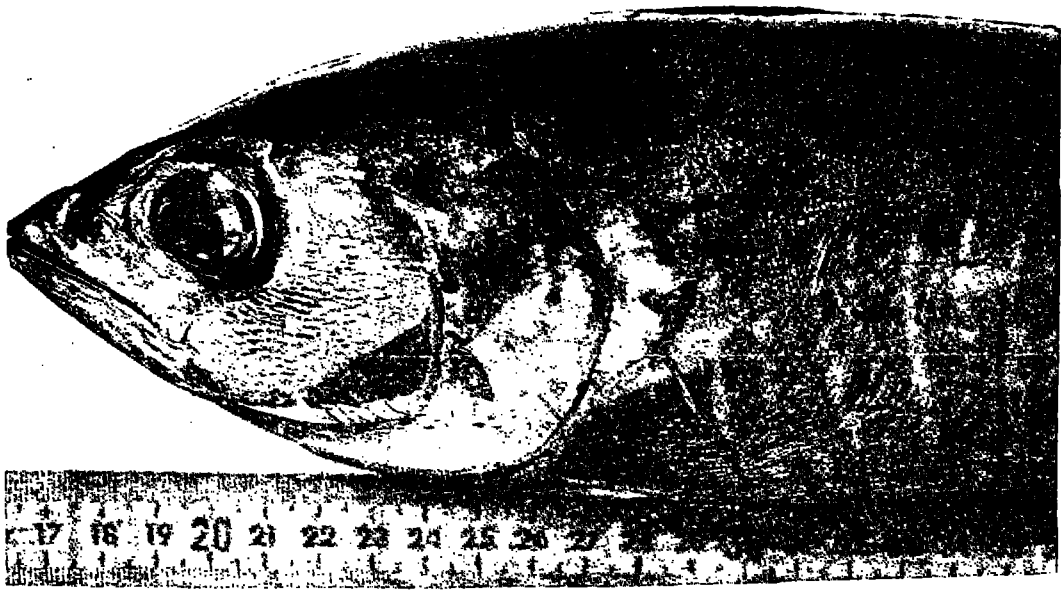


FIGURE 1.—Left- and right-side close-ups and a full-length, left-side photo of the *Thunnus albacares* with only one pectoral fin.

1 cm high and has an area of 2.0 cm². The anal fin is also 1 cm high and has an area of 2.2 cm². The combined total surface area of both sides of the second dorsal and anal fins is 8.4 cm², which is larger than predicted (7.2 cm²) by the Magnuson and Weininger equation (1978, app. II). The total number of second dorsal and anal fin rays and dorsal and ventral finlets agrees with that for other yellowfin tuna (Gibbs and Collette 1967, table 1).

Table 1 compares caudal keel area and caudal and right pectoral fin dimensions of the study specimen and seven SIO fish of differing L. Also shown are values calculated for several of the same parameters using allometric equations for *T. albacares* (Magnuson 1978, table X; Magnuson and Weininger 1978, app. II). The caudal keel area of the one-finned fish (6.2 cm²) is smaller than the value expected from the equation (6.7 cm²) but is well within (i.e., 93%) the range of variation (77-102%) seen in the SIO specimens (Table 1). Comparison of the measured and the equation-derived caudal data for the one-finned fish with the same set of values for the next smallest (32.5 cm) and largest (37.0 cm) SIO fish indicates that the caudal fin of the one-finned fish has a slightly smaller span but larger area than would be expected for its L. This is further reflected

in its aspect ratio (AR; 4.63), which is lower than that of any of the SIO specimens. This lower value probably does not represent an artifact of preservation because in the other material caudal span and area increased directly with L. There is also general agreement between the measured and calculated values for each, showing that neither preservation nor measurement protocols affected caudal fin data. As would be expected from the underlying formulae, caudal AR calculated from the equations increases with L. However, among the measured data, there is no correlation between AR and L. It is also noteworthy that both the mean and predicted AR values of all of these small yellowfin (5.64, 5.34, Table 1) are in good agreement but well below the summary range (6.8-7.2) given for larger *T. albacares* by Magnuson (1978, table IX). This serves to emphasize that while AR may differ between species of scombrids (Magnuson 1978), it also varies within each species as a function of body size.

