Activity Patterns of Striped Marlin in the Southern California Bight

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The billfish resource along the west coast of Mexico and California is important to both commercial and recreational fisheries. In Mexico, the striped marlin *(Tetrapturus audax)*,is taken in large quantities by commercial longline vessels and by recreational fishermen (Squire and Au 1989). In California, the striped marlin is considered to be among the most desirable of big-game fishes. Although not taken off California in numbers comparable to landings from Mexican waters, it nevertheless supports a very valuable recreational industry (Squire 1987a). In recognition of its value to California's sport fishing public, the striped marlin has been legally designated as a game fish for "sport only" utilization and cannot be taken or possessed by commercial fishermen, or imported into California fish markets. The California Department of Fish and Game (CDFG) has documented increased fishery interactions and conflicts in recent years between recreational and commercial fishermen. Tensions between recreational groups and the commercial fishing industry have increased with the expansion of the drift gill-net fisheries for thresher shark *(Alopias vulpinus)* and swordfish *(Xiphias gladius)* in the late 1970s and early 1980s (Beford and Hagerman 1983, Beford 1987).

Knowledge of striped marlin activity patterns, such as vertical and horizontal swimming patterns, variability of swimming speeds, and temperature-depth preferences, can provide fisheries managers with essential information needed for resolving user conflicts. Acoustic telemetry has been used to monitor the behavior patterns and physiological characteristics that influence habitat preference of large free-swimming pelagic fish (Holland et al 1986, Yuen 1970, Yuen et al 1974, Carey and Robison 1981, Carey and Olson 1981, Yonemori 1982). The current studies with striped marlin are, in part, designed to determine their behavior and vulnerability to various types of commercial and recreational fishing gears and to gain information on the availability of striped marlin off southern California. The correlation of behavioral patterns with various environmental parameters can also be valuable in stock assessment and distribution studies.

During September, 1982, biologists with the National Marine Fisheries Service (NMFS) succeeded in tagging with a sonic tag and tracking a striped marlin (SM82-1) for a period of 24 hours off the coast of southern California. Four years passed before another attempt was made. In 1986, the CDFG recognized the need for information on the behavior of striped marlin as part of studies concerned with incidental catches by the drift gill-net fishery for swordfish. A cooperative research project between the CDFG's Marine Resources Division and the NMFS' Southwest Fisheries Center's Pelagic Fisheries Resources Division was established in 1986 to track striped marlin off southern California. During the summers of 1986 and 1987, ten striped marlin were tagged with sonic transmitting tags and their movements tracked. Results of this project to date are reported herein.

Methods

The tracking vessel was the 59-foot sport fishing boat, *"Pacific Clipper,"* under contract to the CDFG. It accommodated a scientific crew of up to six, with ample space for fishing,

tagging, and tracking equipment. Our tagging and tracking equipment consisted of Vemco* V4P sonic transmitter tags, CS-40 directional hydrophone and a VR-60 receiver-decoder, all similar to that described by Holland et al (1986).

The depth transmitters came in two full-scale pressure ranges of 0 to 100 psi and 0 to 1,000 psi. Depth sensitivity was subject to 2 percent error at full scale. The 1,000 psi tags were used initially, until we established that striped marlin tended to stay in the upper portion of the water column. Output frequencies were set at 29.00 and 34.00 kHz; anticipated battery life was 7 to 14 days, depending on the depth of the fish. The transmitted signal was received through a directional hydrophone, bolted to a rotatable shaft, and was attached to a control motor which turned the hydrophone up to 180 degrees in either direction. This assembly was mounted amidships on the starboard side of the vessel's hull. The rotational control unit for the hydrophone was operated from inside the cabin. A plastic PVC faring was mounted over the hydrophone to reduce external noise while underway at speeds of up to 6 knots.

The receiver digitized the telemetered pulses and stored both time and depth data for later transfer to a computer. The receiver's audible signal was recorded on cassette data tapes as a back up in case any problems ocurred with the internal data storage memory. The strength of the signal received was used to estimate the distance to the target, thus allowing the tracking team to maintain a desired distance from the tagged fish. We estimate our normal operating distance from the fish was approximately 200 to 400 m (650 to 1,300 ft) and our maximum range from which we could receive the signal was about 800 m (2,600 ft).

During tracking, the vessel's location was recorded at 15 minute intervals through the use of Loran-C. Since the distance from the vessel to the fish was routinely kept under 400 m (1,300 ft), the location of the vessel was assumed to be the same as the fish.

During tracking, XBT (expendable bathythermograph) casts were taken to obtain water temperature profiles at intervals of approximately 6 hours.

Fishing and tracking operations were conducted in the most promising areas as determined by daily angler success rates. Cruise dates were scheduled to coincide with recreational marlin tournaments whenever possible. Sport fishing clubs and tournament organizers were asked for assistance in catching marlin for tagging. All but two of the fish were caught and donated by sport fishermen.

When an angler notified the "*Pacific Clipper*" that a fish was hooked-up, and would be donated, a course and distance to the donor vessel was plotted. If we could reach the donor vessel in the time it would take to bring the marlin alongside the catcher vessel we would proceed at top cruising speed to that location. Once alongside, a tagging team would be sent by rubber raft to board the donor vessel and tag and release the fish. The weight of each fish was estiamted at the time of release.

Results

In all, 11 striped marlin were tagged and tracked (including the fish tracked in 1982; SM82-1). Three of the marlin were tracked for less than 5 hours and eight were tracked from 20 to 48 hours (Table 1). Only those tracks with durations of 20 hours and longer are included in the analysis. Marlin tracks lasting 20 hours

Table 1. Tagging and tracking statistics for 11 striped marlin.

