

NOTES

ENERGY FOR MIGRATION IN ALBACORE, *THUNNUS ALALUNGA*

The relations between immigrants and residents of a specific fishing ground can likely be evaluated from examination of the relative fat content of individuals from a time sequenced sampling of the fishery. These kinds of information are not yet estimable for pelagic populations.

The problem of energy availability and utilization in migrations of fish is a perplexing one. Migrations are energetically quite expensive unless a fish is passively carried by currents. Recently recorded migrations of two tagged albacore, *Thunnus alalunga* (Bonnaterre), across the Pacific Ocean indicate that they traveled an average of 48 km/day (Japanese Fisheries Agency 1975). As these fish were approximately 80 cm long on release, the average migration speed was about 0.65 body lengths/s (55.6 cm/s). This is well within the range of observed swimming speeds for this species. These albacore were reported to have

traveled from lat. 35°44'N, long. 171°37'E (Figure 1, point E) to lat. 47°00'N, long. 125°30'W (Figure 1, point F), a distance of 5,239 km in 110 days. The caloric equivalent, in grams of fat,¹ utilized by these two fish at the estimated rate of travel of about 55 cm/s would be about 1,450 g or 14.5% of their expected weight at the onset of migration. Although great amounts of feed would not be necessary for this migration given the 1 kcal/g average available caloric content for forage (Sharp and Francis 1976), the albacore has been reported to have up to 18.2% fat in the edible flesh portions (Sidwell et al. 1974). Muscle tissue constitutes 58.2% of the total body weight of albacore (Dotson unpubl. data) which means up to 10.6% body weight in fat has been observed, a value approaching that necessary to provide the caloric energy for these migrations.

There is little doubt that albacore do not migrate directly, that feeding does occur, and that the fish probably do grow in overall length and ¹9.4 kcal/g fat.

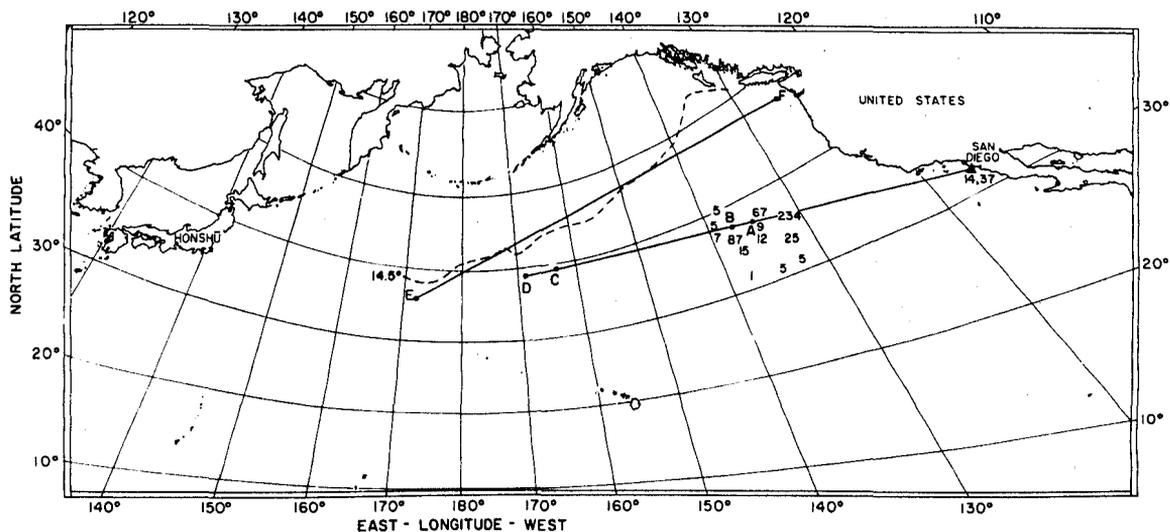


FIGURE 1.—A great circle plotting chart is shown and the quantity and location of albacore samples is indicated by the numerals. A length-mass equation was developed for the 477 albacore caught west of long. 130°W during June 1974. The numbers 14 and 37 near San Diego represent the samples collected in July and September 1975, respectively. Using \blacktriangle as the origin the letters A and B along the line represent the distances which a 63-cm albacore could swim utilizing 404 g of fat at A, its minimum speed; B, the observed diurnal-nocturnal activity level. Points C and D on the same line represent the distance that the 65-cm fish with the greatest observed mass deficit (999 g) could have traveled utilizing the energy of this quantity of fat at the two respective activity levels described above. Points E and F are the release and recapture positions of two albacore tagged by Japanese researchers. The minimum temperature habitat limit of albacore (14.5°C) is depicted by a dashed line. The great circle route does not differ markedly from this boundary but likely represents a conservative estimate of the total distance traveled between points E and F.

