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Research Article

Horizontal and vertical movements of sailfish (*Istiophorus platypterus*) in the Arabian Gulf, determined by ultrasonic and pop-up satellite tagging

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Abstract Small-scale movement behavior of sailfish (*Istiophorus platypterus*) in the Arabian Gulf was evaluated between April 2002 and April 2004 using temperature- and pressure-sensitive ultrasonic telemetry. Of nine sailfish tagged, eight were successfully tracked for periods ranging from 3 h 33 min to 52 h 6 min. Total tracked distances ranged from 5.5 to 78.7 km, while maximum linear displacement from tagging locations ranged from 4.6 to 37.0 km. Average speed based on vessel positioning ranged from 0.29 to 0.75 m s^{-1}. The cumulative mean vertical distributions showed that 84.3% of time was spent above 10-m depth, even though water temperature altered little with increased depth. Data from two pop-up satellite archival tags deployed in 2002 were used to compare time spent at 5-m depth intervals with data from ultrasonic tags. There was no significant difference ($P<0.05$) in preferred depths between ultrasonic and pop-up tags for day or night, suggesting that the sailfish in this study recovered from capture stress and returned to normal behavior in relatively short times. Information on vertical and horizontal distribution can reveal preferential habitat that benefits fishery management practices relating to time/area closures, as

well as determining optimal gear selection that reduces incidental bycatch and promotes conservation of sailfish in the Arabian Gulf.

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Introduction

The sailfish, *Istiophorus platypterus* (Shaw and Nodder 1792), is found worldwide, predominantly in coastal tropical and subtropical waters (Nakamura 1983). It is the only member of the billfish families (Istiophoridae, Xiiphidae) normally inhabiting the Arabian Gulf (also known as Persian Gulf, hereafter referred to as Gulf). Sailfish are seasonally present within the Gulf waters of the United Arab Emirates (UAE) from November until April. Sailfish aggregations are targeted, predominantly for tag and release, by recreational fishers along the coasts of Abu Dhabi and Dubai. Recaptures of fish tagged with conventional tags show a springtime migration leading northwest, further into Gulf territorial waters of Iran where incidental capture in gillnets occurs (Hoolihan 2001; 2003). Tag recapture data and evidence of genetic isolation (Hoolihan et al. 2004) indicates that this population completes its life cycle within the Gulf. Knowledge of movement, behavior, and preferential habitat of Gulf sailfish is needed for developing sound conservation management plans and is particularly beneficial when taking into consideration issues such as gear selectivity and time/area closures.

The advent of electronic tagging has facilitated understanding of fish migration, preferential habitat, species-specific behavior, post-release survival and fishing gear selectivity. Ultrasonic telemetry was first used to track sailfish in order to understand post-release survival in recreational fishing (Jolley and Irby 1979). Since then ultrasonic tracking studies on striped marlin (Holts and Bedford 1990; Brill et al. 1993), blue marlin (Yuen et al. 1972; Holland et al. 1990; Block et al. 1992a, 1992b), black marlin (Pepperell and Davis 1999), and swordfish (Carey and Robison 1981; Carey 1990) have helped define behavioral traits such as swimming speeds, the preference for the mixed layer by marlins, and the diel vertical movements exhibited by swordfish.

The present study evaluates small-scale movements and behavior for the purpose of understanding Gulf sailfish habitat preferences, which can benefit future conservation management practices. Ultrasonic telemetry is used to determine vertical and horizontal movements of nine tracked sailfish.

The results were compared with data from two pop-up satellite archival tags (PSATs) previously deployed.

Materials and methods

Ultrasonic tagging

Tracking was conducted in the southern Gulf waters of the UAE adjacent to the cities of Abu Dhabi and Dubai (Fig. 1) using a 10-m sportfishing vessel. The study area is characterized by water depths of less than 30 m with sandy substrate and bathymetric variation of a few meters.

