The occurrence of yellowfin tuna (*Thunnus albacares*) at Espiritu Santo Seamount in the Gulf of California

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Pelagic fishes are not evenly dispersed in the oceans, but aggregate at distinct locations in this vast and open environment. Nomadic species such as mackerels, tunas, and sharks form assemblages at seamounts (Klimley and Butler, 1988; Fontenau, 1991). Fishermen have recognized this behavior and have placed moorings with surface buoys in deep waters to provide artificial landmarks, around which fish concentrate and are more easily captured. These fish aggregating devices (termed FADs) are common in the tropical oceans (see review, Holland, 1996). In a sense, it may only be the larger size that separates a seamount from a man-made FAD.

Fish may aggregate at seamounts for very different reasons. The opportunity to feed is greater because biomass at all trophic levels, from primary producer to apex consumer, is greater than in the open ocean (Boehlert and Genin, 1987). The disturbance of flow by the seamount creates eddies downstream that retain nutrients critical to the growth of phytoplankton, and this enrichment supports a greater abundance of consumers from zooplankton to apex predators. The dipole nature of seamount magnetic fields and the outward radiating valleys and ridges of magnetic minimums and maximums might provide landmarks in oceanic landscape that fish use as a reference to guide migration (see discussion of magnetic "topotaxis" in Klimley, 1993). Yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*) tunas do not reside long at the Cross Seamount near Hawaii, an observation inconsistent with the theory that tunas feed on prey that remain aggregated at the site; rather their rapid passage suggests that the site is a landmark used to guide migrations (Holland et al., 1999). Adult yellowfin tuna also stay briefly (<5 min) at FADs off Kaena Point, Oahu (Klimley and Holloway, 1999).

Describing the degree of residency of pelagic fishes at different geographic locations helps ascertain whether the affinity to seamounts and FADs is common throughout the oceans. Holland et al. (1999) determined the rates of dispersion of tuna by attaching unique tags to individuals, releasing them, and later identifying them from these tags. This method results in the removal of individuals from the population and yields a percentage of individuals that have either left the area or have been captured (Holland et al., 1999). Detecting coded ultrasonic tags by an automated monitor provides additional information because marked individuals can be detected repeatedly over a period of time. However, fewer tags can be deployed because of their greater cost. We used this method to reveal synchronicity among visits of yellowfin tuna, time of visits, and duration of visits at the Espiritu Santo Seamount in the Gulf of California.

Methods

We tagged 23 yellowfin tunas with coded ultrasonic beacons during a five-month period between 11 April and 12 September 1998. They were tagged <150 m from two monitoring stations: Espiritu Santo North (ESN) and South (ESS), separated by 500 m at the Espiritu Santo Seamount (24°42′N; 110°18′W) in the southern Gulf of California (Fig. 1). The seamount rose to within 18 m of the surface and extended 700 m along a northwesterly–southwesterly axis. Monitoring station ESN was situated at the northwest end of the seamount ridge at a depth of 47 m; station ESS was at 37 m on the southwest end.

The monitors were deployed for 30 months, during which they recorded when the tagged tuna swam within the 150-m range of reception of the monitors. Using SCUBA, we removed the monitors from the moorings at four-month intervals, downloaded the records of tuna presence near the seamounts to a laptop computer, and replaced the monitors during the same day. We located a station by the rosette of buoys, which floated at a depth of <10 m and which was visible from the surface, by towing a diver at the surface near the GPS coordinates for the mooring.

Manuscript approved for publication 30 January 2003 by Scientific Editor.
Manuscript received 4 April. 2003 at NMFS Scientific Publications Office.
Fish. Bull. 101:684–692 (2003).