Fish	Date	Weight (estimated) kg	Location	Time tracked hrs	Distance traveled nm	dir	Donated by skipper
SM82-1	9/22/82	55	425 spot	24	24	WSW	NMFS
SM86-1	9/27/86	50	Avalon	24	37	S	H. Sutton
SM86-2	10/01/86	55	Mackerel Bank	3	5.5	S	—
SM87-1	9/13/87	50	East of Slide	3.5	4	E	G. Stotesbury
SM87-2	9/16/87	70	East of Slide	20	22	SE	NMFS/CDFG
SM87-3	9/17/87	70	East of Slide	48	57	SE	J. Belus
SM87-4	9/25/87	55	14-mile Bank	24.5	31	E	W. Woodard
SM87-5	10/02/87	80	267 spot	30.5	44	S	G. Jasper
SM87-6	10/04/87	—	267 spot	24	23	NW	G. Jasper
SM87-7	10/17/87	—	267 spot	4.5	6	SW	D. Denholm
SM87-8	10/19/87	65	Dana Point	24.5	16	S	R. Rafkin

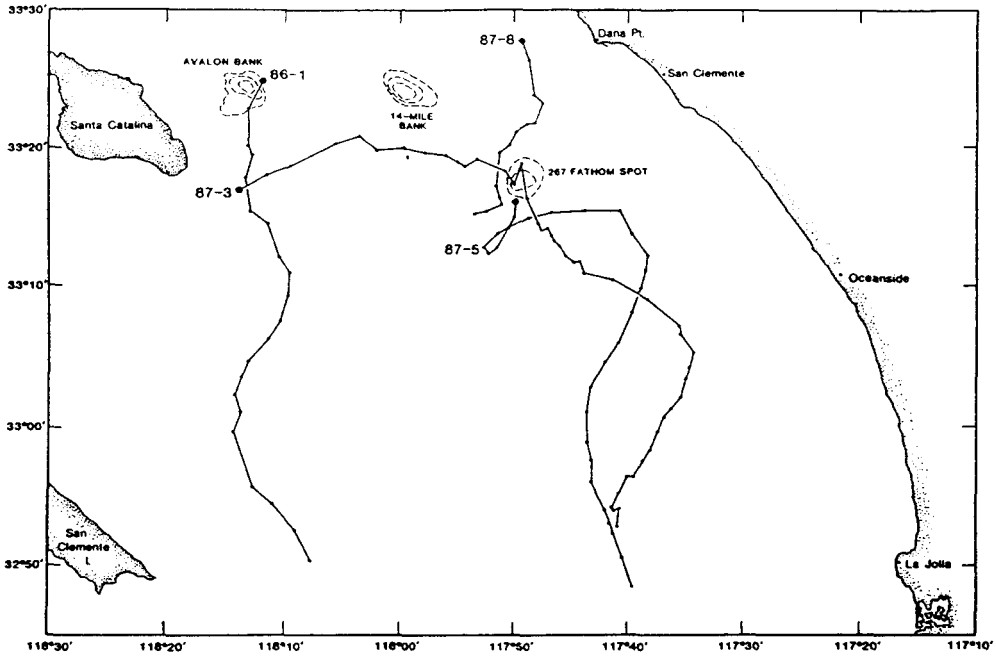

Figure 1. Horizontal movement of four striped marlin generally showing a predominant movement away from the tagging area and in a southward direction. Dots along the track lines indicate intervals of approximately one hour.

or more totaled 219.5 hours and covered 258 nautical miles within the southern California Bight (Figs. 1 and 2). Individual activity and depth profiles for seven of the striped marlin tracked are shown in Figure 3.

Summary of Striped Marlin Tracks

SM82-1. This 55-kg (120 lb) fish was caught on an artificial lure trolled from the tracking vessel 28 miles southwest of Point Loma, San Diego, on September 22, 1982. This marlin was brought to the vessel in 23 minutes, tagged just below the dorsal fin, and released at 1130 hrs in excellent condition. It immediately descended to 25 m (80 ft) and moved north 1.5 nm in the next hour. The fish continued traveling north at a depth of 8 to 10 m (26 to 32 ft) for three more hours. It became relatively inactive at sunset, until shortly after 2100 hrs when it made a short dive to 30 m (100 ft) and began moving west to southwest at about 1.0 knot (kt). The fish stayed at 5 to 10 m (16 to 32 ft) and continued in the same westward direction for the next 17 hours. It made four dives to at least 35 m (104 ft) between midnight and sunrise. The fish traveled an average of 1.0 kts while moving 24 nm in the 24-hour track. Its maximum speed was recorded at 2.0 kts during the midmorning hours. The fish remained in 21°C (70°F) water throughout most of the track. Nearly 86% of the tracking time was spent in the well-mixed surface water above 10 m (32 ft). Its deepest dive to 75 m (244 ft) occurred just after 0200 hrs. The temperature was 12.5°C (54.5°F). Only 3% of the tracking time was spent below 40 m (130 ft).

SM86-1. This 50-kg (110 lb) marlin was caught September 27, 1986, on an artificial lure and donated to our research by a tournament participant. It was tagged and released in good condition at 1230 hrs on the Avalon Bank, located six miles east of Avalon, Santa Catalina Island. This fish remained within 5 m (16 ft) of the surface as it began moving south. The fish continued south for 37 nm at an average speed of 1.5 kts, varying between 0.5 and 3.5 kts. Just after sunset, this marlin descended to 20 m (65 ft) and maintained that depth for 6 hours. Between 0100 and 0400 hrs it made a series of dives between 5 and 30 m (16 and 98 ft). It spent 63% of the tracking period at or above 12 m (39 ft). During the daylight hours, only 10% of its time was below 12 m (39 ft). During nighttime hours, it spent nearly 80% of the time