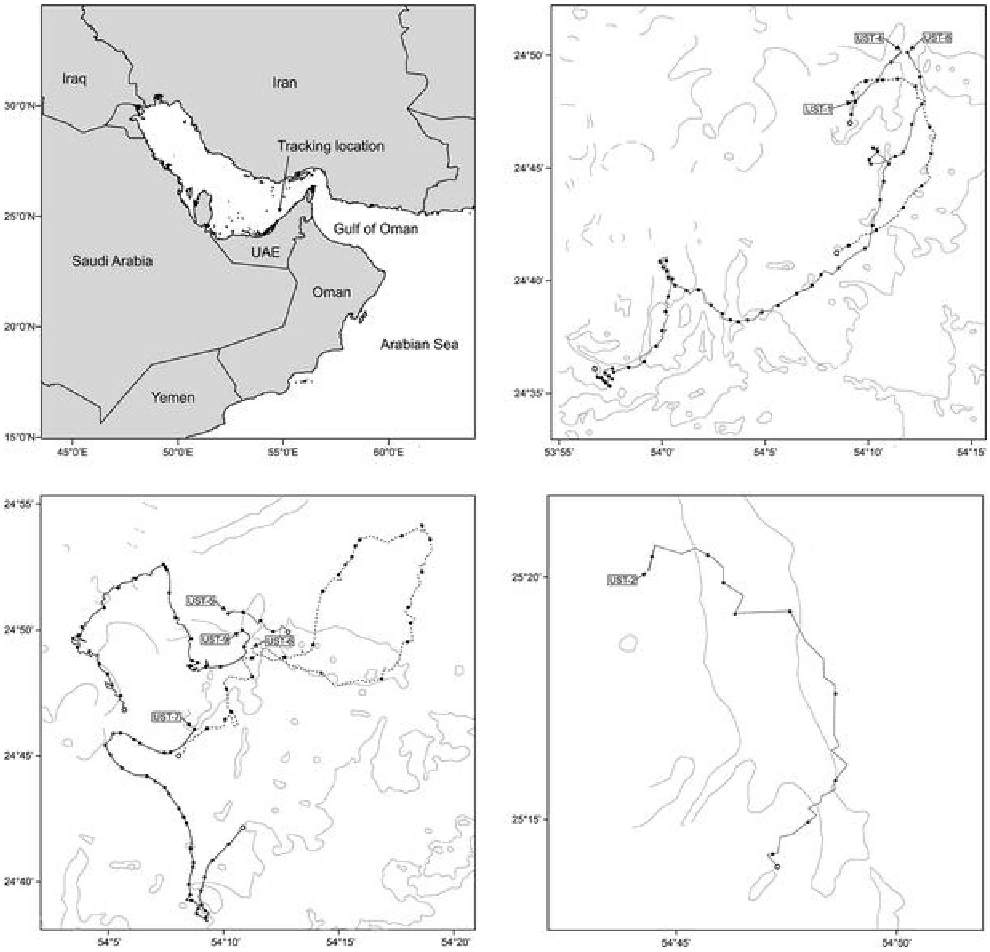

Fig. 1 Regional map and eight ultrasonic tracks for sailfish in the Gulf. Ultrasonic tag (UST) *labels* designate start of each track and *unshaded circles* the end. *Shaded circles* designate position on the hour

Conventional rod and reel techniques using trolled dead and live baits were employed for catching sailfish. Captured specimens were manually restrained (until calm) while alongside the vessel by grasping the bill, then lifted aboard through a transom door and double tagged with a conventional and an ultrasonic tag. Conventional tags (FIM-96, Floy, Seattle, Wash., USA) with nylon darts were inserted into the epaxial muscle. Ultrasonic tags (USTs) were attached by either one of two methods (Table 1). The first method used a 33×8×0.5-mm stainless steel "H" dart infixed into the epaxial muscle with a 15-cm-long 300-lb test monofilament tether. The second method used an anchor/tether system attached to the sheath of the anterior dorsal fin. The anchor system consisted of a closed loop of 80-lb test monofilament (12 cm length) tied to a ~20-mm-diameter plastic clothing button. A needle was used to pass the monofilament medio-laterally through the fleshy ridge forming the dorsal fin sheath, with the button acting as an anchor within the sheath. Extension and retraction of the dorsal fin was not affected. The monofilament protruding from the lateral side was then simply looped around the transmitter. This method eliminated the need to insert a large steel dart into the body muscle and made possible the shedding of all foreign parts following a short transmitter battery life (~21 days). Onboard tagging procedures were completed in 30–45 s for both methods. Times from hooking to boating fish were not recorded, but were generally of the order of around 15 min per fish.

[Table 1 will appear here. See end of document.]

Vertical and horizontal movements were monitored with V16TP ultrasonic transmitters (Vemco, Halifax, NS, Canada) measuring 16×106 mm and weighing 42 g out of water. Operating frequencies ranged between 51 and 84 kHz with pulse coded signals of depth and ambient water temperature transmitted every ~3 s (sensitivity =0.1 m, 0.1°C). Transmitter signals were received by a Vemco VR28 Controller (receiver) coupled to a Vemco V41 four array directional hydrophone system housed in a V-Fin depressor wing towed astern at approximately 3–4 m depth. Data were stored to a notebook computer operating Vemco Track28 software linked directly to the VR28 controller. Onboard GPS data were directed by NMEA 0183 input to the notebook computer allowing automatic location update to the Track28 software files at ~6- to 12-s intervals. All tracking was done in real time and vessel GPS location was assumed to be virtually identical to the tracked sailfish.

