Horizontal and Vertical Movements of Pacific Blue Marlin Captured and Released Using Sportfishing Gear*

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Despite the commercial and recreational importance of Pacific blue marlin *Makaira nigricans*, little is known about their biology or behavior. This is due mainly to their large size and pelagic habitat and the difficulty in maintaining them in captivity or observing their behavior in the wild. However, two techniques are available to elucidate their movements: capturing and releasing marlin fitted with identification tags, and tracking of fish carrying ultrasonic transmitters.

The recovery of tagged marlin has enhanced our understanding of the long-term geographical range of individual fish and their minimum rates of travel (Squire 1974, Squire and Nielsen 1983, Bayliff and Holland 1986), and growing interest in the tag and release of marlin by sportfishermen should produce an increasingly precise picture of marlin movements. However, this technique cannot answer questions regarding the vertical movements of marlin, and questions remain concerning both the survival of tagged fish following the trauma of capture and the nature of their behavior immediately upon release.

Fine-scale observations of the horizontal and vertical movements of pelagic fish can be obtained for periods of up to a few days by tracking fish equipped with depth-sensitive ultrasonic transmitters (Holland et al. 1985, 1990; Bayliff and Holland 1986). For billfishes, this technique has been used to track swordfish *Xiphius gladius* (Carey and Robison 1981) and striped marlin *Tetrapturus audax* (Holts and Bedford In press). Similarly, Yuen et al. (1974) tracked Pacific blue marlin but used temperature-sensitive transmitters to monitor ambient water temperature from which depth was later calculated using bathythermograph data. However, this study heightened concerns about tagging mortality rates because three of the five tagged fish died soon after release.

Here we report on the movements of six Pacific blue marlin tracked in the waters around the Hawaiian Islands. Of particular interest were survivorship and behavior of the fish immediately upon release, their patterns of vertical movement, and their overall patterns of horizontal movement. To discern any common patterns of movement associated with one particular area of ocean, three fish were caught and tracked from one well-defined location on the Kona coast of Hawaii. For comparison, two other tracks were initiated several miles away along the same coast, and one marlin was tracked off the Waianae coast of Oahu.

Methods

The ultrasonic tracking techniques employed were identical to those used previously to track yellowfin tuna (Holland et al. 1985, 1990; Bayliff and Holland 1986). The transmitters used in the present study had a nominal life span of 3 days and a maximum working pressure of 500 psi (Vemco, Halifax County, Nova Scotia). The signal, encoding depth information by variable pulse interval, was recorded on audiotapes for later onshore plotting of vertical movements of the fish. Horizontal location was determined every 15 minutes (or more frequently when necessary) by using a combination of Loran-C, radar, visual, and bathymetric fixes. Water temperature was measured by expendable bathythermographs deployed approximately every 3 hours.

Aggregate depth and temperature distributions were calculated (with 10-m and 1°C bins, respectively) as percentages of the total track time spent at any particular depth or temperature. For temperature, the combined distributions of all fish were calculated as the percentage of time spent in the various temperature strata relative to the upper mixed layer.

Each transmitter was attached with a 10-cm length of 130-lb test monofilament to a stainless steel "arrowhead" (~2.75 × 1.75 × 0.1 cm; Fig. 1) modified from the type

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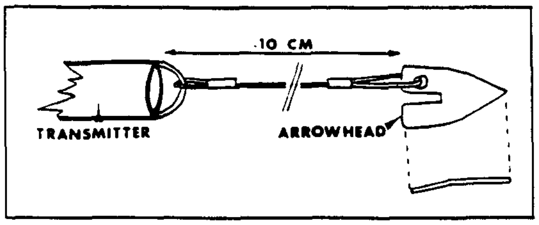

Figure 1
Tag attachment system for Pacific blue marlin. A stainless steel arrowhead, with downcurved tines and central notch to accommodate the prong of the applicator pole, is attached to the transmitter body with a 10-cm length of 130-lb test monofilament crimped in two places.

used by Yuen et al. (1974) and Carey and Robison (1981). The arrowhead fitted into the tip of a standard tagging pole to which the transmitter was loosely bound with rubber bands (Yuen et al. 1974, Holland and Bayliff 1986). The fish was harpooned in the trunk musculature, thereby allowing the transmitter to lie against the surface of the fish alongside the forward half of the dorsal fin. Once the transmitter was attached, the fish was released by cutting the leader, leaving the hook in place.

