Behavior of Skipjack Tuna, *Katsuwonus pelamis*, as Determined by Tracking with Ultrasonic Devices

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YUEN, H. S. H. 1970. Behavior of skipjack tuna, *Katsuwonus pelamis*, as determined by tracking with ultrasonic devices. J. Fish. Res. Bd. Canada 27: 2071–2079.

A 50-kHz transmitter was placed in the stomach of a 44-cm (estimated) skipjack tuna, *Katsuwonus pelamis*, at Kaula Bank, Hawaii. With a few interruptions the fish was tracked from August 30 to September 6, 1969. The fish made nightly journeys of 25–106 km away from the bank and, with one exception, returned to the bank every morning to remain there for the day. Another skipjack tuna, about 40 cm long, was tracked for 12 hr at Penguin Bank, Hawaii. It also stayed at the bank during the day and left at night. Both fish swam close to the surface at night but swam at various depths during the day. The repeated morning returns of the skipjack tuna to Kaula Bank imply that skipjack tuna can navigate and that they have a sense of time.

Received June 9, 1970

THE FOREMOST POSITION of the fishery for skipjack tuna, *Katsuwonus pelamis*, in Hawaii is largely maintained by an annual influx of "season" fish of 60–70 cm length (Uchida, 1967). As important as this migratory component is to the fishery, its movements into, within, and out of the Hawaiian area remain a mystery. Shippen (1961), after an analysis of the distribution of skipjack tuna catches in time and space, suggested that the fish entered the fishery from the west and departed towards the west. On the other hand, a method for predicting the annual catch of skipjack tuna of the Hawaiian fishery can be explained only by hypothesizing entry from the northeast (E. C. Jones, personal communication). The capture in Hawaii of two skipjack tuna tagged off Baja California (Rothschild, 1965) gave some support to this hypothesis. A study of movements within the fishery (Royce and Otsu, 1955) through the analysis of data on sightings and visual tracking of surface schools was inconclusive because of the effects of weather conditions on sightings and the brevity of tracking attempts, which did not exceed 15 min.

Smaller skipjack tuna about 40–50 cm long, although they too are seasonal, are caught in small quantities throughout the year. Recoveries of tagged skipjack tuna of this size revealed only localized movements with no obvious pattern (Yamashita and Waldron, 1959). An association of these fish with banks is indicated by the common practice of fishermen to go to areas with banks to fish them. The relation between fish and bank is unknown.

The increasing success at tracking fish bearing ultrasonic transmitters (Trefethen, 1956; Trefethen et al., 1957; Johnson, 1960; Novotny and Esterberg, 1962; Bass and Rascovich, 1965; Hasler et al., 1969; Henderson et al., 1966;

Printed in Canada (J1820)

Dizon et al., 1970) offered an approach for studying the movements of the skipjack tuna. In August 1969, the BCF (Bureau of Commercial Fisheries) Biological Laboratory, Honolulu (now the National Marine Fisheries Service), initiated field work to determine the feasibility of tracking the large commercially important skipjack tuna equipped with ultrasonic transmitters for extended periods and to obtain information on the behavior of the smaller skipjack tuna associated with banks.

As large skipjack tuna were not available at the time, work was limited to smaller fish. From August 30 to September 9, 1969, ultrasonic transmitters were placed in two skipjack tuna and tracked. Methods and results are described and discussed in this report.

MATERIALS AND METHODS

Transmitter characteristics are listed below. The transmitters contained a magnetic reed switch and were activated by the removal of a magnet taped on the outside (Fig. 1).

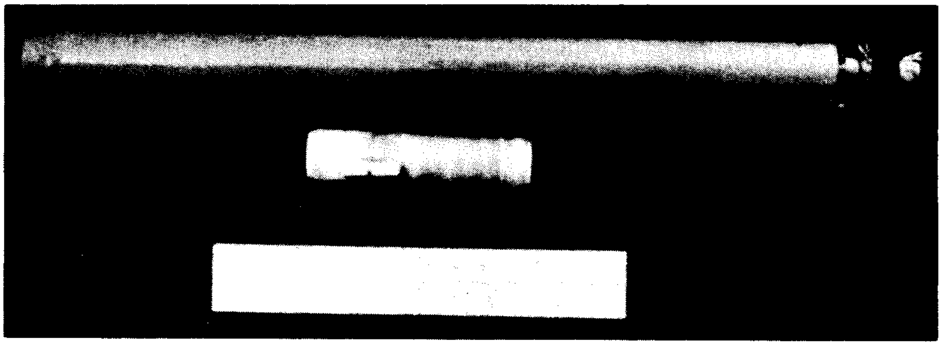

FIG. 1. Tag and applicator.