Data processing included filtering to remove spurious values and application of linear interpolation, based on comparing the previous two data points, to account for missing records. Interpolation at 15-s intervals was used to improve the graphical presentation of individual depth and temperature profiles. Horizontal speed values were calculated based only on linear displacement of the vessel between GPS points. The tracking techniques did not allow for measuring small-scale (~50 m) horizontal movement. These small weaving movements, as well as vertical displacement, were not factored into speed calculations.

Measurements of water and bathymetry parameters were conducted hourly for some tracks (UST-6, 7, 8, 9). A Hydrolab (Austin, Tex., USA) Datasonde4 multiprobe water monitor and Surveyor 4 data recorder were used to measure water temperature, salinity, conductivity, pH, and dissolved oxygen at 5-m intervals, as well as maximum depth. Maximum depth values were compared with vessel echo-sounder readings and bathymetry charts to compile a seafloor depth profile, which was superimposed on vertical movement plots of individual tracks. The mean aggregate depth distributions were distributed in 5-m bins as percentages of total track time using all data except fish number UST-3, which died shortly after release. Illustration of horizontal movement patterns were plotted using ArcMap 8.1 (ESRI, Redlands, Calif., USA) GIS software program (Fig. 1).

Pop-up satellite tagging

Two PSATs manufactured by Wildlife Computers (Redmond, Wash., USA) were deployed on sailfish in 2002. The pop-up tags archived depth and ambient water temperature at 1-min intervals (Table 2). PSATs were tethered with 400-lb monofilament line to a stainless steel H dart anchor (55×12×1 mm) anchored in the epaxial muscle. Capture and tagging procedures were similar to those described for ultrasonic tagging. PSAT depth and temperature data were processed identically to USTs for removal of spurious data and interpolation of missing records, with the exception that interpolation was conducted at the recorded time intervals of 1 min rather than 15 s. For the purpose of comparing vertical distribution of ultrasonic and PSAT tagged sailfish, 5-m depth profiles of the ultrasonic tags and the initial 7 days (post-deployment) for the PSATs were evaluated. The 7-day period was considered an adequate time by which to compare post-release behavior of PSAT and ultrasonic tags. A more detailed analysis of the complete PSAT dataset will be presented in a future paper.

[Table 2 will appear here. See end of document.]

Results

Between April 2002 and April 2004 nine sailfish were captured and released with ultrasonic tags in the Arabian Gulf approximately 40 km north of Abu Dhabi (*n*=7) and Dubai (*n*=2) (Fig. 1). One fish released off Dubai (UST-3) died shortly after release. The other eight fish were tracked for periods ranging from 3 h 33 min to 52 h 6 min (Table 1). All tracks were terminated voluntarily due to limits on vessel time with the exception of UST-1, for which signal contact was lost. The total distance of individual tracks ranged from 5.5 to 78.7 km, while the maximum linear displacement from tagging locations ranged from 4.6 to 37.0 km (Table 1). The average speed of tracked sailfish, based on vessel positioning, ranged between 0.29 and 1.00 m s^{-1} (Table 1). The cumulative mean vertical distribution of all ultrasonic tags showed 84.3% (SD 12.6) of time was spent above 10 m (Fig. 2). For the four sailfish tracked overnight, 88.1% (SD 8.46) and 70.0% (SD 17.91) of total time was spent above 10 m at day and at night, respectively (Fig. 3).

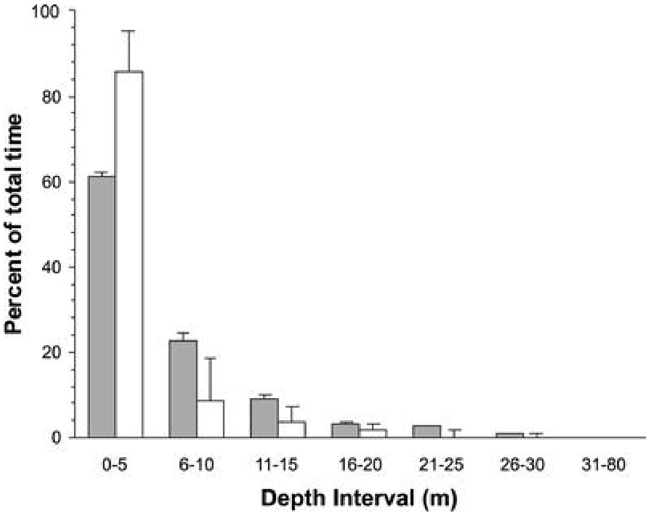

Fig. 2 Cumulative vertical distribution as percent time (mean±SEM) for USTs (*shaded*) and pop-up satellite archival tags (PSATs; *unshaded*) distributed in 5-m bins