Fish were caught by surface trolling with artificial lures and standard sportfishing rods and reels. Two of the fish were caught on the tracking research vessel *Kaahele'ale*, and four were caught by teams participating in the 1988 and 1989 Hawaii International Billfish Tournaments (HIBT). In these latter cases, the transmitter and applicator pole were passed to the anglers' vessels during the fighting of the fish. Crew members then tagged the fish while the tracking vessel stood by ~100 m away. Once the fish had been released, tracking began.

To replicate tracks from one well-defined area, three tracks were initiated on the fishing grounds off Keahole Point, Hawaii. This is an area approximately 5 nautical miles (nmi) long and 2 nmi wide that is renowned for high catch rates of marlin during certain periods of the summer. For comparison, two other tracks were initiated from locations ~12 nmi south of the Keahole grounds, and one fish was tracked off Barbers Point, Oahu.

Results

Six Pacific blue marlin were tracked. The three Keahole fish were all caught within a 1-nmi radius over a span of 19 days in 1988; one track was 24 hours, and two were of 42 hours duration each (Fig. 2). In 1989,

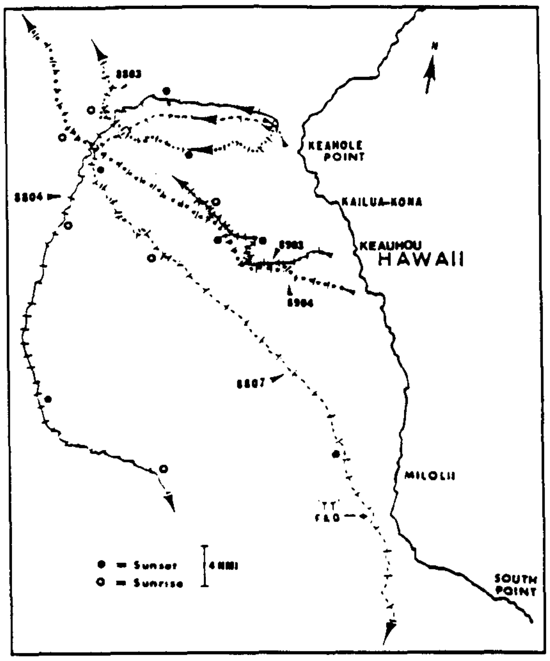

Figure 2
Horizontal movements of five Pacific blue marlin tagged off the Kona coast of Hawaii: three off Keahole Point and two off Keauhou. Lines perpendicular to the tracks represent hourly positions.

over a period of 4 days, two marlin were tracked from starting points ~4 nmi apart off Keauhou and were tracked for 26 and 29 hours (Fig. 2). The Barbers Point fish was tracked for 7 hours. Thus, all fish survived for at least 7 hours after release, and there is no reason to believe that any of the fish subsequently died as a result of the capture and tagging procedure.

Synopsis of tracks

Fish 8710 (weighing ~150 kg) was caught on a single-hooked artificial lure trolled behind the tracking vessel *Kaahele'ale* at a location 7 nmi west of Barbers Point, at 0904, 18 October 1987. After a fight time of 30 minutes, the fish was brought to the side of the boat. The fish was cleanly hooked through the bill and was immobile. The transmitter was embedded dorsolaterally, about a third of the way back along the dorsal fin. After release, the fish glided downwards and away from the boat and swam away on a southwesterly (offshore) course, which it maintained for the duration of the track. After 7 hours the fish was lost while at the surface. Data on the rate of horizontal movement for

Table 1

Rates of horizontal movement of captured and released Pacific blue marlin off Hawaii.

Track ID	Duration (hr)	Average speed (km ± SD) Day	Night	Total	First hour
8710	7.0	1.21±0.27	NA	1.21±0.27	1.50
8803	24.0	1.48±0.31	1.37±0.32	1.43±0.30	1.20
8804	42.0	2.04±0.43	1.78±0.37	1.90±0.42	3.25
8807	42.0	2.25±0.67	2.09±0.67	2.18±0.65	3.25
8903	26.0	0.95±0.54	0.65±0.36	0.83±0.49	1.80
8904	29.0	1.62±0.37	1.68±0.39	1.65±0.37	3.00

this fish and the other five marlin are summarized in Table 1.

In terms of vertical behavior, this fish dove when released and spent the next 4 hours in the top 3 or 4 degrees of the thermocline at depths varying between 50 and 70 m. The fish then moved closer to the surface, spending 92% of the last 3 hours of the track within the surface mixed layer, moving between the surface and 35 m.