Frequency	50 ± 1 kHz	Shape	Cylindrical capsule with rounded ends
Repetition rate	2 pulses per sec		
Pulse length	50 msec	Dimensions	8.1 cm long, 2.0 cm diam
Power output	52 db relative to 1 microbar at 1 yard	Weight in air	62 g
		Lifespan	250 hr

Prior to the field work, trial runs were made on captive fish to test a tagging technique and to determine the effects of the transmitter on skipjack tuna. The trials were made on two skipjack tuna 48 cm long. These fish were part of a school that was held in a plastic swimming pool with a capacity of 45 m^3. The transmitters were placed in the stomachs of the fish. The two skipjack tagged in this manner behaved as the other members of the school held in captivity and were not distinguishable from them. Both tuna, one dissected 3 days and the other 4 days after the insertion of the transmitters, contained the remains of food fish in their stomachs, indicating that they had resumed feeding.

Skipjack tuna to be tracked were caught by trolling lures with barbless hooks. As soon as a lure was struck the ship was reversed and the line pulled in by hand evenly and firmly. When the fish was alongside the ship it was scooped up in a dipnet. The hook was removed and the fish tagged while still in the net. Tagging consisted of inserting the transmitter into the pharynx with a plastic applicator (Fig. 1) and allowing the fish to swallow the transmitter. The fish was released by lowering the net into the water.

Neither of the two fish tracked was measured. The length of the first fish was estimated by taking the mean length of 11 fish that were caught from the same school. The size of the second skipjack tuna was gauged by eye.

Signals from a tag were received through the listening mode of the continuous-transmission, frequency-modulated sonar (Yuen, 1968) on the research vessel *Townsend Cromwell*. The hydrophone, located 4 m below the surface, had a beamwidth (at the down 6 db level) of 6° horizontally and 15° vertically. The tag could be detected as far as 2.3 km with this equipment.

During tracking operations, contact with the transmitter was maintained by continually scanning in bearing and tilt about 6° on either side of the last observed position. The ship was maneuvered to maintain a distance of approximately 1 km from the tagged fish to avoid affecting the behavior of the fish. Because of errors in estimating the distance of the transmitter by its signal strength and confusion in operations, however, there were a few occasions when the distance between ship and transmitter was as little as 200 m or was greater than 2.3 km, the detectable range.

During tracking the following data were recorded: time of day, transducer bearing, transducer tilt, ship's course, ship's speed, receiver gain setting, and signal strength. Also recorded were all orders directing the ship's movements and the time the orders were given. Ship's course was read to the closest degree from a repeater of the ship's gyrocompass. Speed was measured to tenths of knots by an electromagnetic underwater log. Signal strength was measured by an oscilloscope. These data were scheduled to be taken at 5-min intervals. In practice the recording interval ranged from 2 to 10 min, but most were at 5 min. The officer on watch was asked to plot the ship's position every hour but he often did so more frequently. Positions were determined by radar at Kaula Bank and by loran A at Penguin Bank (Fig. 2).

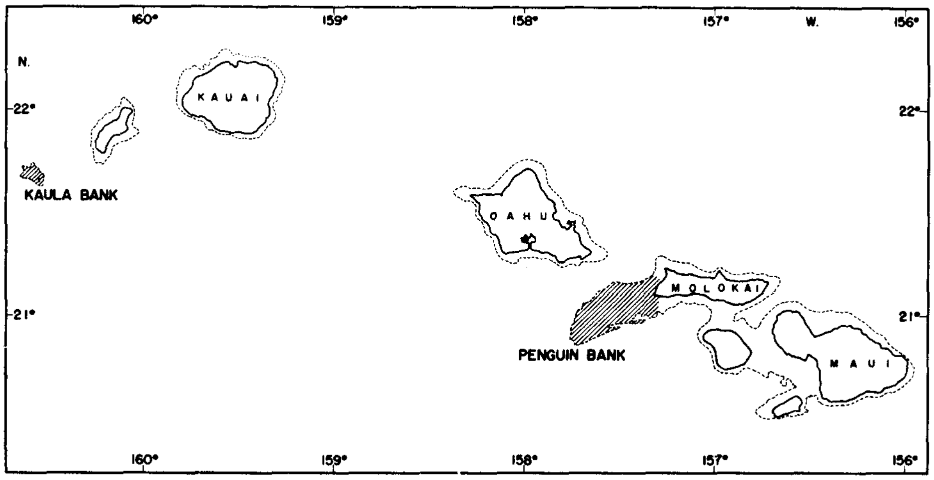

FIG. 2. Location of Kaula Bank and Penguin Bank.