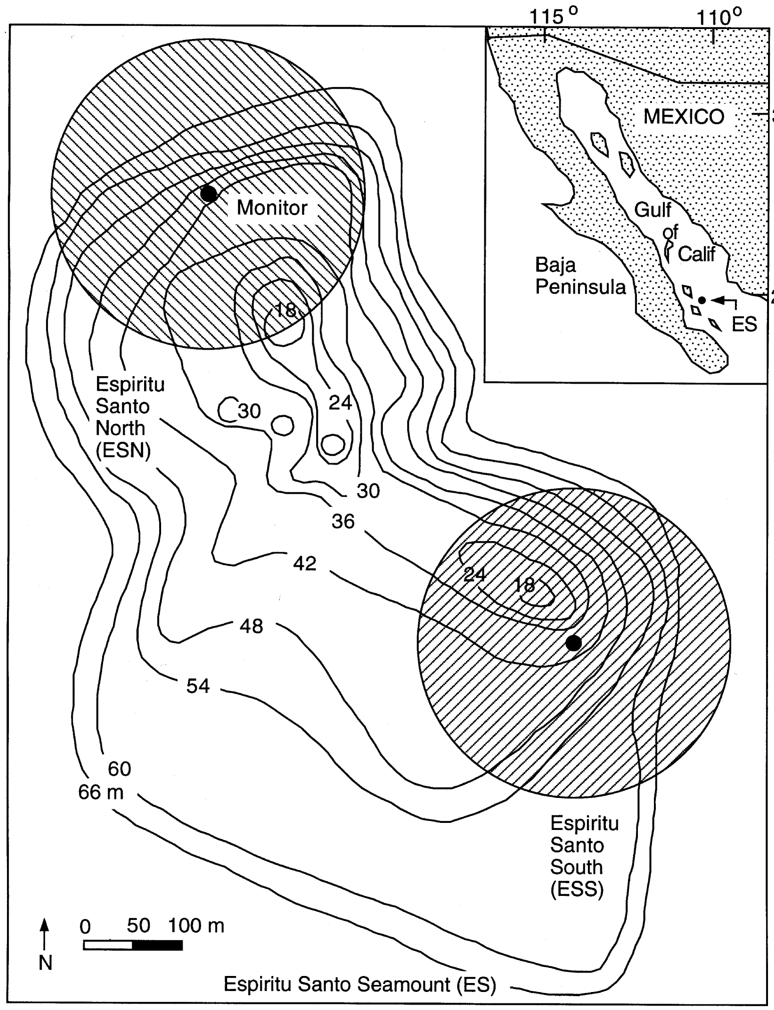

Figure 1

Bathymetric contour map of seamount Espiritu Santo (ES). The circles with cross-hatching indicate the range of the tag-detecting monitor from the seamount. The insert shows the geographic location of the seamount (ES) in the Gulf of California.

We determined the maximum range of signal-detection of one monitor by lowering a transmitter to 10 m under a small boat and lowering the monitor to a similar depth under a larger support vessel. We recorded the separation distance between the two boats using radar because the small boat and transmitter drifted away from the support vessel that was anchored in place at the highest point on the seamount. The VR01 monitor (Vemco Ltd., Shad Bay, Nova Scotia, Canada) detected tags at a distance of 150 m in seas with waves <0.5 m high (see circles, Fig. 1). Later models (Vemco Ltd., VR02) used in the study have a published reception range of ≥500 m in calm seas (see http://www. vemco.com). The range of tag detection by the monitors decreases with rising sea state because of the increase in wave-generated ambient noise.

The tuna were caught by rod and reel and lifted aboard 1–30 minutes after being hooked. Smaller individuals (≤15 kg) were weighed with a scale with a hook that fit into the operculum; intermediate sized fish (>15 and ≤25 kg) were weighed in the net and the net's mass subtracted from the cumulative value; and the masses of largest tuna (>25 kg) were estimated on the basis of their length by using the regression equation, $y=0.216x + 2.981$ given in Moore (1951). The tags were inserted into the peritoneum of the tuna while salt water was flushed over their gills by using the technique described in Klimley and Holloway (1999). The tuna were retained on board for tag implantation less than a minute.

The transmitters (Vemco Ltd., V16-6L) were cylindrical and had a diameter of 16 mm, length of 106 mm, and net mass in water of 16 g. They emitted individually coded tone bursts of 70 kHz separated by 60–90 s intervals. The amplitude of the pulses was 147 dB (re: 1 μP) at a distance of 1 m. The theoretical operating life of a transmitter was 476 days. Each tag was distinguished on the basis of a unique pulse burst by an automated tag-detecting monitor attached to the ESS and ESN detection stations. Water

Table 1

Length and mass of the 23 yellowfin tuna (*Thunnus albacares*) tagged in the present study and the date and time of tagging. "N" indicates tagging near northern monitor; "S" denotes tagging near southern monitor. An asterisk in front of a measurement indicates that the value is derived from the mathematical relationship between mass and length given in Moore (1951); "TL" denotes total length.