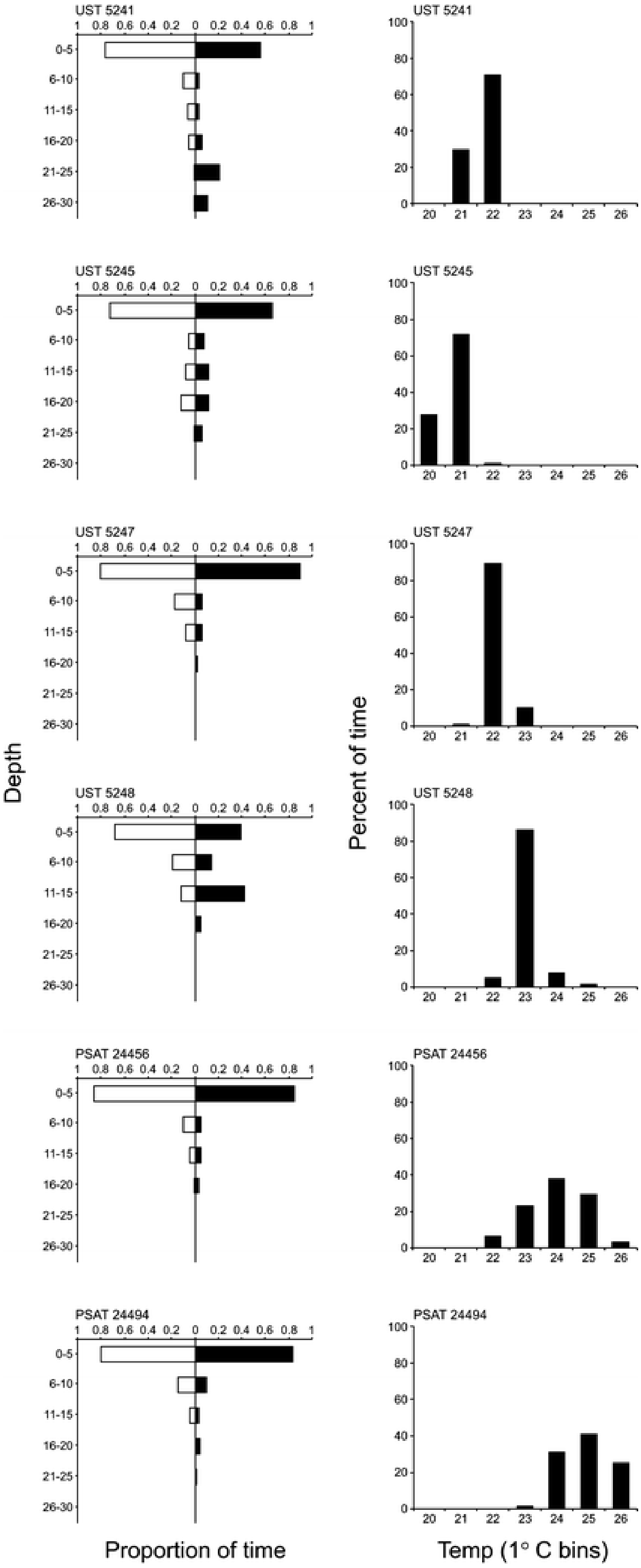

Fig. 3 Comparison of proportion of time at day (*unshaded bars*) and night (*shaded bars*) for USTs and PSATs in 5-m-depth bins (*left*). PSAT data is limited to the first 7 days after deployment. The proportion of total time at temperature in 1°C bins (*right*)

Two PSATs deployed in March 2002 were recaptured by commercial fishers after being at-large for 58 and 66 days, and traveling linear distances of 150 and 543 km, respectively (Table 2). Both tags were returned intact, allowing access to the full complement of archived data instead of summary information routinely provided in a normal pop-up release and data transfer via the Argos satellite system. For the initial 7 days of deployment, the cumulative mean vertical distribution of the two PSATs showed 94.5% (SD 0.99) of time was spent above 10 m (Fig. 2), while the corresponding values for diel distribution above 10 m were 96.3% (SD 1.13) for day and 91.9% (SD 1.89) for night.