Because the fish were likely to be within 1 km of the ship and certainly not farther than 2.3 km and because the navigational error term did not justify further refinement, the positions of the fish were considered to be the same as the ship's when the data were analyzed.

RESULTS AND DISCUSSION

The first skipjack tuna was tagged and released at 2:52 PM on August 30. It was estimated to be 44 cm long. It was in a school that had been sighted at 1:05 PM at Kaula Bank and had been pursued for 28 km (Fig. 3) before the fish was tagged. The marked fish was under continuous surveillance until 8:00 AM, August 31, when contact was lost. It was found at 9:32 AM, August 31 and tracked continuously until 10:31 AM, September 1, when the sonar broke down. A trip was made to Honolulu to repair the sonar, and the ship was back at Kaula Bank at 6:30 AM, September 3, at which time search for the signal

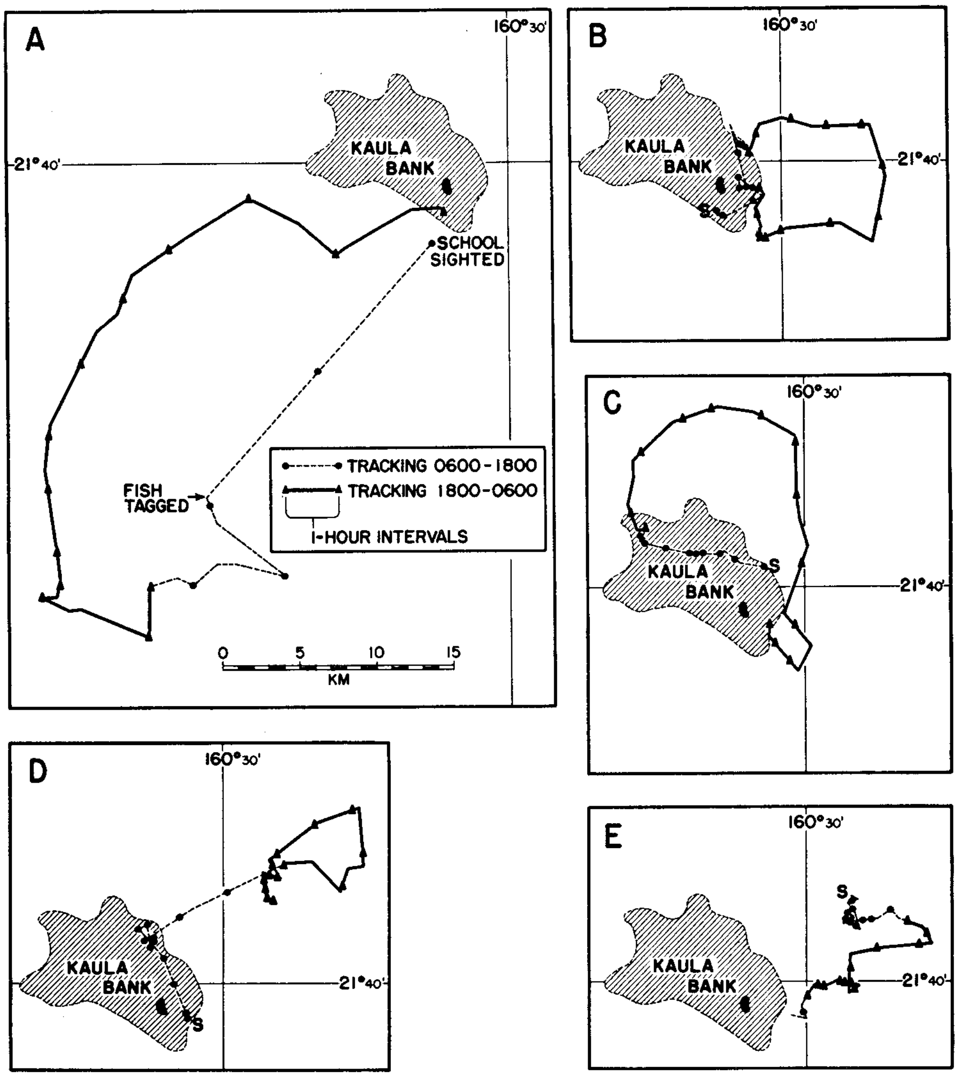

FIG. 3. Track of tagged skipjack tuna at Kaula Bank: (A) from 2:52 PM, August 30, to 6:00 AM, August 31; (B) from 6:00 AM, August 31, to 6:00 AM, September 1; (C) from 7:38 AM, September 3, to 6:00 AM, September 4; (D) from 6:00 AM, September 4, to 6:00 AM, September 5; (E) from 6:00 AM, September 5, to 7:30 AM, September 6.