Both the length and area of the right pectoral fin of the one-finned fish are much less than those of the 37 cm SIO specimen (Table 1). When measured and computed pectoral fin areas are compared, there is good agreement between both values for the 37 and 42.5 cm L fishes but not for the 36.5 cm L one-

TABLE 1.—Comparative caudal and right pectoral fin measurements for the one-finned yellowfin tuna (36.5 cm L) and seven specimens of different lengths (L) from the SIO collection. Data for each fish includes the actual measured values (m) and values calculated (c) from equations in the footnotes (Magnuson and Weininger 1978, app. II).

Fork length (cm)	Caudal keel		Caudal fin		Right pectoral fin		
	Area ¹ (cm ²)	Span ² (cm)	Area ³ (cm ²)	Aspect ratio ⁴	Length		Area ⁵ (cm ²)
					(cm)	(%)	
25.8 m	2.7	9.5	12.7	7.11	5.63	(21.8)	6.7
c	3.1	6.8	9.9	4.67			9.4
28.5 m	3.8	8.0	12.3	5.20	6.00	(21.0)	5.3
c	3.8	7.7	12.1	4.90			11.3
31.5 m	3.7	9.0	15.8	5.13	7.71	(24.5)	11.1
c	4.8	8.8	14.8	5.23			13.5
32.5 m	4.8	10.0	15.7	6.37	7.25	(22.3)	10.6
c	5.2	9.1	15.8	5.24			14.2
*36.5 m	6.2	10.0	21.6	4.63	7.50	(20.5)	12.8
c	6.7	10.5	20.0	5.51			17.5
37.0 m	5.3	11.0	21.6	5.60	9.67	(26.1)	17.8
c	6.9	10.7	20.6	5.56			17.9
40.0 m	8.5	12.5	25.4	6.15	10.40	(26.0)	14.3
c	8.3	11.7	24.1	5.68			20.6
45.0 m	8.8	12.2	30.3	4.91	11.00	(25.9)	25.3
c	10.8	13.5	30.7	5.92			25.4
m				\bar{x} , SE 5.64, 0.30			
c				\bar{x} , SE 5.34, 0.15			

¹Caudal keel area = $0.00198 L^{2.26}$
²Caudal span = $-2.27 + 0.35 L$
³Caudal area = $0.013 L^{2.04}$
⁴Aspect ratio = $\text{Span}^2/\text{area}$
⁵Pectoral fin area = $0.116 L^{1.79/4}$
⁶One-finned fish.
⁷Fin was torn.

finned fish. In general, application of the pectoral area equation to the smaller SIO fish (Table 1) does not result in close correspondence between estimated and observed areas, suggesting that the relationship derived from larger individuals does not fit smaller yellowfin tuna. The relative length of the pectoral fin in yellowfin tuna changes abruptly with size. In fish between about 35 and 42 cm L, pectoral fin length should normally be about 25% L (Gibbs and Collette 1967, fig. 26). This contrasts with the value for the one-finned fish of 20.5% L.

The left pectoral girdle is present, but clearly abnormal in gross examination. The posttemporal is reduced in overall size; the upper (pterotoc) fork is somewhat reduced and lower (epiotic) fork weakly developed and without a flattened articular surface. The rear margin of the supracleithrum is eroded, and the lateral surface rough. The cleithrum is almost as large as that of the right side, but the lateral groove for muscle attachment is reduced, and the upper process that normally curves out over the scapula is absent. The scapula is a block of bone without an articular facet for the first pectoral ray, and the scapular foramen is represented by a slit in the lateral surface. The coracoid is much reduced posteriorly, and its reduced lower process is tightly applied to the cleithrum so that the interosseus space is almost absent. The pectoral actinosts may be represented by a small lump of bone that is tightly attached to the scapula. A number of bone chips

were embedded in the tissue overlying the pectoral girdle. The postcleithra appear to be essentially normal.