Tuna no.	Date	Time (h)	TL (cm)	Mass (kg)	Site (N/S)
1	11 Apr 1998	13:04	80.0	7.3	S
2	11 Apr 1998	13:21	96.0	10.8	S
3	12 Apr 1998	08:46	91.0	10.3	S
4	12 Apr 1998	08:51	106.0	13.8	S
5	12 Apr 1998	09:54	104.0	15.5	S
6	17 Jun 1998	09:54	91.5	17.0	S
7	24 Jun 1998	10:38	86.5	11.3	S
8	26 Aug 1998	10:05	138.0	*51.7	N
9	26 Aug 1998	10:45	58.0	4.5	N
10	26 Aug 1998	11:43	66.0	5.5	N
11	26 Aug 1998	12:16	76.0	7.0	N
12	26 Aug 1998	10:14	155.0	*73.1	N
13	28 Aug 1998	10:50	71.0	7.2	N
14	28 Aug 1998	11:25	155.0	*73.1	N
15	10 Sep 1998	17:44	149.9	*66.2	S
16	10 Sep 1998	18:32	91.5	18.50	S
17	10 Sep 1998	18:44	*75.0	8.50	S
18	10 Sep 1998	19:07	111.8	*27.6	S
19	11 Sep 1998	17:25	114.5	20.5	N
20	11 Sep 1998	17:51	71.0	7.00	N
21	11 Sep 1998	18:25	106.5	20.5	N
22	12 Sep 1998	6:41	104.5	23.0	N
23	12 Sep 1998	7:30	141.0	*55.1	N

temperature was recorded every half hour at the seamount by a Stoaway Tidbit temperature logger (Onset Computers Corp., Pocassett, MA) attached to the mooring line adjacent to the tag-detecting monitor. We calculated a daily temperature by averaging the half-hourly temperatures.

We used log-survivorship analysis (Fager and Young, 1978) to ascertain whether the tunas returned to the monitoring stations after favored time periods. A frequency histogram of the time intervals between randomly occurring point events in a Poisson process is described by a negative exponential distribution. A log-survivor plot of these intervals generates a straight line with a slope proportional to the probability of an event occurring at a given time after the preceding event. This analysis is used to identify intervals between events that occur more frequently than expected by chance because inflections in the resulting curve are more easily distinguished from a straight line than the shape of the distribution on a frequency histogram with a negative exponential distribution. An inflection in the log-survivor curve indicates a change in the probability of an event occurring at a given time after the last event—in our case the time between successive arrivals of tunas within the ranges of the two monitors.

Results

Twenty-three yellowfin tunas were tagged from 11 April 1998 to 12 September 1998 (Table 1). Individuals were tagged during daylight hours from 6:41 to 19:07 hours. The tunas ranged in length from 71.0 to 155.0 cm TL. They ranged in mass from 7.25 to 73.1 kg. There appeared to be two discrete size classes, small individuals varying from 7.25 to 23.0 kg and large ones from 51.7 to 73.1 kg. The masses of the larger individuals were determined from their lengths by using a regression equation (Moore, 1951).

The yellowfin tunas stayed at seamount Espiritu Santo over varying time periods (Fig. 2). Nine of the 23 tunas left the seamount on the same day that they were tagged (Fig. 2A). Two of the nine returned to the seamount once for a single day, one within a week of tagging and the other after two and one-half months. Six tunas stayed intermediate periods of time after tagging, ranging from two to six weeks. One of these tunas (no. 9) was eventually caught at the seamount. Another tuna (no.10) visited for a single day after an absence of five weeks and returned again after a similar period to stay for 15 months. Four