from the skipjack tuna was started. At 7:38 AM contact with the transmitter was resumed. On September 4 the fish was lost from 3:45 AM to 5:42 AM. From 6:38 AM to 9:12 AM that same morning acoustic contact was broken because the fish was too close to shore for the ship to follow. It was tracked nonetheless because the school it was in was visible. Contact with the fish was lost twice more: 4:30–4:55 AM on September 5 and 1:57–3:02 AM on September 6. Tracking was voluntarily ended at 7:30 AM, September 6.

We terminated tracking the skipjack tuna at Kaula Bank to collect comparative data from another bank. At 12:55 PM on September 8 a second skipjack tuna about 40 cm long was tagged at Penguin Bank. This fish was tracked until 12:45 AM, September 9, at which time it was lost.

The fish at Kaula Bank exhibited a pattern. At about nightfall each day, the fish left the bank to follow an irregular and wide-ranging path offshore during the hours of darkness; by about sunrise it was back at the bank and it remained there until night (Fig. 3). Even though the route differed from night to night the fish was back at the bank five of the six mornings it was observed. On the excepted morning it was 9 km from the bank and it remained there throughout the day. It was at the bank the following morning after a night of traveling. The fish at Penguin Bank also left the bank at the end of the day (Fig. 4).

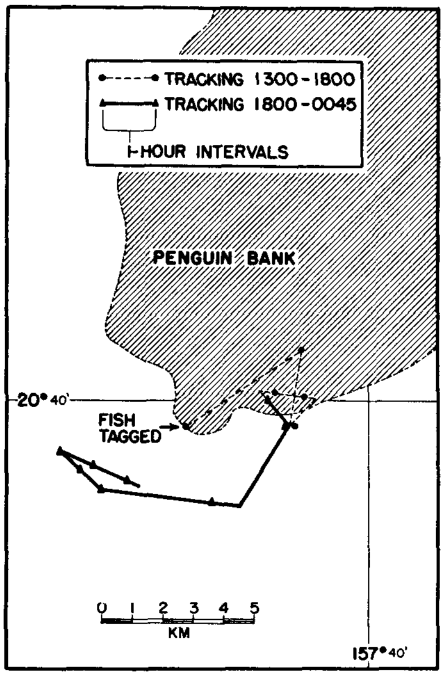

FIG. 4. Track of tagged skipjack tuna at Penguin Bank.

On its nocturnal journey the fish at Kaula Bank covered distances of 106, 31, 40, 36, and 25 km, in that order. The first night's journey was considerably longer than the others. The long pursuit before tagging is suspected as a cause of the atypical length of that run.

During the day a school of skipjack tuna was often visible at the position whence the transmitter signals were being received. On several occasions, during both day and night, the ship inadvertently approached within 200 m of the tagged fish. When the sonar was switched to the active mode at these times, many targets were observed in the vicinity of the tag. I assumed from these observations that the tagged skipjack tuna rejoined their schools and that their behavior was typical and representative of other skipjack tuna.

To investigate in more detail the daily periodicity evident from the fish's track, the means and variances of the distance traveled for each hour of the day were calculated. The variances (Fig. 5A) fell into three levels: less than 1.1,