Elements in the left side of the pelvic girdle are larger and have a different orientation from those of the right. Also, the left pelvic fin is both smaller in area and shorter than the right (Fig. 2). Pelvic fin lengths and areas in the one-finned fish are left 2.9 cm, 3.2 cm²; right 3.5 cm, 4.7 cm². Comparable values for the 37.0 L SIO fish are left 3.5 cm, 4.5 cm²; right 3.7 cm, 4.9 cm². X-rays showed that the centra of vertebrae 19 and 20 are abnormal (Fig. 3). They lie parallel to one another and overlap by about 80% in the horizontal axis. There is considerable erosion of the adjoining surfaces of the two centra and their neural and haemal spines are displaced. This deformity, together with the reduced left pelvic fin, the absence of a left pectoral fin, and a deformed left pectoral girdle, suggests the presence of a congenital malformation.

As would be expected from our density findings, the gas bladder of the one-finned fish was small (17 × 5 mm, length × diameter), but about the same size as that of other yellowfin tuna (Magnuson 1973, 1978). Finally, we found no differences in the left and right body myotomes. The total red muscle was estimated to be 6.7% of wet weight, which is within the 95% confidence limits of the value reported for yellowfin tuna (5.2-7.8%) by Graham et al. (1983).



FIGURE 2.—Anterior ventral view showing the reduced size of the left pelvic fin.