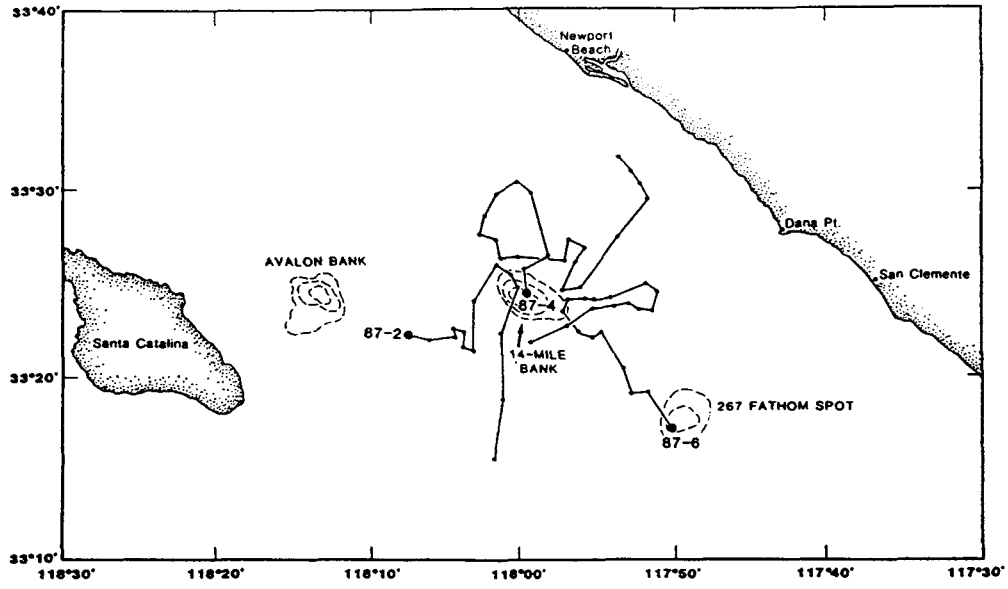

Figure 2. Horizontal movement of three striped marlin showing considerable movement but without leaving the tagging area. Dots along the track line indicate intervals of approximately one hour.

below 12 m (39 ft), with four short descents below 40 m (130 ft). The period of least movement occurred between the hours of 0400 and 0700, although it made two short dives to 40 m (130 ft). The fastest sustained speed was 2.0 and 3.5 kts during the last 6 hours of the track.

SM86-2. This 55-kg (121-lb) fish was tagged and released near the west end of San Clemente Island at 1100 hrs on August 1, 1986. It was tracked for only 13 hours, when the signal was lost due to a damaged hydrophone wire. Replacement of the defective hydrophone took approximately 30 minutes, but efforts to relocate the fish were unsuccessful. This striped marlin traveled 5.5 nm in a southward direction and stayed very near the surface during the tracking period.

SM87-1. This 50-kg (110-lb) fish was donated by a tournament participant and tagged and released off the east end of Catalina Island at 1143 hrs, September 13, 1987. This fish was exhausted when released but otherwise in good condition. It was tracked for just over 3 hours in an eastern direction before it was lost due to a malfunctioning hydrophone. The average speed was 1.2 kts over the period.

SM87-2. This 70-kg (155-lb) marlin was caught on a jig trolled behind the tracking vessel, and was tagged and released in good condition at 1530 hrs near the east end of Catalina Island on September 16, 1987. It was tracked for 22 nm over the next 20 hours. For the first 2 hours of the track it remained within 1 mile from the point of release at a depth of 10 m (33 ft). It then began moving east by northeast at about 1 kt, at a depth varying between 20 and 33 m (65 and 107 ft). Between midnight and sunrise, it passed slowly (0.6 kts) over the top of the "14-Mile Bank," also known as Lasuen Knoll, at a depth of 10 m (33 ft). It turned south in the early morning and maintained 2.3 kts for over 2 hours. Its deepest dive was to 55 m (180 ft) just after sunset. It spent 100% of its daytime hours in the mixed layer, but only 61% of its nighttime hours were in the mixed layer.

This marlin was observed twice during the track. It was seen jumping or "greyhounding" just 4 hours after release, presumably in an attempt to shake the tag off its back. At 1100 hrs the following morning, we observed the fish actively feeding on surface schools of anchovies for over 20 minutes. The fish began swimming south after feeding. The track had to be terminated when the fish entered a military restricted zone.

SM87-3. This 70-kg (154 lb) marlin was donated by a tournament participant 3 miles off the east end of Catalina Island. It was released