mass during the migratory period. What appears to be an important question is whether or not the migrations of albacore and other tunas are extra demanding, meaning sufficient short-term energy is required to induce fat store utilization even though feeding is still accomplished. Too often the concepts of growth and fat deposition are integrated such that it is considered unlikely that morphological growth can take place during fat store utilization. Certainly from observations of adolescent growth in mammals it is obvious that there is no necessary dichotomy here. The two processes require separate biochemical pathways and are very likely separated temporally, well within the standard day.

In a preliminary effort to examine the question of fat utilization, the length-mass relationship of albacore collected offshore preceding their appearance in the onshore eastern Pacific surface fishery has been compared with fish freshly arrived in this fishery, and with fish which have presumably been grazing and reconditioning for the postsummer exodus from the onshore area. Calculations from these data support the hypothesis that fat stores are utilized for migration energy.

We hope that these calculations and subsequent inferences will stimulate further research into the considerable problem of highly variable length-mass information and its potential use in studies of migratory fishes.

Observations

In June 1974, 477 albacore 463 to 794 mm long were captured in the area between long. 130° to 140°W and lat. 30° to 40°N (Figure 1). A curve was fitted by regression to the length-mass data from these fish resulting in the equation (Dotson 1977),

$$M = 4.514 \times 10^{-5} L^{2.8746} \quad (1)$$

where M is the mass in grams and L the fork length in millimeters. Measured values fell within 250 g of the regression line.

Mass and length measurements were made on 14 albacore (600 to 657 mm FL, mean 631) collected during July and 37 fish (516 to 851 mm FL) collected during September 1975, in a region 110 km south of San Diego, Calif. (Figure 1). The mass of September-caught albacore was not different from those estimated by the length-mass regression curve. The mass of July-caught albacore,

however, averaged 404 g below those estimated by regression (range: 172 g greater to 999 g less). Analysis of body densities indicated that the mass deficit of the albacore caught in July was probably due to fat loss, or simply stated, as a fish of a given length gets lighter its density increases (Dotson 1977).

The albacore fishery near the coast commenced in July 1975. The albacore in this fishery are known to migrate from the offshore region (Laurs and Lynn in press), and it is assumed, therefore, that the mass (fat) deficit was utilized as an energy source during migration to the coast.

Calculations and Inferences

Using the observed mass deficits observed in the July 1975 sample, it is possible to estimate the migration path length assuming 1) little or no growth occurs during the migration, and 2) the fat utilized is the only energy source during migration.

Based upon studies of swimming energetics of tunas, Sharp and Francis (1976) estimated the relation between swimming speed (V) in centimeters per second, fork length (l) in centimeters, and the swimming caloric expenditure per unit time (C_s) in kilocalories per hour. The basic equation for this relation, in calories utilized per hour, is as follows:

$$C_s = 8.7 \times 10^{-8} (l)^2 (V)^3 Cd. \quad (2)$$

The coefficient of drag (Cd) is estimated using the relation (Sharp and Francis 1976)

$$Cd = 0.262 \exp [-(4.805 \times 10^{-6})Re] \quad (3)$$

where Re (Reynolds number) = lV/ν (at $Re \geq 6.8 \times 10^5$, $Cd = 0.01$), ν is the kinematic viscosity of seawater, approximated by the value 0.01.

Sharp and Francis (1976) also estimated the metabolic maintenance energy (C_m) (i.e. stasis energy requirements) for tunas to be 1 g cal/g per h. The metabolic weight (W_{met}) is approximated by the relation

$$W_{met} = (M_f)^{0.8} \quad (4)$$

$$C_m = W_{met} \times 10^{-3} \text{ kcal/g, per h} \quad (5)$$

where M_f is the mass of the fish in grams.