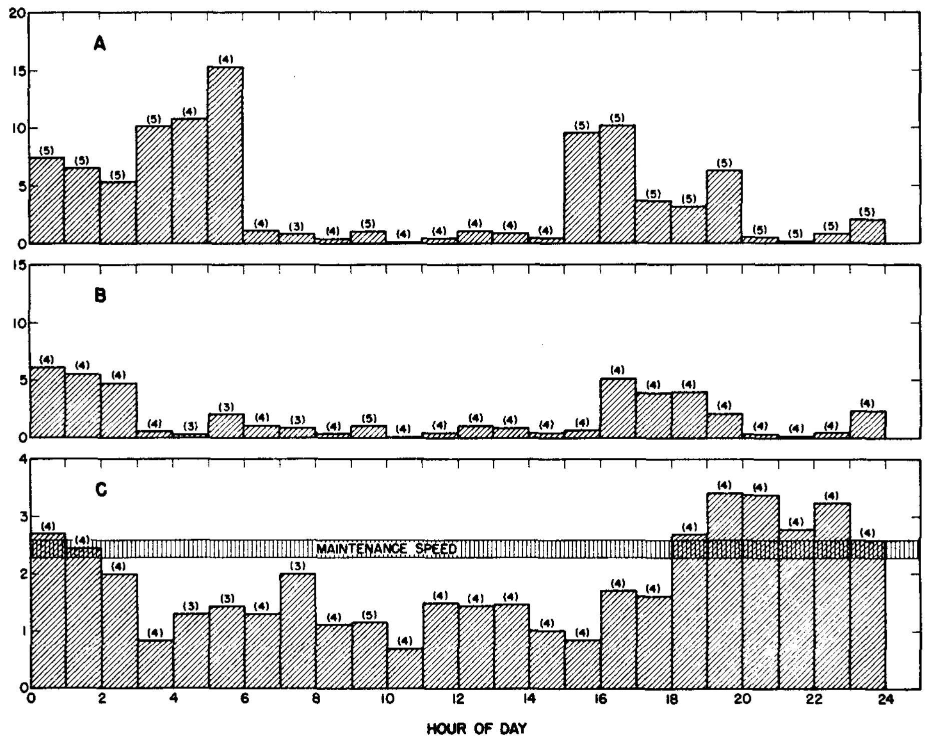

FIG. 5. Daily swimming pattern: (A) variance of distance traveled per hour calculated from all data; (B) variance of distance traveled per hour excluding data of first 15 hr; (C) mean distance traveled per hour.

2.0–7.5, and greater than 9.5. At the highest level the primary source of variation was the unusual distance traveled during the first 15-hr period after tagging. The means and variances were then recalculated without these extra high values (Fig. 5B and C).

The prominent feature of the histogram of distance traveled per hour (Fig. 5C) is the higher level from 6:00 PM to 2:00 AM. The increase, occurring as it did at 6:00 PM, immediately suggested that it was triggered by sunset, which occurred between 6:09 and 6:17 PM on the days concerned. The data from individual days, however, show that the start of the increase occurred between 4:00 and 7:00 PM. This 3-hr spread is reflected in the higher level of variances during that period (Fig. 5B). Another period of higher variances from 12:00 AM to 3:00 AM is obvious in Fig. 5B. This is the period during which the changeover from the high rate of travel to the lower rate began.

The distances traveled were based on positions of the ship so that they indicate the net hourly movements of the ship and not necessarily those of the tagged fish. Under the conditions of collection of the data, the distance traveled by the ship will always be less than that traveled by the fish but will approach that of the fish as the route of the fish approaches a straight line. The distance traveled by the ship could be zero if the fish made many turns. Depending on the circumstances, then, changes in the distance traveled (Fig. 5C) could mean changes in swimming speed, changes in swimming pattern, or both.

For hydrodynamic and physiological reasons tunas swim continuously. The swimming occurs at various minimum speeds. The minimum speed for skipjack tuna is not known but it has been calculated for *Euthynnus affinis*, a closely related species (Magnuson, 1970). For an *E. affinis* of 44 cm fork length minimum speed is 2.3–2.6 km/hr. If we assume that the tagged tuna did maintain this speed, then from 2:00 AM to 6:00 PM, when the rate of travel was below this level, its swimming pattern must have included much turning.

When the hydrophone is at 0° (aimed horizontally) to $7\frac{1}{2}$° vertical tilt to receive the signal, the fish may be at any depth from the surface to about 500 m. If the signal is received at a tilt greater than $7\frac{1}{2}$°, however, the fish cannot be within 4 m of the surface. The percentage of tilt angle records that exceeded $7\frac{1}{2}$° was calculated for every hour of the day (Fig. 6). Since the intervals between readings were fairly constant, this percentage also represents the percentage of time that the fish was away from the surface for certain. From 5:00 AM to 8:00 PM the fish at Kaula Bank (Fig. 6A) spent an average of 29% of the time away from the surface. For the remaining hours the average was 2.6%. This average should be less because the readings greater than $7\frac{1}{2}$° between midnight and 2:00 AM were obtained one night when the ship inadvertently passed directly over the fish. From the time it was tagged until 5:00 PM the fish at Penguin Bank spent a large proportion of its time away from the surface (Fig. 6B). Beyond 5:00 PM until it was lost, however, the hydrophone was aimed horizontally 92% of the time and was tilted a maximum of 5° the rest of the time.