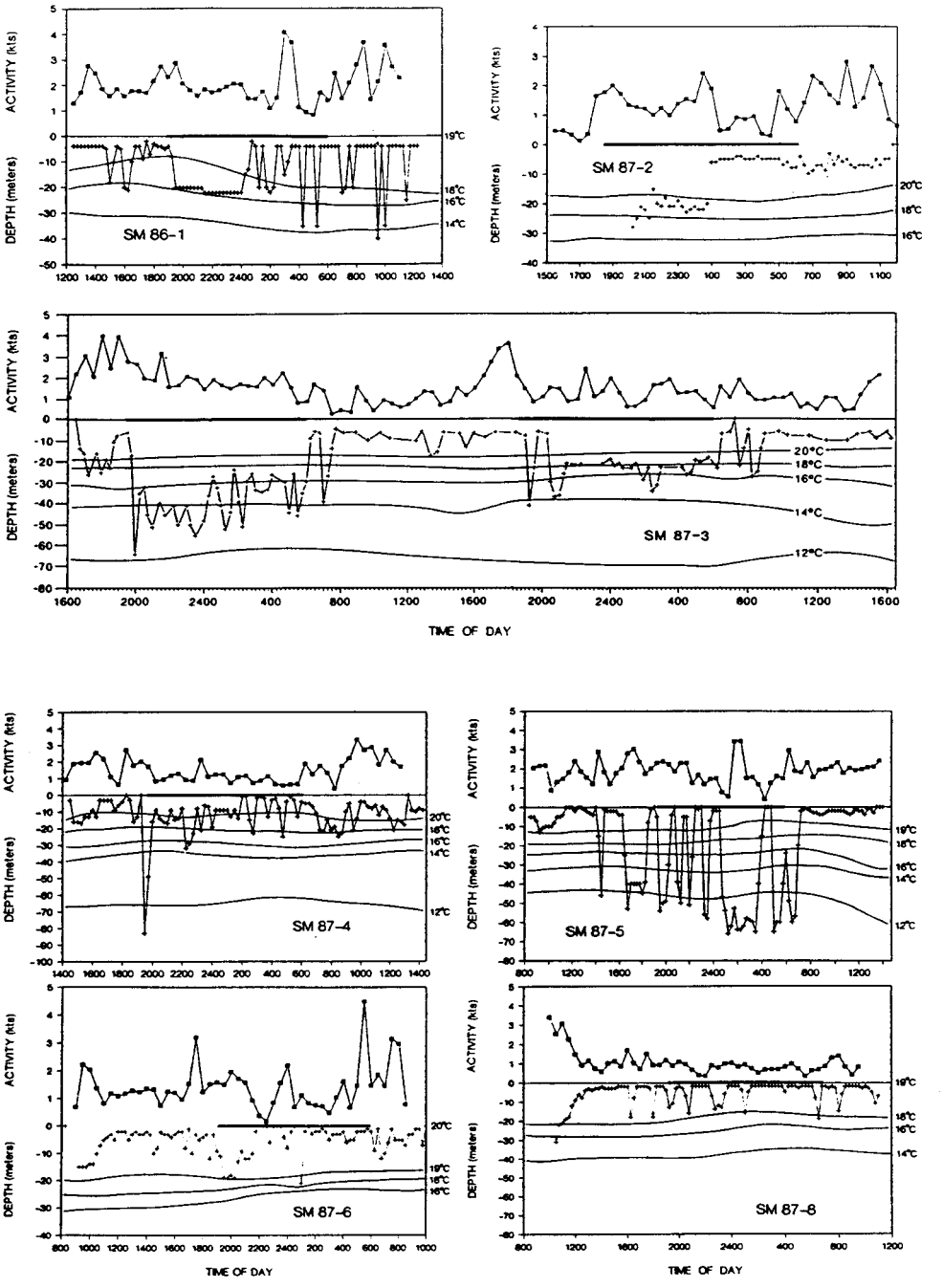

Figure 3. Activity and depth profiles for seven striped marlin tracked at least 20 hours. Activity data (knots) were taken from position data every 15 minutes and smoothed with a running average over 45-minute periods. Depth data were likewise smoothed over 15-minute periods to accommodate computer graphics and may not indicate precise depths attained by individual fish.

at 1615 hrs on September 17, 1987, and tracked for 48 hours and 57 nm. It began moving northeast at 1.8 kts and then altered course to east at 2100 hrs and remained on this heading until 0400 hrs. It made its deepest dive shortly after sunset (2038 hrs) to a depth of 93 m (305 ft). It returned to a depth of about 40 m (131 ft) within 4 minutes and began making numerous vertical excursions between 25 and 65 m (80 and 210 ft) during the nighttime hours. At sunrise it assumed a depth of 6 to 7 m (21 ft) for the remainder of the day. Horizontal movement decreased to between 0.5 and 1.0 kts during the first 10 hours of daylight and then increased to 3.0 kts in the late afternoon, when the fish began "tailing" (tail seen breaking surface while swimming) down-swell. The fish made two dives to nearly 40 m (131 ft) just after sunset and continued southeast and east at a depth of 20 to 30 m (66 to 98 ft) and speed of 1.0 kt during the rest of that evening. The following morning, it again ascended to a depth of 6 to 7 m (20 to 23 ft). The marlin increased its speed to over 2 kts in the second afternoon and was lost when it began tailing down-swell.

This fish was seen several times during the tracking period. It jumped twice three hours after we began tracking, and jumped again several times the following afternoon. Following this jumping display it was observed "tailing" down-swell. The next morning it jumped several more times and "finned" at the surface for about 20 minutes. That afternoon it was again seen "tailing" down wind. This marlin was most active in the afternoons and appeared least active in early mornings.

SM87-4. This 55-kg (121 lb) marlin was tagged at the "14-Mile Bank" at 1358 hrs, September 15, 1987, and tracked for over 24 hours and 31 nm. After release it descended to 24 m (79 ft) for almost two hours, then ascended to 10 m to 15 m (33 to 49 ft) and began moving to the north at about 1.0 kt. It made a short dive to 90 m (295 ft) just after sunset and then returned to between 20 and 30 m (66 and 98 ft). During the evening it moved west, along a warm temperature front and then southwest and finally south into cooler, 18°C (65°F) surface water. At 2300 hrs, it began moving east at 1.0 kt and continued with several short dives until sunrise. Here it remained inactive for an hour and then proceeded north in the warmer surface waters and within 3 nm of the beach. The time spent between 20 to 30 m (66 to 98 ft) increased during the first hours of daylight. This marlin spent 76.7% of its time below the warm mixed surface layer. It did not appear to spend any more time at depth during the night than it did during the day. At 0700 hrs the fish was observed swimming and feeding with four other marlins. It appeared most active in the early mornings and late afternoons. This fish was lost in the afternoon when it turned down-swell and increased speed.

SM87-5. This 80-kg (176-lb) marlin was donated by a sport fishermen on October 2, 1987, approximately 20 nm southwest of Newport Beach, near a high spot on the local charts called the "267 Spot" (267 fathoms). This was one of the largest marlin tracked and was bait-caught and "tail-wrapped" (the fishing line wrapped around its tail). Although landed tail first and exhausted, it was released at 0827 hrs and tracked for over 30 hours and 44 nm. When released, it descended to 10 m (33 ft) and began moving south at 1.5 kts). In the early afternoon, it reversed its direction and began moving northeast. This marlin made two dives to 55 m (180 ft) in the afternoon.