Assuming that the mean mass deficit of 404 g of

the albacore caught in July was fat loss and given that fat yields about 9.4 kcal/g, less ~15% due to the cost of fat mobilization (SDA), leaving about 8.0 kcal/g, the caloric value of the fat loss is 3,272 kcal. The mean length of the albacore in the July sample was 63 cm with a computed mass for the offshore region (from Equation (1)) of 5,030 g. As this would be the weight at the initial stage, it seems appropriate to use as the mass for the calculations the equivalent of one-half of the observed loss in mass (202 g) subtracted from the computed initial mass to give a value of 4,828 g. Using these equations, the rate of caloric expenditure per hour was estimated for a 63-cm albacore swimming at 54 cm/s which is the estimated minimum speed a 63-cm albacore can swim and maintain hydrostatic equilibrium, V_{100} (Magnuson 1970; Dotson 1977). Where C_s plus C_m is equal to the total caloric expenditure (C_{total}) during migration, then:

$$\begin{aligned} C_{total} &= C_s + C_m \\ &= 2.78 \text{ kcal/h} + 0.89 \text{ kcal/h} \\ &= 3.67 \text{ kcal/h.} \end{aligned} \quad (6)$$

The caloric equivalent of the fat divided by the hourly caloric utilization rate, C_{total} , Equation (6) yields the number of hours that swimming at 54 cm/s could be sustained utilizing this energy source alone and is estimated to be

$$\frac{3,272 \text{ kcal}}{3.67 \text{ kcal/h}} = 892 \text{ h or } \sim 37 \text{ days.}$$

The speed and time multiplied together yield the linear distance traveled during this period. This was calculated to be 1,730 km (935 nmi).

Based upon sonic tracking experiments, the average swimming speeds of three albacore 84, 85, and 87 cm in length have been observed to be 95 cm/s during the day and 62 cm/s at night (Laurs et al. 1977). The minimum swimming speed for hydrostatic equilibrium of these fish (V_{100}) is estimated to be about 42 cm/s (Dotson 1977). Assuming the ratio of observed speed (V_0) to minimum speed (V_{100}) to be relatively constant over the size range, then diurnal and nocturnal speeds can be estimated where $V_0/V_{100} = 42 \text{ cm/s} = 2.260$ is the multiplier for daylight speeds and $(62 \text{ cm/s})/(42 \text{ cm/s}) = 1.575$ is the multiplier for night speeds. The result of this estimation is that the daylight and nighttime speeds for a 63-cm albacore are 122 and 80 cm/s, respectively. Assuming equal time spent at each speed, about 6.08 kcal/h are utilized.

If the tracking observations are representative of migratory swimming speed, and therefore caloric expenditures, then the fat energy would have been utilized in a period of nearly 22 days and the linear distance traveled would be about 1,960 km (1,060 nmi).

From the nearshore area of capture, the maximum linear distance traveled using the average fat loss of a 63-cm albacore is indicated by points A and B in Figure 1. The two values indicated represent a) 37 days at a minimum speed of 54 cm/s, and b) the estimated diurnal rates of 80 and 122 cm/s for equal portions of 22 days. The interesting result is that both the distances are within the area where the offshore samples with the greater length-mass relationship were collected and compared with the onshore material.

The maximum observed mass difference from the offshore mean of an albacore caught inshore is 999 g or 18% of its body weight for a 65-cm fish (Dotson 1977). Assuming the total weight difference to be fat, at its calculated minimum speed of 54 cm/s, this albacore could have traveled 4,200 km (2,270 nmi) over a period of 90 days utilizing only this fat as an energy source. This would place the fish well out in the mid-Pacific, as shown by point C in Figure 1. Swimming at the estimated day and night speeds of 122 and 80 cm/s for equal parts of the day this fish could travel 4,680 km (2,520 nmi) in 54 days (Figure 1, point D).

These observations, calculations, and hypotheses should indicate some of the potential effects which can be examined in the future, given broad-scale sampling and interest in the migrations of tunas. Fat content is an important indicator of the calories available for migration and/or spawning in fish of sufficient maturity. The importance of immigrants to population assessment in managed fisheries is obvious. Certainly, spawning success and behavior is dependent upon the available caloric stores. For tunas where migration and grazing up to spawning condition may be competitive processes, a thorough examination of the fat level cycles may offer insights into both periodicity and location of the potential spawners. This is an area of minimal understanding in tunas to date. Considering the importance of these processes in the life cycles of tunas, it seems that a certain amount of importance should be placed upon obtaining comprehensive data from several behavioral categories of tunas where inferences could be made about the relation of fat stores and behavior.