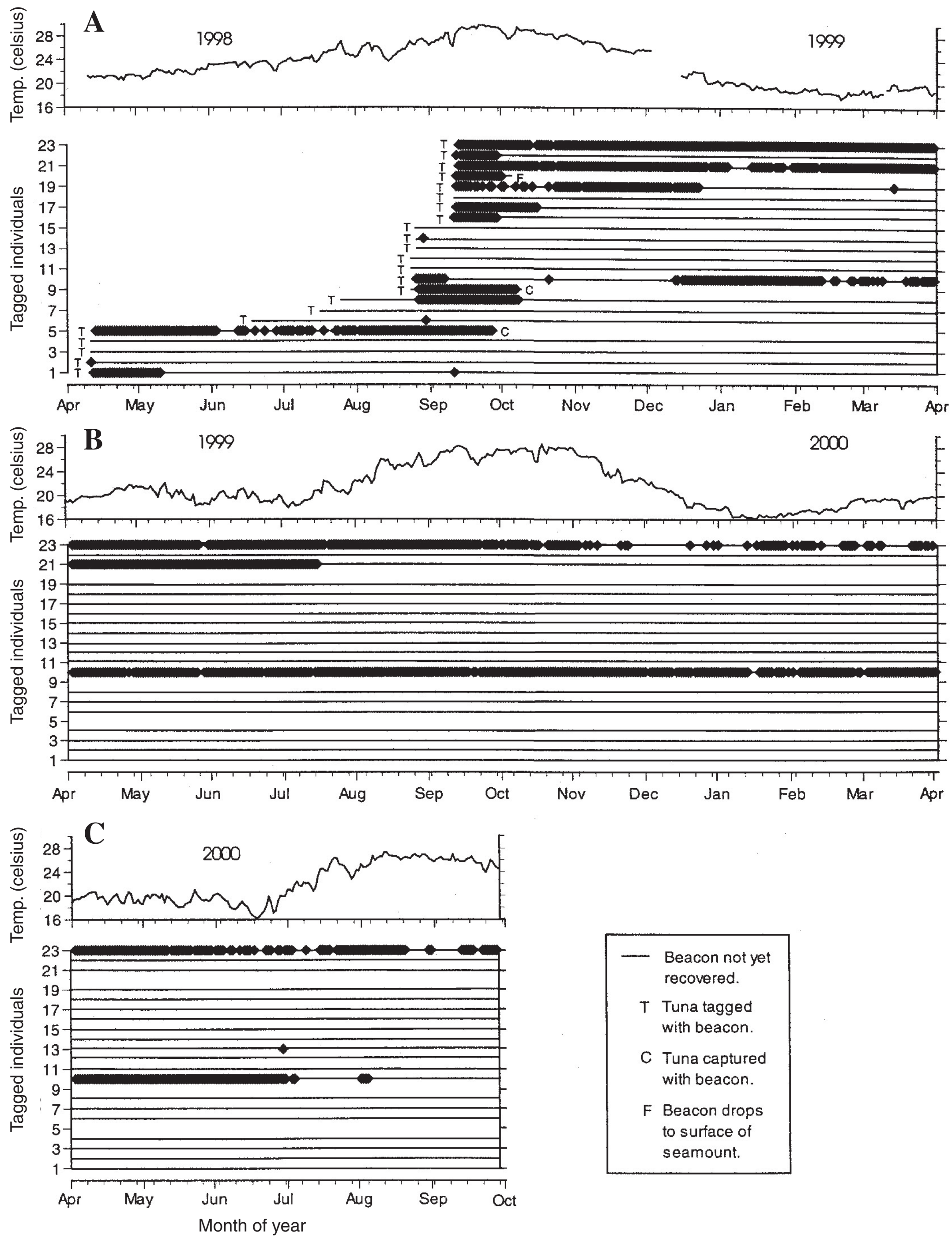

Figure 2

Chronology of daily visits by 23 tagged yellowfin tuna to the seamount and temperature record over a 30-month period beginning April 1998 and ending October 2000. Each visit, indicated by a solid diamond, is based on the detection of a tag during a 24-h period by either the north (ESN) or south (ESS) monitoring stations. The lines in the graphs show that the ultrasonic tag had yet to be recovered from a yellowfin tuna. T = day of tagging, C = day of capture, and F = date of shedding of tag.

individuals (nos. 5, 19, 21, and 23) stayed for longer periods of time, ranging from six to 18 months. One of these tunas (no. 5) was also caught by a fisherman. It is likely that some tunas are nomadic and stay only a single day, whereas others are resident, remaining at the seamount throughout the year.

It is unlikely that the tags on the two tunas (nos. 10 and 23), which stayed at the seamount longest, were shed and lay on the bottom. The reasons supporting their being attached to living tunas are as follows. First, the two tags were not recorded with equal frequency during all times of the day as might be expected of a tag lying at one location within the range of the monitors. The tags were usually detected for a few hours and then absent for a similar period. This pattern of detection is consistent with the tunas moving within the range of the monitor and later outside its range. Second, the two tags were jointly detected after long periods of absence or ceased being detected simultaneously after long periods of presence. This reception pattern is consistent with the two tunas moving in and out of the detection range of the monitors within the same school. Third, one tuna (no. 23) was detected by the monitor on the south side of the seamount, but not on the north side during one day; the same tuna was detected by the northern monitor, but not the southern monitor on the next day. This pattern of detection was consistent with the tuna swimming over the northern region of the seamount on the first day and over the southern region on the second day.

The yellowfin tunas were present at the seamount at all seasons of the year. Five of the tunas tagged during August and September 1998 (nos. 7, 8, 9, 16, and 17) emigrated during early fall as the water temperature began to decrease (Fig. 2A). However, three individuals (nos. 10, 21, and 23) remained at the seamount from January 1999 to April 1999 when the temperature dropped to 18°C. Two (nos. 10 and 23) remained present when the subsurface water temperature descended to 16°C during the following winter of 2000 (Fig. 2B).

The yellowfin tunas remained at the seamount at all times of the day. This is evident from a 24-h record of the arrivals of 10 tunas during a 15-d period from 16 to 30 September 1998 (Fig. 3). The tunas were present more often during daytime, from 06:00 to 18:00 hours, during the first 12 days. Notice the clustering of the different symbols in Figure 3, each indicating a specific tuna, in separate columns during the period from 06:00 to 18:00 hours. However, the amount of time spent at the seamount became more evenly distributed between daytime and nighttime by 28 September. Note the even dispersion of the symbols over the 24-h period during the last three days of the 15-day period. There was little variation evident in the frequency of arrivals at different times of the day when the arrivals were summed over the entire study (Fig. 4). The percentage of arrivals during each hour of the day (see crosshatched polygon) differed little from an even distribution of arrivals (4.2%/h) throughout the day (see dashed circle).