During the second of these two dives (at 1730 hrs), it approached a commercial drift gill net, of the type used to catch swordfish. The fish approached the net at a depth of 50 m (162 ft), a depth which could have resulted in entanglement. As the tracking vessel neared the buoy line of the net, it appeared that the fish had stopped moving forward. The tracking vessel passed over the top of the gill net, the cork line hanging 5.5 m (18 ft) below. After crossing, the directional hydrophone rotated 180 degrees back in the direction of the net. The marlin was still there. It became evident after a few minutes that the fish was slowly moving on a course parallel to the length of the gill net. The tracking vessel's electrical power failed at this juncture. The signal was lost for 8 minutes while the receiver was connected to an alternate power supply. Immediately after the power was returned, and the signal regained, we discovered the marlin passing the tracking vessel, on its previous heading but at a depth of only 10 m. Apparently, it had been able to detect the presence of the net and, eventually, after a fair amount of hesitation, swam over or under the net. We are unable to say for sure which happened, as the signal and fish were lost during this critical period.

The marlin turned east at sunset and maintained a speed of 2 kts until it encountered cooler

surface water at 2400 hours. After an hour of inactivity, it resumed swimming to the southeast averaging 1.6 kts as it moved along a band of cooler water. In the 4 hours preceding sunrise, it turned south and traveled between 1 and 2 kts while making several dives to 50 and 60 m (163 and 195 ft). Three of these dives lasted from 30 to 100 minutes. Only one dive was made after sunrise and the fish remained near the surface for the remainder of the tracking period. It spent 79% of the daylight hours in the mixed layer above 20 m (65 ft) and 56% of the nighttime hours below 20 m (65 ft). It was observed at the surface the following morning, accompanied by one other marlin, with both their tails protruding above the water's surface.

SM87-6. This angler-donated fish was released in good condition at 0930 hrs on October 4, 1987. The fish remained at 13 m (42 ft) for the first hour as it began moving north. It remained at 3 to 5 m (10 to 16 ft) depth for the next 4 hours, maintaining a speed of about 1.0 kt. It made a 2-hr dive just after sunset that varied in depth between 15 and 24 m (49 and 78 ft). It then ascended to 5 to 8 m (16 to 26 ft), while continuing northeast and toward shore. The fish reversed its direction between midnight and sunrise and moved off shore, remaining very close to the surface. There were several short 1- to 2-minute dives to 14 to 18 m (45 to 58 ft) as it returned to the "14-Mile Bank." This marlin spent a total of 97% of its time in the mixed layer. The fish was seen "tailing" with one other marlin, just before we lost contact with it at midmorning. This marlin was most active in the afternoon and least active in the pre-dawn hours.

SM87-7. This fish was another angler-donated marlin tagged near the "14-Mile Bank" and released at 1030 hrs on October 17, 1987. This fish moved steadily south and southwest while staying in the upper 3 m (10 ft) of water. It jumped several times, at 1.5 hours after tagging. The fish was lost after moving 6 nm in 4.5 hours.

SM87-8. This 65-kg (143 lb) marlin was tagged and released at 1020 hrs just off Dana Point on October 19, 1987. It was judged to be in "fair" condition at tagging, as it had everted and reswallowed its stomach prior to being landed. It descended to 20 m (65 ft) for the first hour after release and then returned to 6 to 10 m (20 to 33 ft) for the following 2 hours, all the while moving at 1.4 kts to the south-southwest. Turning south at 1500 hrs, it continued at 1.0 kt and a depth of 2 to 4 m (6 to 10 ft) with occasional descents to 15 to 18 m (49 to 59 ft) for the rest of the track. The fish remained inactive from 2300 hrs until just after sunrise. This marlin spent 97% of the track in the mixed layer and 77% of the track was spent at less than 10 m (33 ft). It exhibited no depth difference between day and night.

General Behavior of Striped Marlin

No single repetitive behavior was found to be characteristic of all the marlin tracked during this study. It is possible, however, to make a few generalizations about striped marlin behavior in the waters off southern California. These may be classified into three broad categories for discussion: (1) occasional behaviors for which there may be only one or two observed occurrences, (2) periodic behaviors which seem to occur only during predictable times of the day or night and (3) behavioral responses to environmental parameters.

Occasional Behavior

Feeding. Striped marlin are efficient predators and feed on schools of northern anchovies *(Engraulis mordax),* Pacific saurys *(Cololabis saira),* and the jack mackerel *(Trachurus symmetricus),* as well as smaller members of the mackerels and tunas from the family Scombridae (Eldridge and Wares 1974). Two marlin (SM87-2 and SM87-4) were observed feeding during mid- to late-morning hours following the first night of tracking. Each episode lasted for about 20 minutes. Both marlin were observed slicing through balls (surface schools) of anchovies, dorsal fins breaking the surface briefly as they flashed by. These fish appeared to be taking large mouthfuls of anchovies while charging through the bait schools. We did not observe any evidence of the bill being used as a weapon, although our vantage point limited these observations only to surface activity.

On several occasions, following late-night periods of inactivity, a fish would suddenly dive, from the surface to depths as great as 40 m (130 ft), and made rapid changes in direction. We can not be sure if such behavior resulted from the fish being startled by our presence or if this, too, could have been actual feeding. Since none of these fish were subsequently recovered for examination of stomach content, we are left to speculate as to the true nature of this behavior.

Periodic Behaviors

Breezing. On several occasions we observed a behavior from both tagged and non-tagged marlin which has been described by fishermen as "breezing" or "tailing." The first name is derived from the fact that this behavior seems to occur only when the wind is blowing, usually in the afternoon. In the Southern California Bight there usually is an onshore breeze in the afternoon during the summer. The second name describes what the observer actually sees as the fish swims by.