Fish 8803 (60 kg) was caught and tagged 2 nmi off Keahole Point at 1120, 8 August 1988, by a team participating in the HIBT. The fish was fought for ~20 minutes and described as tired but in good condition when released by the anglers. This marlin moved steadily west for ~12 hours before curving north during the night (Fig. 2). The fish was moving northwest when the track was terminated after 24 hours because of deteriorating sea conditions. The vertical movements of this fish (Fig. 3A) had a consistent "floor" where

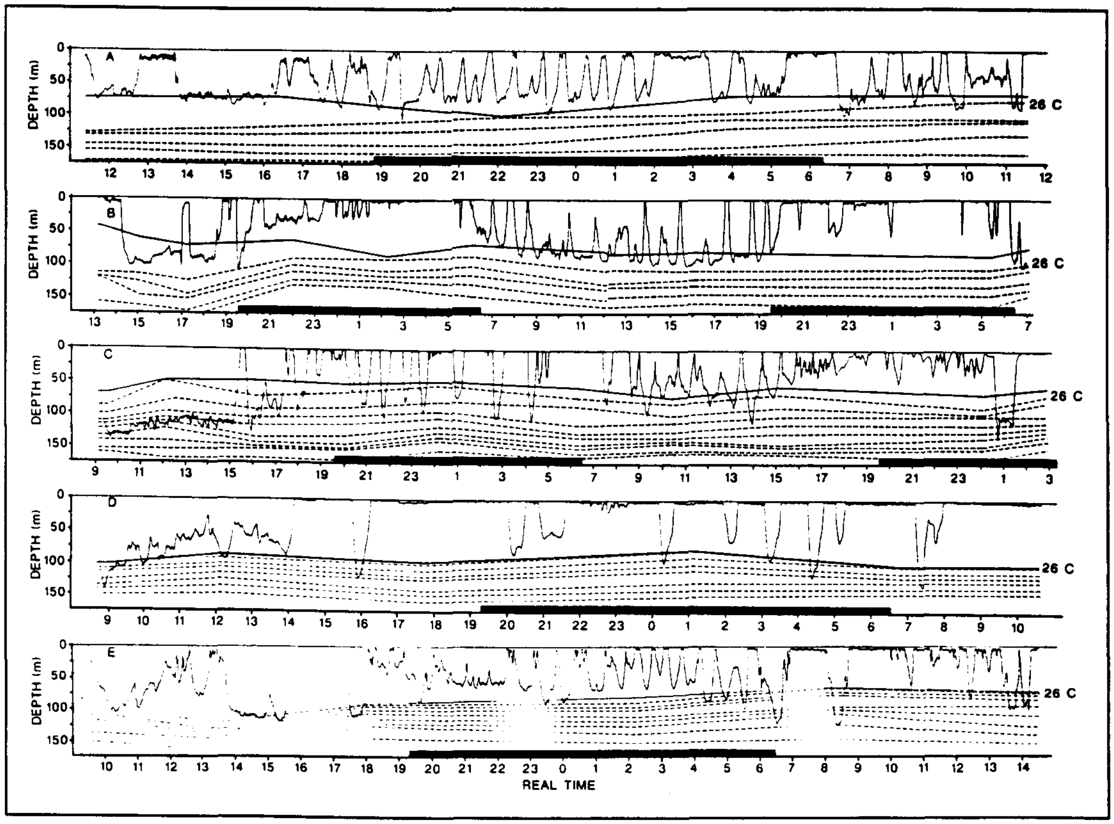

Figure 3

Vertical movements of marlin tracked off Keahole Point and Keauhou, Hawaii. A = fish 8803; B = 8804; C = 8807; D = 8903; E = 8904. Solid horizontal line represents the sharpest inflection in water temperature at the bottom of the mixed layer, whereas dashed horizontal lines represent 1°C isotherms, starting at 1°C below surface temperature. Horizontal bars represent nighttime.

the surface mixed layer met the top of the thermocline at depths varying between 75 and 100 m. During the daytime, the fish moved in and out of the top of the thermocline, with occasional excursions towards the surface; during the night, movements were more completely confined within the mixed layer with more time spent very close to the surface.

Fish 8804 (also estimated to weigh 60 kg) was caught and tagged by an HIBT team at 1310, 11 August 1988, 3 nmi off Keahole Point. Fight time and release condition were similar to fish 8803. After an initial, brief movement towards shore, this fish also proceeded directly west for about 8 hours before curving southward after sunset on the first night (Fig. 2). This direction was maintained all day during the second day until after sunset when it turned more shoreward. However, a southerly course was resumed after sunrise of the third day. The track was terminated after 42 hours.

The daytime vertical movements of this fish were focused around the interface between the mixed layer and the thermocline. From that depth (around 90 m) intermittent excursions were made to the surface. Nighttime distribution was shifted markedly towards the surface (Fig. 3B).