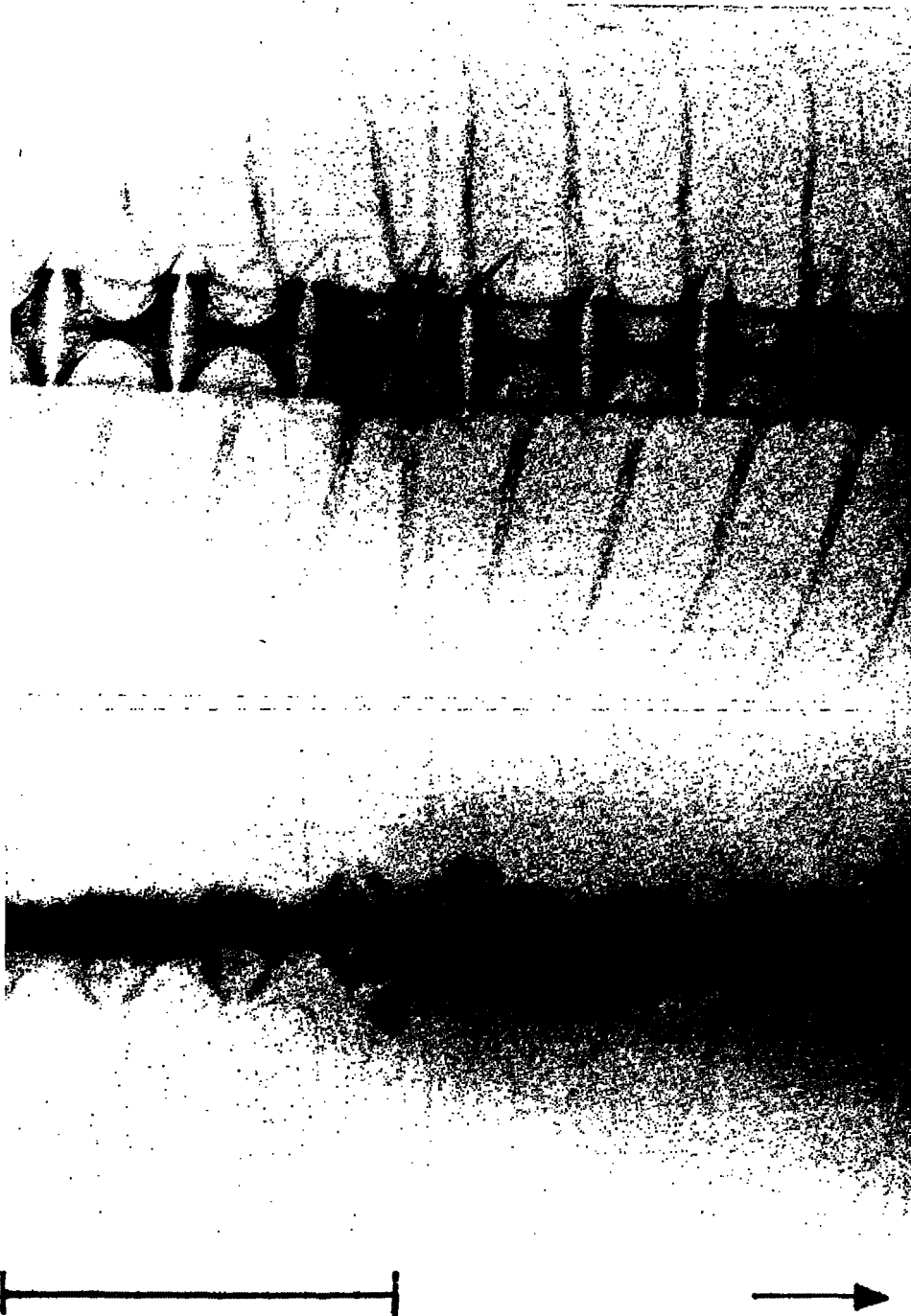


FIGURE 3.—Top: Right-side X-ray of the vertebral column showing the impacted vertebrae and the neural and haemal spine displacement. Bottom: Dorsal X-ray of the same vertebrae. Arrow indicates anterior. Scale is 2.5 cm.

Discussion

Our study suggests that congenital defects led to the absence of a left pectoral fin, the formation of a small right pectoral and left pelvic fins, and to the impaction of two vertebrae. A smaller caudal span may also be a result of such defects. On the basis of age studies (Uchiyama and Struhsaker 1981) we estimate that this fish (36.5 L) was about 9 mo old when captured. (But, because of the vertebral damage, the fish is shorter than it should be and 9 mo is a conservative age estimate.) Thus in spite of significant locomotory handicaps, this fish had been swimming and feeding effectively at the time it was taken by hook and line.

Morphological comparisons with SIO specimens and with equation-derived values for similarly sized yellowfin tuna did not indicate any major structural differences in the one-finned fish that can be interpreted as having facilitated its swimming. However, since the absence of one pectoral fin doubtlessly affects the minimum speed required for hydrostatic equilibrium, the horizontal stability, and the maneuverability of a tuna, it is instructive to consider how the loss might have been compensated. Magnuson (1973, 1978) has amply demonstrated the role of the paired fins in providing lift and reducing minimum equilibrium speed. Total lift (L_t) is calculated as

$$L_t \text{ (dynes)} = M \left[1 - \frac{\rho_e}{\rho_f} (g) \right], \quad (1)$$

where M is fish wet weight, ρ_e is seawater density, ρ_f is fish density, and g is the acceleration of gravity ($980 \text{ cm} \cdot \text{sec}^{-2}$). The amount of lift needed by the one-finned fish ($M = 861 \text{ g}$, $\rho_f = 1.08$, $\rho_e = 1.02$ at 25°C) is $47,203$ dynes.

The minimum speed for hydrostatic equilibrium U_{100} is determined by

$$U_{100} = \left[\frac{L_t}{\rho_f / 2 (C_L A_p + C_L A_k)} \right]^{1/2}, \quad (2)$$

where C_L is the coefficient of lift for the pectoral fins (p) and caudal keel (k) and A_p and A_k are their respective areas (Magnuson 1973). Pectoral fin lift area includes both fins and the flat section of body between them (Magnuson 1978, fig. 4). This can be calculated from an allometric relationship (Magnuson 1973, table 4).

$$A_p = 0.0609 L^{1.87}, \quad (3)$$

and, for a 36.5 cm L yellowfin, $A_p = 50.8 \text{ cm}^2$. With this value, a measured keel area (Table 1) of 6.2 cm^2 , and assuming a lift coefficient of 1.0 for both surfaces (Magnuson 1973, table 4) the calculated (Equation (2)) minimum speed for a 36.5 cm yellowfin tuna is $40.3 \text{ cm} \cdot \text{s}^{-1}$. The same calculation for the one-finned fish ($A_p = 25.4 \text{ cm}^2$) yields a minimum speed of $54.1 \text{ cm} \cdot \text{s}^{-1}$, a 34.3% increase. The one-finned fish would need to swim faster, and thus expend more energy. Its higher speed would also probably have required it to make continuous velocity and position changes in order to keep pace with a school of, on-average, similarly sized and thus slower swimming yellowfin tuna.