During the afternoon breeze, marlin can be seen swimming rapidly down-wind and down-swell. This is characterized by significantly increased speed and a change in direction to correspond roughly to the wind direction. The fish can be seen swimming down-swell at the leading edge of a wind wave, with the upper portions of their caudal fins protruding from the water. While they can only be seen gliding down-swell for up to a couple minutes at a time, this activity may continue for as long as 4 hours and include occasional dives to 20 m (SM86-1 and SM87-5). Swimming speeds as great as 5 or 6 kts may be sustained for short periods. Not coincidentally, most of the tagged fish which evaded our tracking efforts were lost during this activity. A miscalculation of distance from the fish, or a wrong turn, provided the crew with little time to recognize and correct the error before the fish was no longer within signal range.

Sleeping. During the late night and early morning hours, including the period just after sunrise, some fish went through periods of inactivity which we termed "sleeping" behavior. This is characterized by little or no horizontal movement or vertical excursions beyond 5 to 10 m. During these periods, lasting from one to several hours, the fish would remain motionless, just below the surface of the water. Occasionally at sunrise, the tail and dorsal fin could be seen on non-tagged marlin as well as the tagged fish. All fish displayed some slowing of activity during the night hours, although not all fish went through periods of complete inactivity. One fish (SM87-3) exhibited this behavior between 0800 and 1200 hrs, an exception to the time this behavior was generally observed. One other fish exhibited a marginal form of this behavior. Marlin SM87-4 reduced its activity for 4 hours but made three vertical dives to at least 30 m (98 ft) during the period.

Social behavior. Small aggregations of marlin were observed displaying the behavior we previously described as "sleeping." We noted such aggregations during fishing operations, and on two occasions the tagged marlin joined other non-tagged marlin, forming a small group. Once, while we were tracking it, SM87-4 was joined by three other marlin. Several groups of up to 10 marlin were observed with the tagged marlin. SM87-5 was also joined by one other marlin at 0800 hrs the morning after tagging. While such gatherings were observed only during these early morning "sleeping" episodes, or afternoon breezing activity, commercial swordfish spotter pilots have reported that large groups of striped marlin are often seen just below the surface during mid-day, as well.

Environmental Responses

Horizontal displacement. The horizontal movements of striped marlin in this study fall into two groups. There were those that left the area following tagging (Fig. 1), and others that remained in the same general locality where they were first captured (Fig. 2). Five of the eight fished tracked for 20 hours or longer left the area, swimming on a heading ranging from southeast to southwest. The other three marlin followed paths which reversed course or even crossed over a previous track. We did not find, within our study period, that season played any role in predicting whether a fish would leave the area, although the general movement of all fish in a southward direction suggests that migration may play a role.

Relatively large distances were covered, in all cases, considering the time intervals, ranging from 16 nm to 57 nm. The average speed for all tracked marlin was 1.24 kts and the individual average ranged between 0.75 and 1.54 kts. This compares favorably with the top speed, 1.07 kts, reported by Squire (1987b) for striped marlin tagged with conventional tags off southern California, and recovered between 0 and 60 days later. The eight marlin tracked over 20 hours spent an average of 28% of track time at a speed of less than 1 kt and 17% of their time over 2 kts. None was tracked at greater than 3 kts for more than one hour. The highest speeds were generally recorded between sunrise and noon just before sunset. None had speeds greater than 2 kts during the dark. The hours from midnight to dawn were usually the hours of least activity (Fig. 4).

Marlin SM87-8 was the least active (released

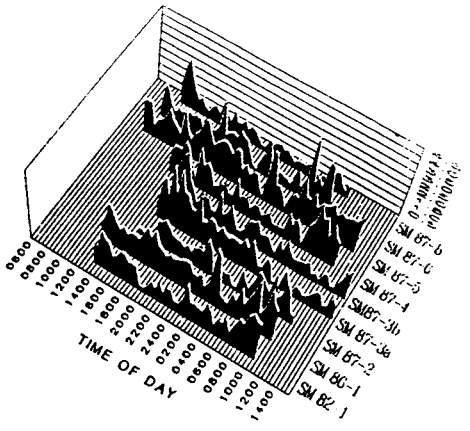

Figure 4. General activity pattern of eight striped marlin tracked for greater than 20 hours. The track of SM87-3 has been split into two 24-hour sections.

in fair condition) and spent nearly half of the tracking time at less than 1 kt and only 6% at greater than 2 kts. By contrast, marlin SM87-5, released in good condition, spent 40% of its time swimming in excess of 2 kts.

Depth preferences. Striped marlin off southern California are surface fishes, i.e., they spend all of their time in the upper, light-penetrating zone. This observation applies despite the fact that they are normally found only in the deep clear offshore waters, where the depth ranges between 400 and 2,000 m (1,300 and 12,000 ft). The greatest depth recorded by a marlin in our study was 93 m (305 ft). This was a short duration dive by SM87-3 and occurred just after sunset on the first tracking day. The second deepest dive was to 90 m (295 ft) by SM87-4. Like SM87-3, this dive occurred just after sunset and lasted only a few minutes.

Few marlin in our study descended to such depths. Marlins SM87-2, SM87-6, SM87-8 spent their entire tracking period in less than 40 m (131 ft). Four marlin (SM86-1, SM87-2, SM87-3 and SM87-5) spent their nighttime hours at significantly ($a = .01$, Kolmogorov-Smirnov) greater depths than their daytime hours. These fish modified their depths just after sunset. All four descended to depths approximately two to two-and-one half times their daytime depths. Marlin SM87-3 and SM87-5 returned to within 10 m of the surface at sunrise, but SM87-2 returned to near the surface at 0100 hrs and maintained that depth throughout the remainder of the tracking period. Marlin SM87-5 exhibited a pattern of extended deep dives during the hours of darkness that was not observed in the others. One particular dive to 70 m (230 ft) lasted 2.5 hours.