Fish 8807 was caught by the *Kaahele'ale* at 0900 on 27 August 1988, 3 nmi off Keahole Point. The fish, which was fought for 35 minutes, was caught using an artificial lure with a single hook that lodged in the base of the marlin's bill. The fish, weighing in excess of 160 kg, was completely immobile and floating belly-up at the side of the boat when the transmitter was attached near the midline in line with anterior insertion of the anal fin.

When the leader was cut, the fish sank slowly upside down under the boat but, after ~30 seconds, righted itself and began to swim slowly downwards. During the next hour, the fish traveled 3.25 nmi and, as with the previous two Keahole fish, headed steadily west, in this case for 7 hours. After sunset, the fish slowed and assumed a southeasterly course which it retained for the remainder of the track. After sunset on the second night, the fish returned close to the island and briefly visited fish aggregating device (FAD) TT off Milolii (Fig. 2). The fish was lost in rapidly deteriorating sea conditions off South Point, Hawaii, after 42 hours of tracking. At this time, the fish appeared to be continuing in a southerly direction.

Immediately upon release, this fish descended into the uppermost 2 or 3 degrees of the thermocline, where it remained for 6 hours as it swam steadily offshore. Upward excursions towards the surface started 3 hours before sunset, and movements on the second day were mostly in the thermocline-mixed layer interface with frequent upward movements, some of which reached the surface. As with the other Keahole marlin, nighttime distribution was shifted towards the surface, with considerable amounts of time spent at the surface (Fig. 3C).

Fish 8903, weighing ~75 kg, was caught and released 3 nmi off Keauhou Bay by a team in the 1989 HIBT. The fight time was ~20 minutes and the fish was lively when the transmitter was attached. Immediately upon release, the fish headed offshore for 5.5 hours before turning north (Fig. 2). This initial deviation in direction occurred ~11.5 nmi offshore and coincided with the marlin's first movement to the surface from the top of the thermocline, where it had been since the initial release (Fig. 3D).

Compared with other fish tracked in this study, this fish spent large amounts of time swimming slowly very close to the surface, often with the tips of its dorsal and caudal fins protruding above the surface. Although this "lazy" surface behavior is not uncommonly observed by fishermen, this was the only fish to demonstrate this behavior in the current study. The track was terminated after 24 hours, with the fish continuing to swim slowly at the surface in a northwesterly direction.

Fish 8904, also weighing ~75 kg, was caught and released by an HIBT team at a location ~2 nmi offshore of Kealakekua Bay, after a 36-minute fight. This fish also ran west (for ~6 hours) to a point 11.5 nmi offshore, at which time contact was lost for ~2 hours. When relocated, the fish had adopted a northwesterly course which it maintained for the remainder of the 29-hour track (Fig. 2). Vertical movements were similar to those of other fish, being largely constrained by the top of the thermocline and the surface, and averaging closer to the surface at night than during the day (Fig. 3E).

Temperature and depth distribution

Pooling the data from all six fish indicates that 82% of the daytime and 97% of nighttime distribution occurred in the mixed layer and top 2 degrees of the thermocline. In terms of depth, approximately 36% of the daytime and 60% of nighttime was spent between the surface and 30 m, the rest of the time being spent at greater depths (Fig. 4).

Discussion

Although the sample size reported here is quite small, these data represent a significant increase in the number of Pacific blue marlin tracked. Also, several aspects of the behavior of these marlin show remarkable consistency.

For instance, the behavior of all the fish tracked in this study was strongly influenced by the interface

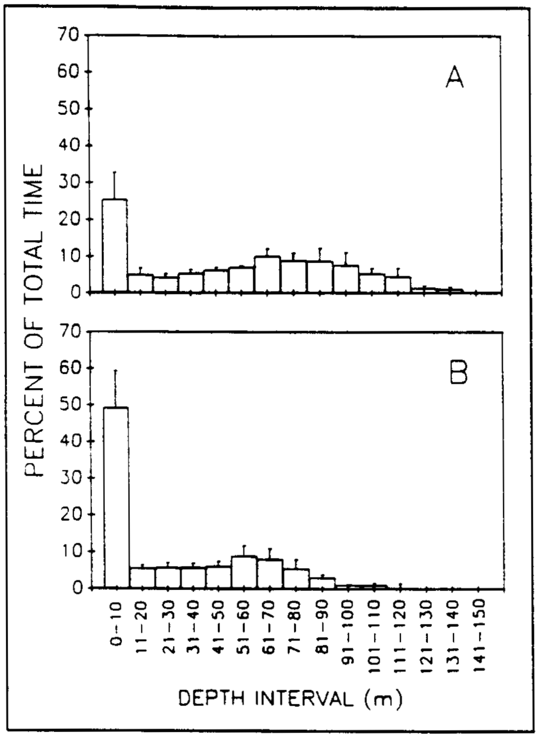

Figure 4
Aggregate depth distribution of six Pacific blue marlin off Hawaii during daytime (A) and nighttime (B).