We determined the frequency of various lengths of stays at the north (Fig. 5A) and south sites (Fig. 5B) at the Espiritu Santo Seamount. A stay for a particular tuna was defined as the period of detections with no separation intervals greater than 15 min. Let us say that tuna 1 was detected at 08:00, 08:14, 08:28, and 09:00 hours. The duration of the stay of tuna 1 would be 28 min. The second detection followed the first by 14 min (<15 min), and the third followed the second also by 14 min (also <15 min). However, the fourth detection followed the third by 32 min (>15 min) and was therefore not pooled into a single duration. This stay would then be placed in the 15:00–29:59 min time class in Figure 5. Twenty-seven percent of the detections at ESN and 33% of those at ESS were separated by greater than 15 min and were thus considered single detections and included in the 00:00-h class. Fifty-three percent of the visits to ESN and 37% of the visits to ESS were between 00:01 and 14:59 min. Twenty-one percent of the visits to ESN and 20% of the visits to ESS were between 15:00 and 59:59 min. The majority of visits were less than 1 hour in duration and only a few exceeded an hour.

The intervals spent away from the seamount were similarly short. Sixty percent of all absences at ESN were less than 1 h (Fig. 6) as were 65% of the absences from ESS. Ninety percent of the absences from both sites were less than 5 hours. Only 0.1% of the visits exceeded 23 hours. There appeared to be no favored period of absence as indicated by the smooth slope of both curves in the log-survivor plot. Only 72 periods of absence at ESN and 114 periods at ESS exceeded a day. Of these longer periods, 42% of the absences from ESN (Fig. 7A) and 46% of the absences from ESS (Fig. 7B) were for two days. Only 7 % of the absences from ESN and 4% of the absences from ESS were between 10 and 19 days. Only 2% of periods of absence from ESN exceeding a day were greater than 100 days (Fig. 7A).

Discussion

We found that yellowfin tuna remained at the seamount for periods ranging from a few days to greater than a year. Fifty percent of 458 yellowfin tuna tagged with dart tags at the Cross Seamount off Hawaii were recaptured at that seamount within 15 days of tag application (Holland et al., 1999). This "half-life" of tuna residence was short, suggesting that the seamount served as a landmark to guide migration and not as a destination for feeding.

Thirty-eight yellowfin tuna were tagged with ultrasonic beacons at two buoys off the western coast of Oahu and monitored over a 13-month period by automated "listening" monitors (Klimley and Holloway, 1999). These monitors (VR20) possessed a more sensitive receiver than our monitors (VR01 and VR02). The former had a maximum range of 1.1 km. The maximum published range of our monitors was 0.5 km. Twenty-seven of the tuna returned to the buoys a mean of 4.2 visits per tuna. The mean duration of each visit was only 40.1 min and the mean period of absence was 17.2 days. Seventy-three percent of the tuna tagged on the same day returned together. The tunas often arrived at the same time of the day and returned only to the buoy at which they were tagged. This allegiance of tunas to one school, their predilection for returning to the site of tagging, and the precise timing of their visits are consistent with the theory that the species has migratory pathways consisting of way-points that are visited with regularity. That the tuna spent little time at the FAD suggests that the buoys are not feeding destinations, but rather landmarks used in migration.