A comparison of means for diel 5-m depth bins for the four USTs tracked overnight and PSAT data was conducted using all data for USTs and the first 7 days (post-deployment) for PSATs (Fig. 3). The 7-day limit was used on the assumption that during this period the PSAT tagged sailfish had remained in the vicinity and were subjected to environment conditions comparable to ultrasonically tagged individuals, yet had time to fully recover from the stress and trauma of tagging. There was no significant difference ($P<0.05$) between UST and PSAT diel 5-m bin depth distribution means when tested with Welch's (1938) approximate *t*-test, a method allowing comparison of sample groups with unequal variances.

For the four sailfish ultrasonically tracked overnight, temperature ranged from 20°C to 26°C, of which 90.8% fell within 21–23°C. The temperature for the two PSATs ranged from 22°C to 26°C, of which 70.8% fell within 24–25°C (Fig. 3).

Water sampling indicated thorough mixing of the water column with no evidence of a thermocline (Fig. 4). There was little variation in temperature, pH or levels of dissolved oxygen throughout the water column. Salinity and specific conductivity levels increased slightly at depth. For tracks including water testing (UST 6–9) the cumulative mean values for measured parameters were: pH, 7.84 (SD 0.11); salinity, 41.47 ppt (SD 1.63); specific conductivity, 61.59 mS/cm (SD 2.22); and dissolved oxygen, 5.92 mg/l (SD 0.28).

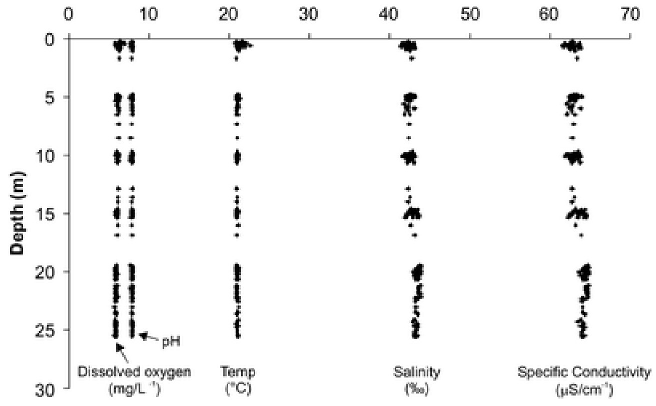

Fig. 4 Example of hourly water profile (UST-7) conducted during tracking

Summary of individual ultrasonic tracks

UST-1 (estimated at 16 kg) was tagged at 0920 hours (Fig. 5) and tracked for 10 h 25 min, spending 94.2% of time above 10 m. It moved in a semi-circular clockwise path 25.4 km in length and 12.4 km linear displacement south of the starting point. Movement was slow for the initial 2 h and then picked up to speeds ranging 0.75–1.1 m s^{-1}. This fish proceeded on a course leading to successive locations characterized by raised topography that are known by recreational fishermen to attract baitfish and sailfish. UST-1 paused for a few minutes at each of these locations, presumably to investigate or pursue prey. Contact with the transmitter was lost at 1945 hours while changing vessel course to avoid an approaching ship. The signal was not relocated and tracking was curtailed. Moon phase was waxing crescent with 27% of disk illuminated.