This pattern of descending to somewhat deeper depths during the nighttime hours has not been reported from other tracking studies and seems contrary to studies involving swordfish *(Xiphias gladius)* (Carey and Robison 1981), yellowfin tuna *(Thunnus albacares)* (Yonemori 1982), and skipjack tuna *(Katsuwonus pelamis)* (Yuen 1970). In these studies, the fish spent greater portions of time at depth during the day than at night.

Temperature preferences. Striped marlin are predominantly surface swimming fish and treat the thermocline break as a hindrance to vertical movements. Three of our marlin (SM82-1, SM87-6, and SM87-8) spent only 2.9% to 6% of their time below the thermocline. Others (SM87-3 and SM87-5) showed less reluctance to enter the cooler waters below the thermocline and spent from 25.3% to 76.7% of their time below the mixed layer. Dives from the mixed layer to below the steepest portion of the thermocline's temperature gradient were typically of short duration and quite abrupt. The coldest temperature reached was recorded by SM87-3 (also SM87-5) at 10°C (50%), although the time it spent in this 10°C water was less than 3 minutes. This fish spent about half of its 48-hour track in the mixed layer and half below it in water from 14 to 19°C (57 to 66°F). Of the daytime hours, 88% of the time was spent in the mixed layer, whereas only 9% of the nighttime was spent above the thermocline. Marlin SM87-4 spent more time below the mixed layer (76.6%) than any of the others. This was a particularly warm and sunny period and surface temperatures reached 22°C with a shallow 13 m thermocline. A total of 42.1% of the tracking period was spent at 16 to 19°C (61 to 66°F). Marlin SM87-5 spent 54% of its tracking time below the mixed layer. Four hours of this time was spent at temperatures between 10 and 12°C (50 to 54°F) indicating that striped marlin are capable of tolerating cold temperatures for extended periods.

There is, as discussed earlier, a difference between observed depth at night and that of the daytime. These marlin spent daylight hours at and near the surface with only short and infrequent excursions into and below the thermocline. During nighttime hours a greater amount of time was spent in and below the steepest part

of the thermocline. Soon after sunset these fish descended to the thermocline and began making more numerous excursions between the surface and 50 to 70 m. They spent from 50% to 100% of the daytime in the mixed layer, compared to only 13% to 66% time at night. Two marlin, SM87-6 and SM87-8, spent 97% of the time in the mixed layer with no statistical difference between day and night. Temperature data for SM82-1 were insufficient for inclusion.

Sea-surface temperature. Satellite imagery of sea-surface temperatures was available for six of the marlin tracks. These photographs provide evidence of a strong surface temperature influence on horizontal movements of the fish. Just as the fish in this study showed a reluctance to spend much time in the colder water below the thermocline, they demonstrated an even greater preference for remaining in areas with warm surface waters. These photographs (Fig. 5), with the marlin tracks overlaid, illustrate a clear tendency for these fish to skirt around and avoid colder water masses. These marlin remained in water with 18.5 to 20°C (65 to 68°F) surface temperatures most of the time and tended to avoid a cooler body of water. Marlin SM87-3 spent its entire 48-hour track in the 20°C) water. Traveling northeast, SM87-5 encountered cooler water near the coast and turned southeast, traveling along the temperature break, and finally turned south and away from the colder water. SM87-6 moved north until reaching cooler water, where it turned northeast until it reached the cooler band of coastal water. It then turned south and then west to remain in the warm water. Although marlin SM87-4 spent

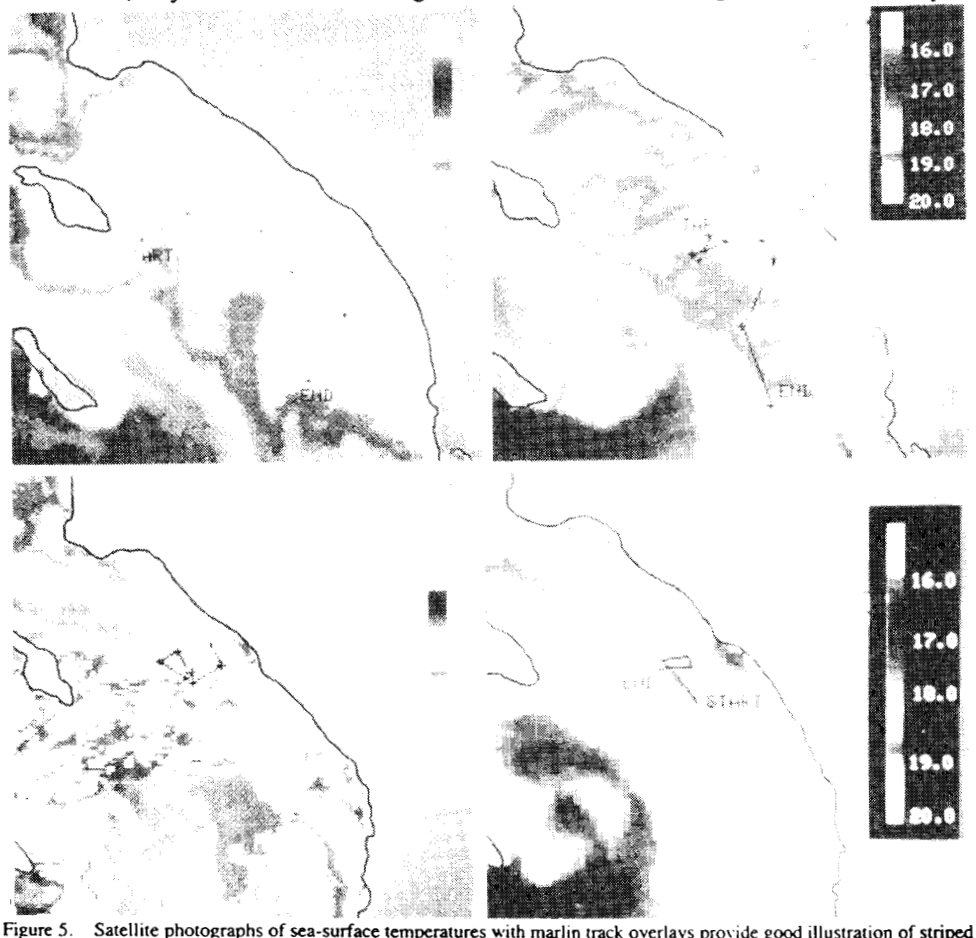

Figure 5. Satellite photographs of sea-surface temperatures with marlin track overlays provide good illustration of striped marlin presence in specific temperature zones.