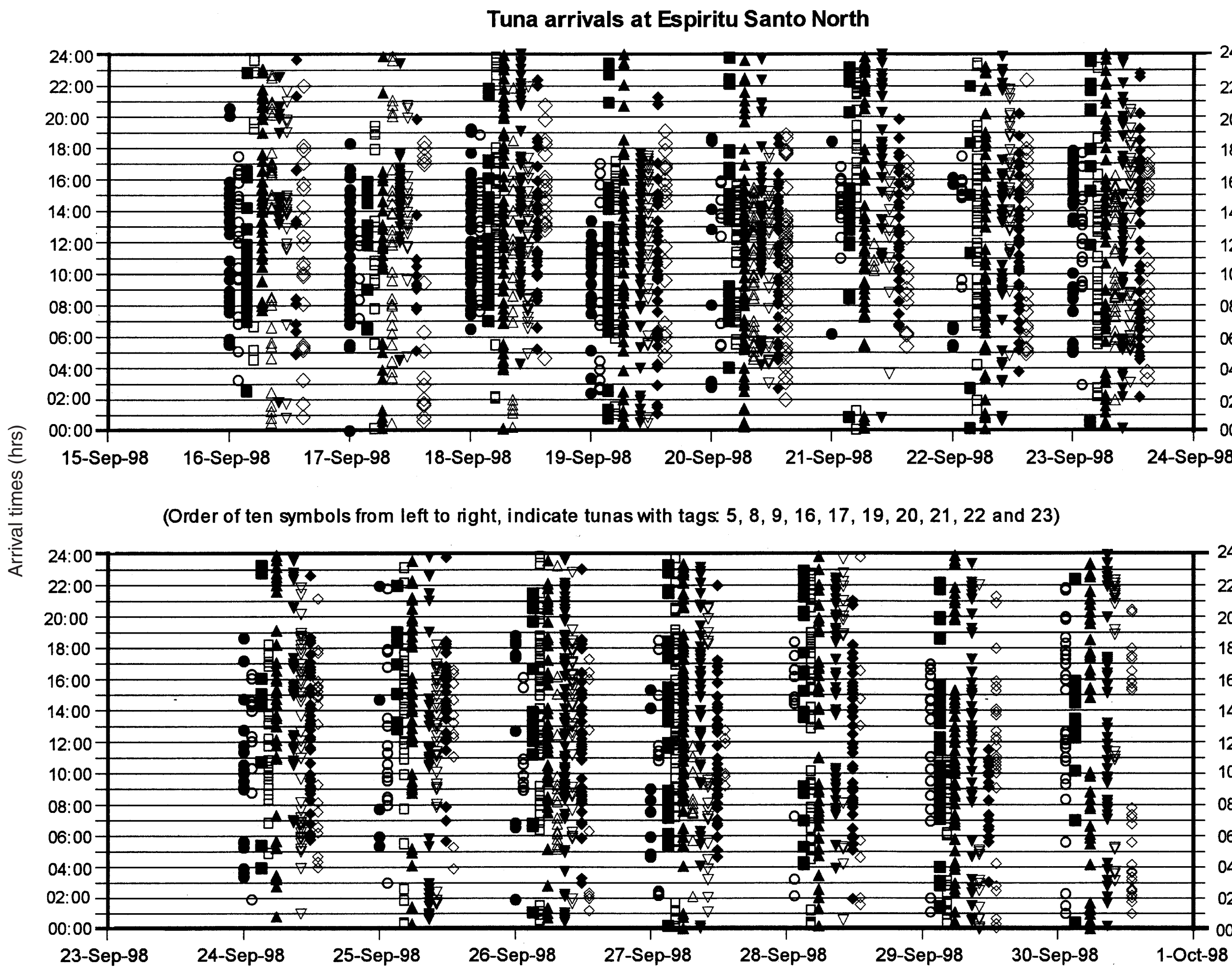

Figure 3

Twenty-four hour chronology of visits by 10 tagged tuna to the monitoring station ESN during 15 days from 16 to 30 September 1998. A unique symbol indicates the presence of a particular individual within the range of the monitor during a 15-min position. Note the predominance of daytime visits during the first nine 24-h periods and then a progressive shift to an equal number of visits during daytime and nighttime (see 28–30 Sept. 1998).

Tuna repeatedly moved in and out of the monitor range over many days or left for the duration of the study. Sixty percent of all absences at ESN and 65 % of the absences from ESS were for less than 1 hour. If these tunas were to swim at a sustained rate of 0.5 m/s (see Magnuson, 1978), they would not move more than 900 m out the reception range of the monitors (60 min × 60 s × 0.5 m/s /2). This close attachment to the seamount contrasts with the behavior of tuna at FADs offshore of Hawaii. Tunas visited the FADs there rarely and spent little time within the range of the monitor before departing for a period of several weeks (Klimley and Holloway, 1999). The present study suggests that the Espiritu Santo Seamount is a substantial feeding ground that can support a year-round resident population of yellowfin tunas. However, other tunas may stay only briefly at the seamount, using it as a landmark, before continuing on their nomadic migrations.

Seamounts have dipole magnetic fields associated with them because of the antiparallel polarity of magnetite within volcanic magma extruded during periods when the earth's polarity was reversed (Parker et al., 1987). Furthermore, maxima (ridges) and minima (valleys) in the magnetic field often lead outward from seamounts due to the extrusion of magma. Klimley (1993) proposed that hammerhead sharks use these for guidance during their nocturnal migrations into the surrounding water to forage. This physical property of the sea floor, originating far below where the fishes swim, could provide a fixed reference (or waypoint) for yellowfin during their migrations. This species of tuna has been shown to sense distinct patterns in a magnetic field (Walker, 1984).