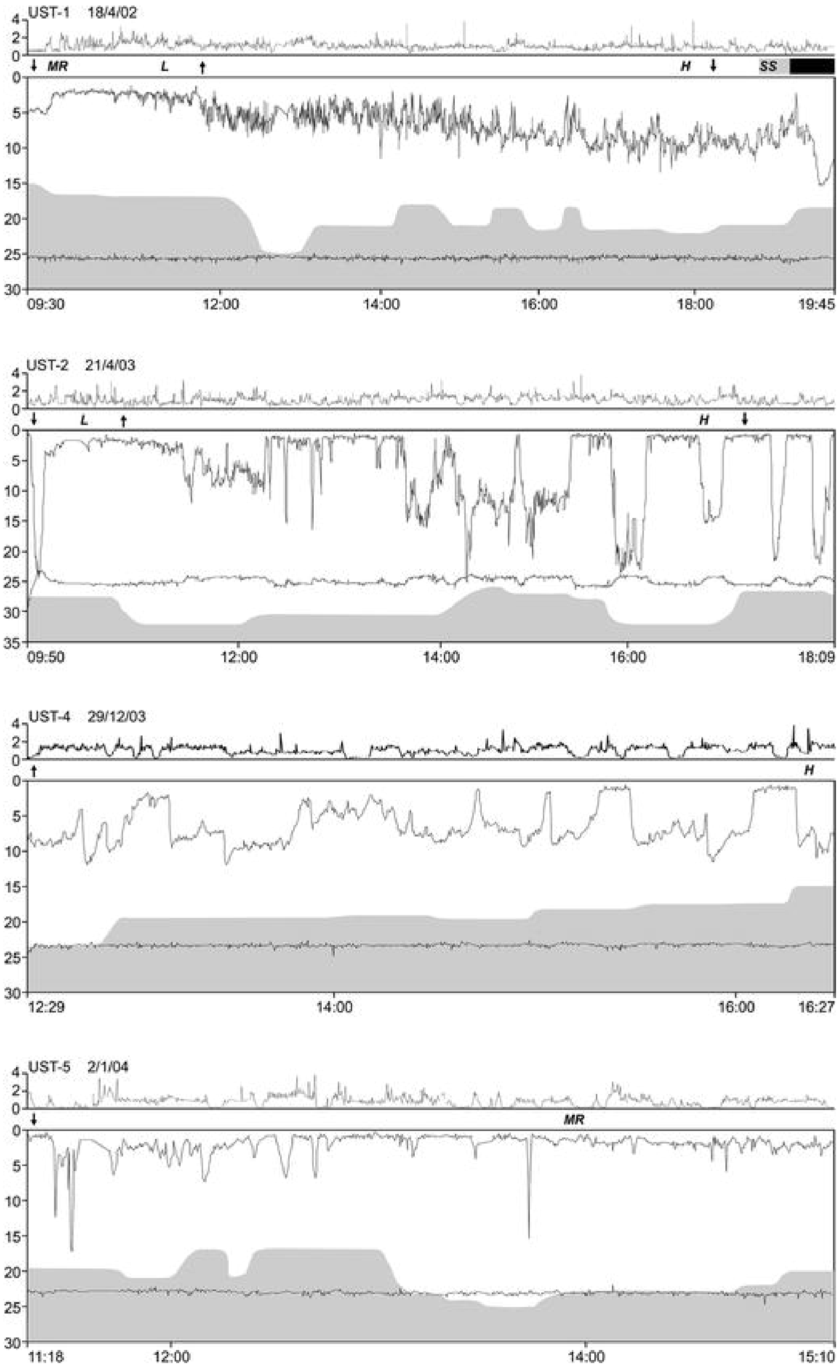

Fig. 5 Vertical tracks, ambient water temperature and speed of UST-1, 2, 4 and 5. The *line plot* in the smaller graphs above the main graphs denote speed (m s^{-1}). The *upper and lower line plots* in main graphs denote depth (m) and ambient water temperature (°C), respectively. *Shading* defines bottom contour. The code in the bar legend between the graphs is: *SR* sunrise, *SS* sunset, *MR* moonrise, *MS* moonset, *H* high tide, *L* low tide, *up arrow* tide flooding, *down arrow* tide ebbing. *Black* indicates night, and *shaded* indicates twilight

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UST-2 (estimated at 18 kg) was tagged approximately 40 km northwest of Dubai (Fig. 5) Tracking began at 0950 hours and continued for 8 h 8 min, with 70.9% of time spent above 10 m. Upon release this fish immediately descended to a depth of around 20 m and remained for 8 min before returning near the surface. Horizontal movement followed a semi-circular clockwise path in a southerly direction (Fig. 1). During the afternoon UST-2 periodically stopped near groups of baitfish (*Sardinella* sp.) and was presumed feeding based on characteristic evasive actions exhibited by the baitfish and surface feeding behavior observed for other sailfish in the immediate vicinity. Total track distance was 22.0 km, and maximum linear distance from the start point was 12.2 km. Moon phase was waning gibbous with 73% of visible disk illuminated.

UST-3 (estimated at 18 kg) was tagged at 1205 hours and died shortly thereafter. For the initial 9 min after release it stayed in the 0- to 5-m depth range and then abruptly sank at the rate of 0.14 m s^{-1} to the seafloor where it remained stationary ~3.5 h until monitoring ceased. This fish moved in an erratic manner immediately prior to death. Moon phase was last quarter.

UST-4 (estimated at 23 kg) was tagged at 1230 hours and tracked for 3 h 33 min (Fig. 5), having spent 93.3% of time above 10 m. The right eye was bleeding from hook penetration during capture. UST-4 initiated a straight course southwesterly for a 7.4-km total track and 7.1-km linear displacement from start point. Patterns of vertical movement were less symmetrical than observed in other sailfish in this study (Fig. 1). Moon phase was waxing crescent.