Literature Cited

- DOTSON, R. C.
1977. Minimum swimming speed of albacore, *Thunnus alalunga*. Fish. Bull., U.S. 74:955-960.
- JAPANESE FISHERIES AGENCY.
1975. Report of tuna tagging for 1974. [In Jap.] Pelagic Res. Sect., Far Seas Fish. Res. Lab., 18 p.
- LAURS, R. M., AND R. J. LYNN.
In press. Seasonal migration of North Pacific albacore, *Thunnus alalunga*, into North American coastal waters: Distribution, relative abundance, and association with Transition Zone waters. Fish. Bull., U.S. 75.
- LAURS, R. M., H. S. H. YUEN, AND J. H. JOHNSON.
1977. Small-scale movements of albacore, *Thunnus alalunga*, in relation to ocean features as indicated by ultrasonic tracking and oceanographic sampling. Fish. Bull., U.S. 75:
- MAGNUSON, J. J.
1970. Hydrostatic equilibrium of *Euthynnus affinis*, a pelagic teleost without a gas bladder. Copeia 1970:56-85.
- SHARP, G. D., AND R. C. FRANCIS.
1976. An energetics model for the exploited yellowfin tuna, *Thunnus albacares*, population in the eastern Pacific Ocean. Fish. Bull., U.S. 74:36-51.
- SIDWELL, V. D., P. R. FONCANNON, N. S. MOORE, AND J. C. BONNET.
1974. Composition of the edible portion of raw (fresh or frozen) crustaceans, finfish, and mollusks. I. Protein, fat, moisture, ash, carbohydrate, energy value, and cholesterol. Mar. Fish. Rev. 36(3):21-35.

GARY D. SHARP

Inter-American Tropical Tuna Commission
La Jolla, CA 92038

RONALD C. DOTSON

Southwest Fisheries Center
National Marine Fisheries Service, NOAA
P.O. Box 271, La Jolla, CA 92038

UNDERWATER SOUNDS FROM RIBBON SEAL, *PHOCA (HISTRIOPHOCA) FASCIATA*¹

Intense downward frequency "sweeps" and broadband "puffing" sounds were recorded underwater in the presence of ribbon seal, *Phoca (Histriophoca) fasciata* Zimmerman 1783. The recordings were made in the waters off Savoonga, St. Lawrence Island, Alaska, on 16, 17, 18, and 23 May 1967.

The seals were encountered in the final ice of the spring made up of windrows of small to moderate floes mixed with brash ice, and with stretches of up

to 1 km of open water between. On this ice typically occur adults and pups of a variety of other pinniped species (*Phoca largha*, *Erignathus barbatus*, *Pusa hispida*, and *Odobenus rosmarus*), but during the spring of 1967 there was a preponderance of *Histriophoca* in this area. This is reflected in the records of the pinniped harvest for this area (Alaska Department of Fish and Game) which show that *Histriophoca* usually composes less than 2% of the catch, but in 1967 it made up 60% of the harvest and most of the *Histriophoca* were caught during the last half of May. The 1967 underwater recordings showed similar differences, contrasting sharply with previous years when *Erignathus* dominated the underwater sound ambient (Ray et al. 1969).

Relatively little is known of the behavior of *Histriophoca* (cf. Scheffer 1958; King 1964). Breeding assemblages occur on ice that rarely approaches shore (Burns 1970) and other social behavior may mostly occur in the water.

Instruments and Methods

Underwater sounds were recorded with a Chesapeake Instrument Corp.² hydrophone system and a Nagra III B tape recorder whose combined response was 50 Hz to 18 kHz (± 2 dB, decibels). The sounds were studied by means of a Kay Elemetrics 7029A spectrographic analyzer and time sequences were measured by a Tektronix 565 oscilloscope.

To make the recordings, appropriate *Histriophoca* habitat in the sea ice was located with the aid of Eskimo hunters, and their skin boat was allowed to drift with the ice while the hydrophone was in the water. Only a few of these seals were seen as we approached, and they always submerged and were difficult to find again. However, some of their underwater sweep sounds were loud enough to be audible in air, implying that these seals were not far away.

Taped sequences of 5 to 8 min duration were analyzed from each of nine locations over 4 days of field study. Higher level underwater sounds, presumably from nearby seals, were analyzed and compared with background lower level sounds. Sounds from distant animals were not used for detailed analysis.

As is usually the case with underwater record-

¹Contribution No. 3753 from the Woods Hole Oceanographic Institution.

²Reference to manufacturers does not imply endorsement by the National Marine Fisheries Service, NOAA.