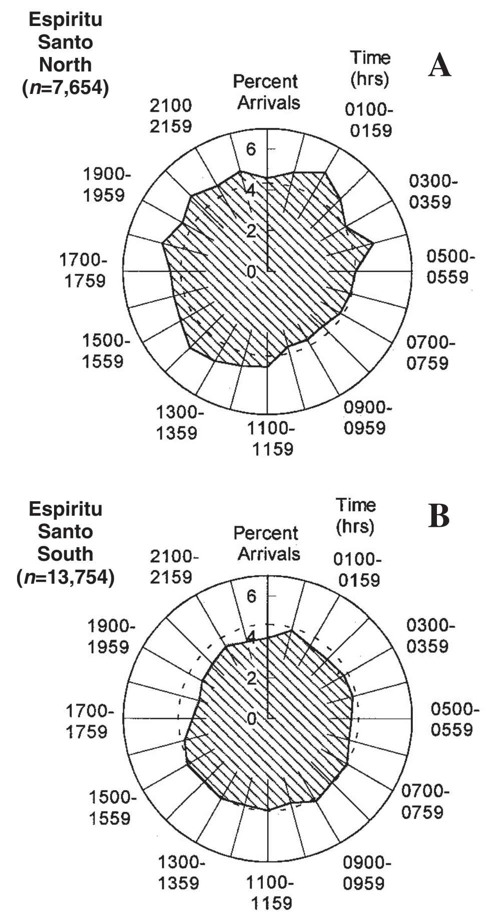

Figure 4

Percentage of visits by 23 yellowfin tuna at different times of day at monitoring stations ESN (**A**) and ESS (**B**). Circle with dashed line indicates an equal percentage of returns occurring every hour of the day.

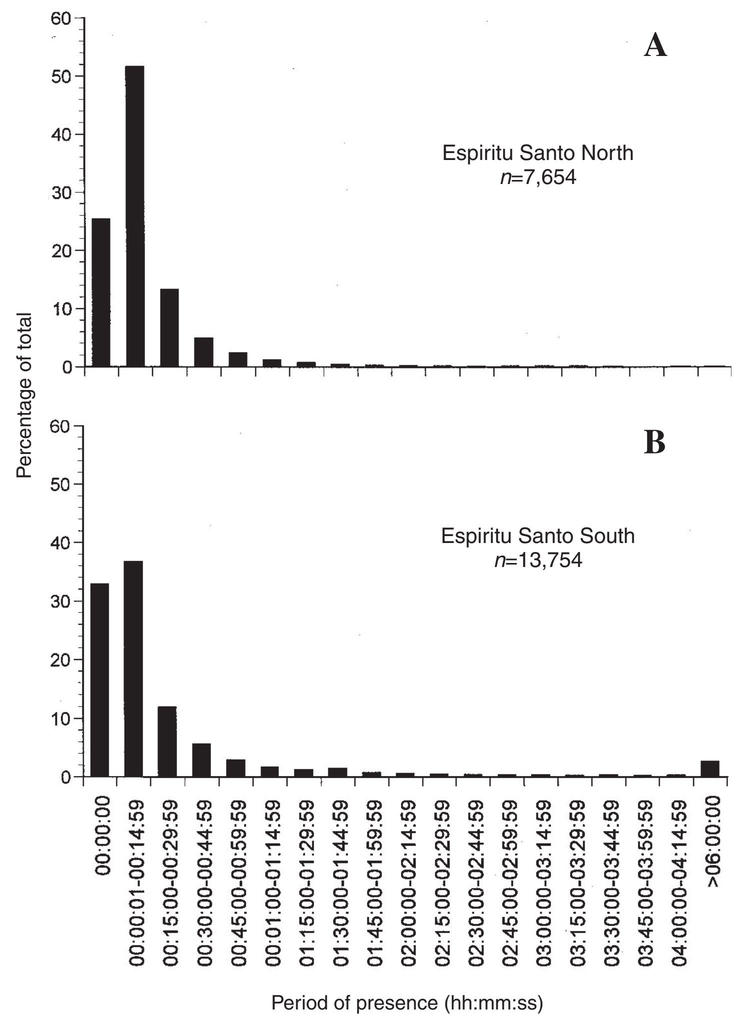

Figure 5

Percentage of visits of increasing duration recorded for 23 yellowfin tuna at monitoring stations ESN (**A**) and ESS (**B**). A single detection of a tagged fish would be placed in the 00:00-min time category.