UST-5 (estimated at 25 kg) was tagged at 1019 hours on 29 December 2004. At this time three sailfish were captured simultaneously. After release of UST-5 an additional 30 min were required to retrieve and release the other two sailfish; meanwhile, UST-5 moved out of signal range. A 1.5-h search failed to detect a signal, so it was decided to capture and track another specimen (UST-4). Just over 4 days later, at 1118 hours on 2 January 2004 a signal was received from UST-5, placing it ~2 km and azimuth of 302° from the original release location. During tracking over the next 3 h, UST-5 slowly returned to the original release location. UST-5 was more surface oriented than other fish tracked in this study, spending 96.7% of time in the upper 5 m (Fig. 5). Total track length was 5.5 km and maximum linear displacement from start point 4.6 km. Moon phase was waxing gibbous with 77% of visible disk illuminated.

UST-6 (estimated at 14 kg) was tagged at 1554 hours and tracked for 24 h 8 min (Fig. 6), having spent 71.1% of time above 10 m. During capture the hook dislodged from the mouth and embedded in the left lateral trunk musculature just above the first anal fin, inflicting some tissue damage but no marked bleeding. This fish appeared quite tired when boated, but still exhibited healthy color and was considered suitable for tracking. The tag was anchored with a plastic button in the sheath of the anterior dorsal fin. Upon release, the fish immediately started moving eastward at a rate of ~0.55 m s^{-1} and altered direction to the north at sundown, then commenced a large clockwise circular track that eventually brought it back to the tagging location at 1000 hours the following morning. During this excursion the fish came to a complete stop at 1938 hours, behaving in a manner suggesting rest or sleep. It remained in this position for ~1.5 h at a depth of 1–2 m drifting with the wind-induced current. When movement resumed, UST-6 initiated an oscillating pattern of vertical movement traveling at depth and near the surface that continued until sunrise (Fig. 6). Total track distance was 61.2 km, while the maximum linear displacement from starting point was 15.5 km. Moon phase was waxing crescent with 8% of visible disk illuminated.

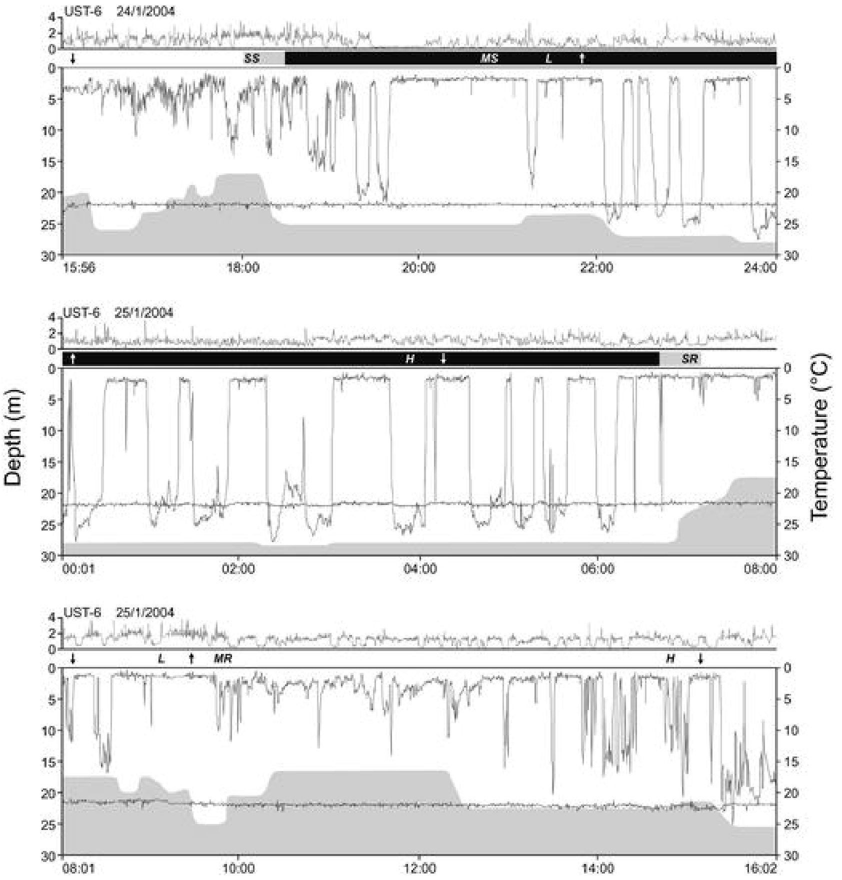


Fig. 6 Vertical track, ambient water temperature and speed of UST-6. Bar legend as per Fig. 1