between the surface mixed layer and the top few degrees of the thermocline, even though the depth of this interface varied between tracks. Unlike yellowfin tuna *Thunnus albacares*, which are also associated with this feature (Carey and Olson 1982, Yonemori 1982, Holland et al. In press), the marlin only rarely dove below the top of the thermocline. Thus, a major portion of the distribution of these marlin was bracketed by the surface and the bottom of the mixed layer. This behavior—not making deep dives, and spending most time in the mixed layer and upper thermocline—is similar to that of striped marlin tracked off California (Holts and Bedford In press), but differs greatly from that of swordfish which make frequent deep dives into cold water (Carey and Robison 1981). Compared with the striped marlin tracked off California, most of the blue marlin in Hawaii spent a relatively small amount of time very close to the surface. This may be due to the shallower depth of the thermocline off California (15–25 m) compared with Hawaii (35–90 m). With the exception of fish 8903, which spent an atypical amount of daytime very close to the surface, the marlin tracked in the present study moved closer to the surface at night. This differs from the striped marlin data, but is consistent with the behavior reported for skipjack tuna *Katsuwonus pelamis* (Yuen 1970), swordfish (Carey and Robison 1981), yellowfin tuna (Yonemori 1982, Holland et al. In press), and bigeye tuna *T. obesus* (Holland et al. In press).

Upon release, all six marlin dove into the upper layers of the thermocline and remained there for several hours. Onset of consistent upward excursions from the thermocline appeared to represent the end of the post-capture recovery period, usually between 4 to 6 hours. The recovery period was initiated by comparatively high-speed swimming, with four of the six fish travelling farther in the first hour following release than at any other time during the tracks. Because marlin are obligate ram-ventilators, these fish may be swimming fast enough to repay the anaerobic metabolic debt incurred during the fight, but not so fast as to acquire new debt. The fast speeds of the first hour are even more remarkable considering that at least two of the fish appeared to be completely exhausted when tagged and released. Holts and Bedford (In press) also report deeper than normal depths and heightened activity levels immediately upon the release of striped marlin.

With the exception of slow-moving fish 8903, the range of swimming speeds of individual fish in our study (1.2–2.18 kn) are similar to the blue marlin (1.2–1.9 kn) of Yuen et al. (1974). This is somewhat faster than the striped marlin speeds (0.75–1.45 kn) observed by Holts and Bedford (In press). In the present study, most of the fish swam slightly slower at night than during the day.

One of the most remarkable features of the current study is the consistent direction of movement displayed by the marlin in the first several hours of each track. Even though the three Keahole fish could have moved anywhere within a 240°-sector without running into land, all three swam along parallel westerly courses that took them directly offshore. Also, initial deviation from these parallel tracks occurred in the same general area ~12 nmi offshore. Similarly, both fish caught off Keauhou swam offshore for ~6 hours along almost identical paths, and both made their first major directional changes between 11 and 12 nmi offshore. This point in these two tracks was separated by only ~0.5 nmi, even though the release sites were over 4 nmi apart. The previously longest track of a Pacific blue marlin (22.5 hours; Yuen et al. 1974) was also initiated off Keauhou, and also commenced with a 7 nmi-movement offshore, as did the Barbers Point marlin tracked in the current study.

These results suggest that direct movement offshore may be a common response to the trauma associated with capture and release. The first major horizontal direction changes often coincide with changes in vertical behavior and may represent the end of the recovery period.

Previous blue marlin tracks, and those acquired in the present study, share the characteristic of essentially straight or slowly curving azimuths. This contrasts with the movements of nearshore tuna (Yuen 1970, Holland et al. In press) and swordfish (Carey and Robison 1981) which frequently display cyclical diel movements that bring the fish back to their starting points. If Pacific blue marlin have such a pattern in Hawaiian waters, the cycle time for this behavior is longer than any of the tracks so far obtained. At present, the impression is that these animals swim along straight or slightly curving courses as they move through the area.

It is difficult to explain the difference in tagging mortality between this study in which no fish died and the previous one in which three of the five blue marlin died (Yuen et al. 1974). Holts and Bedford (In press) also report that none of their 11 striped marlin died as a result of tagging trauma. Their results, and the results reported here, support the practice of releasing marlin caught on artificial lures by sportfishing techniques, even if the fish are apparently exhausted.

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