Conclusions

Twenty-three yellowfin tuna were tagged with coded ultrasonic beacons during a five-month period between 11 April and 12 September 1998. These tunas were captured, tagged, and released <150 m from two monitoring stations: Espiritu Santo North (ESN) and Espiritu Santo South (ESS), which were separated by 500 m, at the Espiritu Santo Seamount in the southern Gulf of California (24°42′N; 110°18′W). The monitors were deployed for a period of 30 months, ranging from April 1998 to October 2000, during which they recorded tagged tunas swimming within their 150 m range of reception. The tunas ranged in length between 71.0 and 155.0 cm TL and in mass from 7.2 to 73.1 kg. The tunas stayed at the Espiritu Santo Seamount for varying time periods. Nine of the 23 tunas left the seamount on the same day that they were tagged. Two of the nine returned to the seamount twice for a single day, one within a week of tagging and another after 2.5 months. Five additional tunas stayed at the seamount for intermediate periods, ranging from two to six weeks. Four individuals stayed for longer periods of time, ranging from 6 to18 months. Tunas were present at the seamount at all times of the day. They moved in and out of the range of the monitors, most often staying for periods <14:59 min. Fifty-three percent of the visits to ESN and 37% of the visits to ESS were of this duration. Smaller percentages of the visits, 21% and 20%, lasted 15:00 to 59:59 min, respectively. The majority of visits were <1 hour in duration and only a few exceeded an hour. The intervals spent away from the seamount were also brief. Sixty percent of all absences at ESN and 65% of the absences from ESS were <1 hour. Ninety percent of the visits to both sites were <5 hours. Only 0.1% of the visits exceeded 23 hours. Tuna individuals

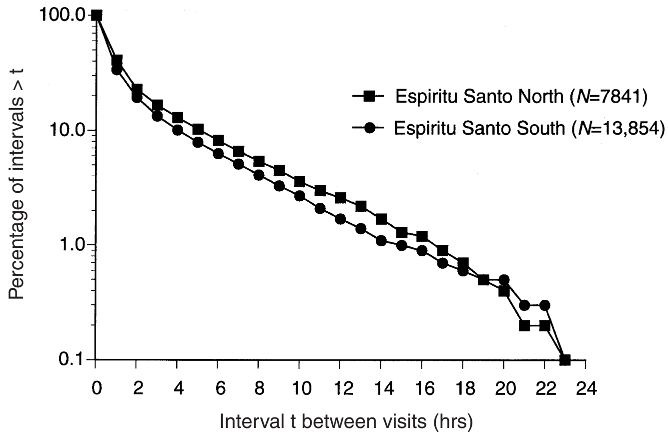

Figure 6

Log-survivor plots of percentages of intervals between successive tuna arrivals greater than time t over 24-h periods at monitoring stations ESN (**A**) and ESS (**B**).

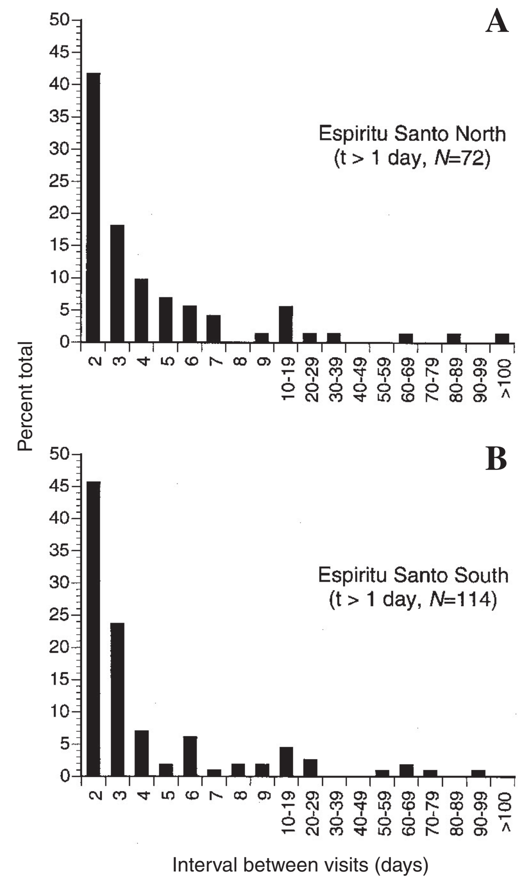

Figure 7

Percentages of visits of greater than one day made by tuna to two monitoring stations with single day intervals ranging from 2–9 days and 10-day intervals ranging from 10–19 to 90–99 days.

may use the site either as a landmark during their migratory transit or as a feeding destination as suggested by the short and long periods of time spent at the seamount.

Acknowledgments

We would like to thank those on the staff of Centro de Investigaciones Biologicas del Baja Norte of La Paz, Mexico, who helped us tag yellowfin tuna at seamount Espiritu Santo. This work was funded by the Biological Oceanography Program of the National Science Foundation (grant: OCE-9802058) and CONACYT of Mexico (grant: PN-9509-1995 and PN-1297-1998).

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