76.7% of its time below the thermocline, it appeared to avoid the warm (22°C) water until near the end of the track. Here, it entered the warm coastal water and swam within 4 nm of the shore, an unusual occurrence for these largely offshore fish.

It is worthwhile mentioning that four of these marlin were lost soon after entering colder bodies of water, and that one (SM87-4) was lost shortly after entering a warmer surface water. None of these fish made a notable change in depth when entering a new body of water, but all changed their speed. Four slightly increased their speed while SM87-2 and SM87-4 slowed down as they entered water of different temperatures.

The photographs, taken from NOAA satellites on the occasion of each tracking cruise, were not available to us until after the actual cruise date. Thus, after reviewing these images, it is now apparent that several fish may have been lost as a result of sudden changes in course after encountering water masses of differing temperatures. The fish may have reversed direction in these cases, whereas we had assumed that the fading signal was due to the marlin outswimming the tracking vessel. In such a case, we may have increased our speed in the wrong direction.

Tagging Efficacy

We found the striped marlin to be a sturdy fish, tolerant of a great deal of handling. Eight of the twelve striped marlin were judged to be in good to excellent condition after they had been tagged and released. Three were listed as fair due to exhaustion. Although not injured, one (SM87-8) had everted its stomach in an attempt to regurgitate the baitfish and hook. It then re-swallowed it's stomach during capture and before tagging. This behavior is an apparently common method by which striped marlin attempt to expel undesired food items. This marlin was tracked for 24 hours, although it was the least active of the eight fish tracked.

During our cruises, we observed only two fish which died as a result of handling during capture. One of these was "tail-wrapped" and towed backwards for nearly an hour before being brought alongside. The other appeared to be in good condition when it was brought to the boat, but a failed attempt to plant a tag resulted in a 5-minute delay during which the fish was held by its bill against the fishing vessel's swim step. While struggling to free itself, it flailed against the swim step repeatedly, finally resulting in its death. Other fish, notably SM87-1, were held by their bills for 20 minutes before our arrival. Marlin SM87-1 appeared to be completely exhausted but not injured. It was subsequently tagged and tracked for 3.5 hours before an equipment failure resulted in our losing the fish.

Tagging-Induced Trauma

For a period of up to 2 hours following tagging and release, most fish displayed rapid changes in both heading and depth. Seven of the marlin descended to a deeper than normal depth and exhibited a heightened activity level immediately after release. Overall speed of travel varied between 2 and 3.5 kts and depths varied between 13 and 33 m (43 and 108 ft). These episodes lasted from 30 minutes to 2 hours, after which these marlin normally returned to near-surface waters. They then settled into swimming patterns which remained more consistent and generally more subdued for the remainder of the tracks. Three marlin did not exhibit a post-tagging pattern and stayed at 5 m or less for over an hour after release. Two moved moved away at 1 and 2 kts while the third (SM87-7) remained at the tagging site for about 2 hours.

We conclude that this initial burst of activity is a result of trauma induced during capture and tagging, and that the subsidence of this behavior, along with subsequent observations of feeding, sleeping, gathering into groups and "breezing," are good indications that this trauma is quickly overcome.

Summary

During September, 1982, a striped marlin was tagged with a sonic transmitter and tracked by National Marine Fisheries Service (NMFS) biologists, in waters off southern California. This event was the first time this species had ever been tracked. In 1986 and 1987, 11 more striped marlin were tagged with sonic transmitters, also off southern California. This renewed effort was conducted as a joint program of the National Marine Fisheries Service and the California Department of Fish and Game. Eight marlin were successfully followed for periods ranging from 20 to 48 hours and covered 254 nautical miles.

No single repetitive behavior was found to be characteristic of all the marlin tracked during this study, although a few behaviors were common to several fish. The behaviors were classified

into three broad categories including occasional behaviors, periodic behaviors, and those influenced by environmental parameters.

Two patterns of horizontal movement emerged from these tracks. Five of the eight moved predominantly in one direction after tagging, usually south. The other 3 marlin remained in the vicinity where they were first captured. Distances traveled ranged from 22 to 57 nautical miles at an average speed of 1.18 kts.

The greatest activity was observed during the late afternoons, when some of the marlin swam rapidly down-wind and down-swell in a behavior known to fishermen as "tailing" or "breezing". General activity of all fish slowed during the night. Several fish exhibited behavior which might be characterized as "sleeping", the fish remaining motionless, just below the surface, for 1 to 4 hours. This behavior was observed only during the night and early morning hours. Vertical movements during day and night hours showed some consistency among all marlin tracked. These striped marlin showed a preference for warm surface water and remained within the mixed layer more than 85% of the time. Four fish spent their nighttime hours at somewhat greater depths than during the daytime.

Vertical movement tended to be exaggerated and erratic for up to 2 hours after tagging. Beyond this time, the fish assumed a behavioral pattern which remained consistent throughout the duration of the track. We believe that this pattern indicates that the trauma induced by capture and tagging is short lived and tracks of as little as 24 hours should faithfully reflect "normal" marlin behavior.

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*use of trade names does not indicate endorsement by the NMFS or CDFG.

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