Alternatively the fish might have assumed a pitched (i.e., head up) swimming mode in an attitude such that its body surface would have contributed to hydrodynamic lift by having a positive angle of attack relative to the direction of motion, and the C_L of the caudal keel would be increased (Magnuson 1978). Of course this would result in increased pressure drag and require more swimming power, but it might have enabled the fish to swim more slowly.

Under any conditions, it seems likely that this fish was not highly maneuverable and would have difficulty remaining upright (i.e., not rolling to the left). It, of course, could not use its left pectoral for braking and left turns, and its left pelvic fin, which would also contribute to these actions, was less effective than normal because of its small size. Tunas normally accelerate with their first dorsal, pectoral, and pelvic fins appressed (Magnuson 1978), but as this fish slowed and needed lift it would have likely began to roll to its left as soon as its right pectoral fin was extended. This could be countered somewhat by its dorsal fin, but the necessity for unilateral use of the right pectoral fin should have always resulted in some amount of leftward roll and a tendency to turn to the right. Both the sharpness of the turn and the net upward or downward spiral movement of the fish would depend upon the degree of fin extension and swimming velocity.

Finally, to compensate for the tendency to roll it is possible that the fish habitually swam with its body tilted as much as 80° to the right. In this position it would retain the largest possible pectoral lift area and might gain sufficient additional lift from the dorsal, second dorsal, anal fins and the body surface to more than compensate for loss of keel lift. It is noteworthy that the second dorsal and anal fin areas of this fish are larger than predicted (see above). The fish would be able to roll from its side to an upright position merely by extending its pectoral fin a bit

farther. Also, side swimming would place both pelvic fins in a position where they could facilitate rapid left (now ventral) turns while possibly adding lift.

Acknowledgments

This study benefited from funds provided by the Foundation for Ocean Research at SIO, and by University of California, San Diego, Biomedical and Academic Senate research grants. We thank Captain Jesus Yamamoto for saving the specimen for study and W. Bayliff for providing it to us. We also thank W. Klawe, W. Bayliff, and A. Dizon for commenting on the manuscript.

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CHROMOSOMAL ANALYSIS OF ALBACORE, *THUNNUS ALALUNGA*, AND YELLOWFIN, *THUNNUS ALBACARES*, AND SKIPJACK, *KATSUWONUS PELAMIS*, TUNA

Chromosomal analysis is being used as part of an investigation of the population stock structure of the North Pacific albacore, *Thunnus alalunga*. There is a growing body of evidence (Brock 1943; Laurs and Lynn 1977; Laurs and Wetherall 1981; Laurs 1983) that North Pacific albacore are not as homogeneous as usually assumed (Clemens 1961; Otsu and Uchida 1963). Results from recent tagging studies suggest that northern and southern substocks constitute the North Pacific albacore population and that these proposed substocks have different migratory patterns (Laurs and Nishimoto 1979¹; Laurs 1983). Laurs and Wetherall (1981) also found that the growth rates were significantly different in the two proposed substocks. In addition, the differences in growth rate are consistent with differences in length frequencies of albacore caught in commercial fisheries off North America (Brock 1943; Laurs and Lynn 1977).

In this paper we report results from chromosomal analysis using C-banding for albacore (from the proposed North Pacific southern substock) and compare them with similar results obtained for yellowfin, *Thunnus albacares*, and skipjack, *Katsuwonus pelamis*, tuna. We demonstrate that there is a chromosomal basis for placing the albacore and the yellowfin tuna in the genus *Thunnus* and that recognizable chromosomal differences exist between the genera *Thunnus* and *Katsuwonus*. These findings corroborate the taxonomy of the albacore and the yellowfin and skipjack tuna based on comparative anatomy (Gibbs and Collette 1967; Collette 1978).

The results reported here are from part of a larger study, which is helping us to evaluate if genetic heterogeneity exists in the North Pacific albacore population. Information on chromosome characteristics is scarce for fishes, and to our knowledge this is the first time chromosome analyses have been reported for scombrid fishes.

Materials and Methods

All blood samples were collected from freshly caught fish either aboard the NOAA RV *David Starr Jordan* (August 1983) or aboard fishing boats

¹Laurs, R. M., and R. N. Nishimoto. 1979. Results from North Pacific albacore tagging studies. U.S. Dep. Commer., Natl. Mar. Fish. Serv., SWFC Admin. Rep. LJ-79-17, 9 p.