The following picture of the behavior of skipjack tuna that are associated with banks can be drawn from these results. They have a general daily pattern. They usually spend the day at the bank, where they swim to and fro and are away from the surface a good part of the time. This type of swimming is probably associated with searching for food and feeding. Later in the day, within a couple of hours of sunset, they leave the bank and swim with few changes in direction until approximately 2:00 AM, when they seem to adopt a more erratic swimming pattern. Although they leave the bank by different routes

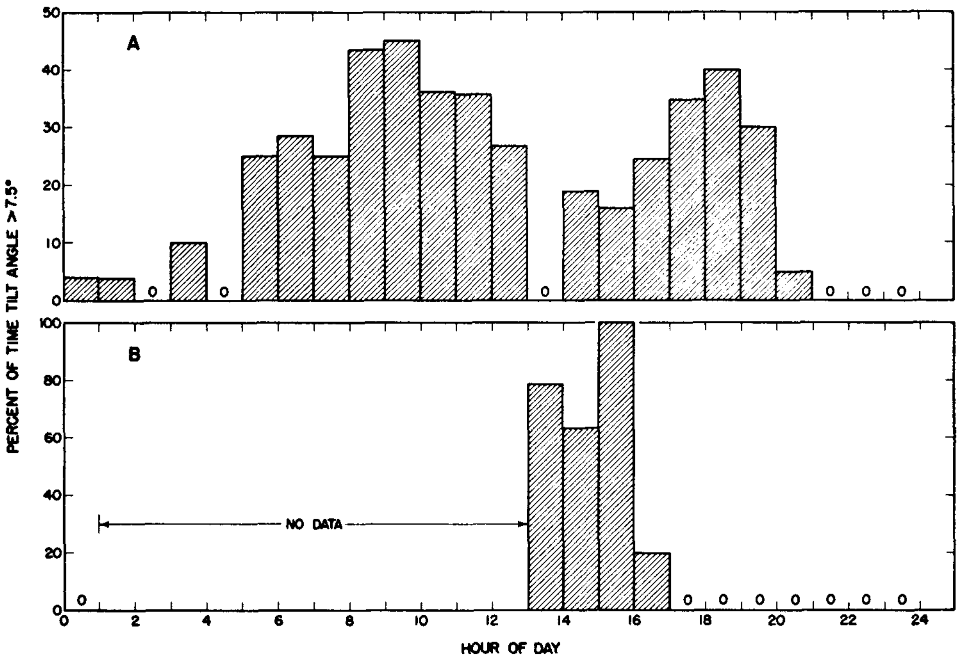

FIG. 6. Daily pattern of swimming depth: (A) skipjack tuna tagged at Kaula Bank; (B) skipjack tuna tagged at Penguin Bank.

from day to day, they are usually back at the bank by sunrise. They are presumed to be close to the surface throughout the night.

The repeated returns to the same spot by the fish at Kaula Bank after journeys of 25–106 km by various routes imply that skipjack tuna can navigate. Their consistent arrival times suggest that they have a sense of time. It is interesting to note that from 3:00 AM to 6:00 AM of the first morning after it was tagged, when it was unusually far from the bank, the tuna at Kaula Bank averaged 8 km/hr, seven times its average speed for that time of the day, as if it were compelled to arrive at the bank by a certain time.

On November 30, 1969, a skipjack tuna (52.2 cm fork length) marked with a Floy dart tag was caught at Kaula Bank (R. N. Uchida, personal communication). It was tagged on May 19, 1969, at 22°01′N and 155°55′W, a position 519 km from Kaula Bank. This recovery and the fact that skipjack tuna over 60 cm long seldom occur at banks indicate that they are not lifetime residents of a bank but come for an undetermined duration and leave.

Skipjack tuna over 60 cm long have different food preferences from those less than 50 cm long (Yuen, 1959). The swimming behavior of the fish tracked at Kaula Bank and Penguin Bank was typical of foraging tuna. This evidence suggests that food preferred by the small but not by the large tuna is found at the banks and that the small tuna frequent the banks for the purpose of feeding.

ACKNOWLEDGMENTS

Special thanks go to Mr J. H. Johnson for his generous assistance in obtaining the ultrasonic transmitters and for his valuable advice. I also thank Drs A. D. Hasler, A. B. Stasko, and R. A. Skillman for reviewing the manuscript and their helpful suggestions.

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