UST-7 (estimated at 25 kg) was tagged at 0842 hours and tracked for 32 h 13 min (Fig. 7), having spent 76.4% of time above 10 m. During capture it strongly resisted being manually restrained, but appeared in good condition when released. Upon release this fish did not dive deep, but remained in the upper 10 m of the water column and stayed in the immediate area, rather than swimming away like the other fish. It then initiated a counter-clockwise semi-circular route in a southerly direction. Total track length was approximately 34 km and maximum linear displacement from start point was 14.2 km. Compared to the other fish, UST-7 traveled quite slowly and appeared mostly to drift with the current. Generally, the vessel drifted with engines in neutral along with the current and UST-7. The vertical movement (Fig. 7) showed a sinusoidal pattern of periods spent near the surface followed by periods at depth, similar to behavior in other sailfish tracked in this study. At the time of track termination, UST-7 was moving toward the starting point. Moon phase was waxing gibbous with 69% of visible disk illuminated.

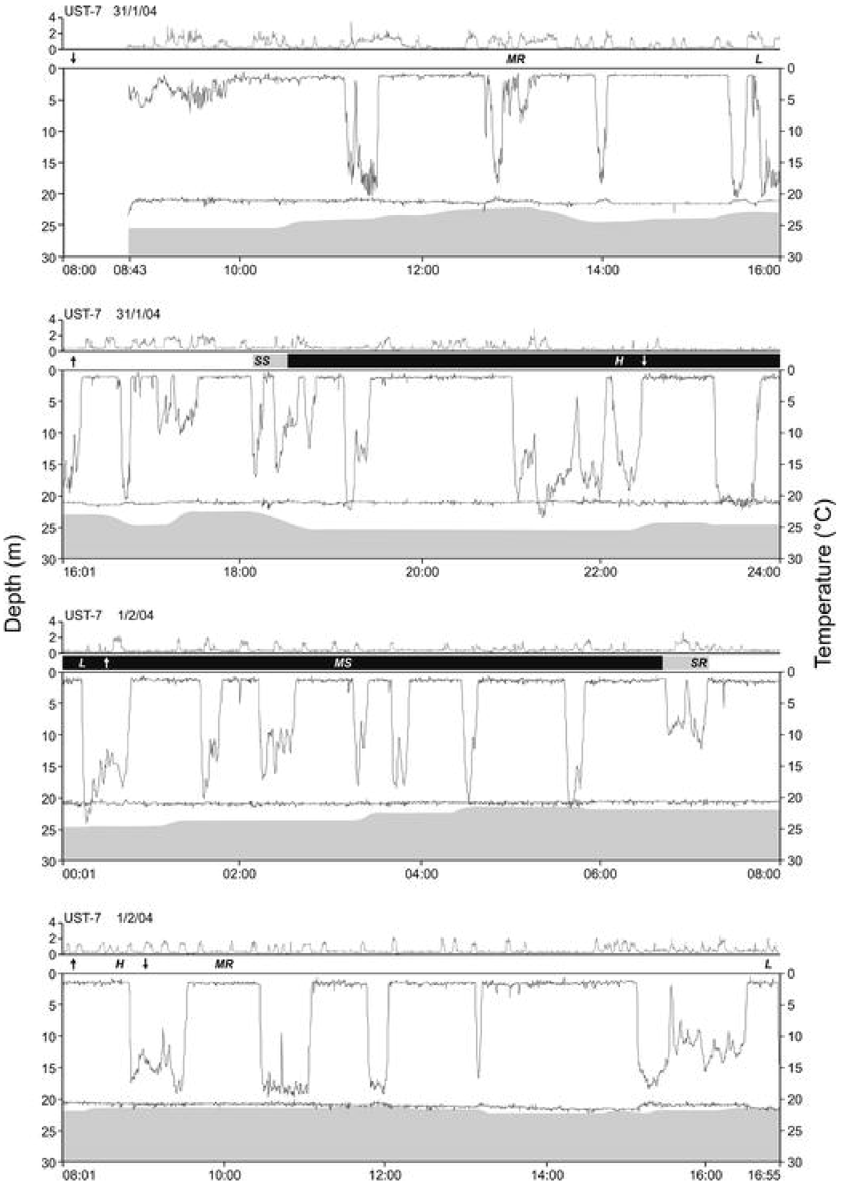
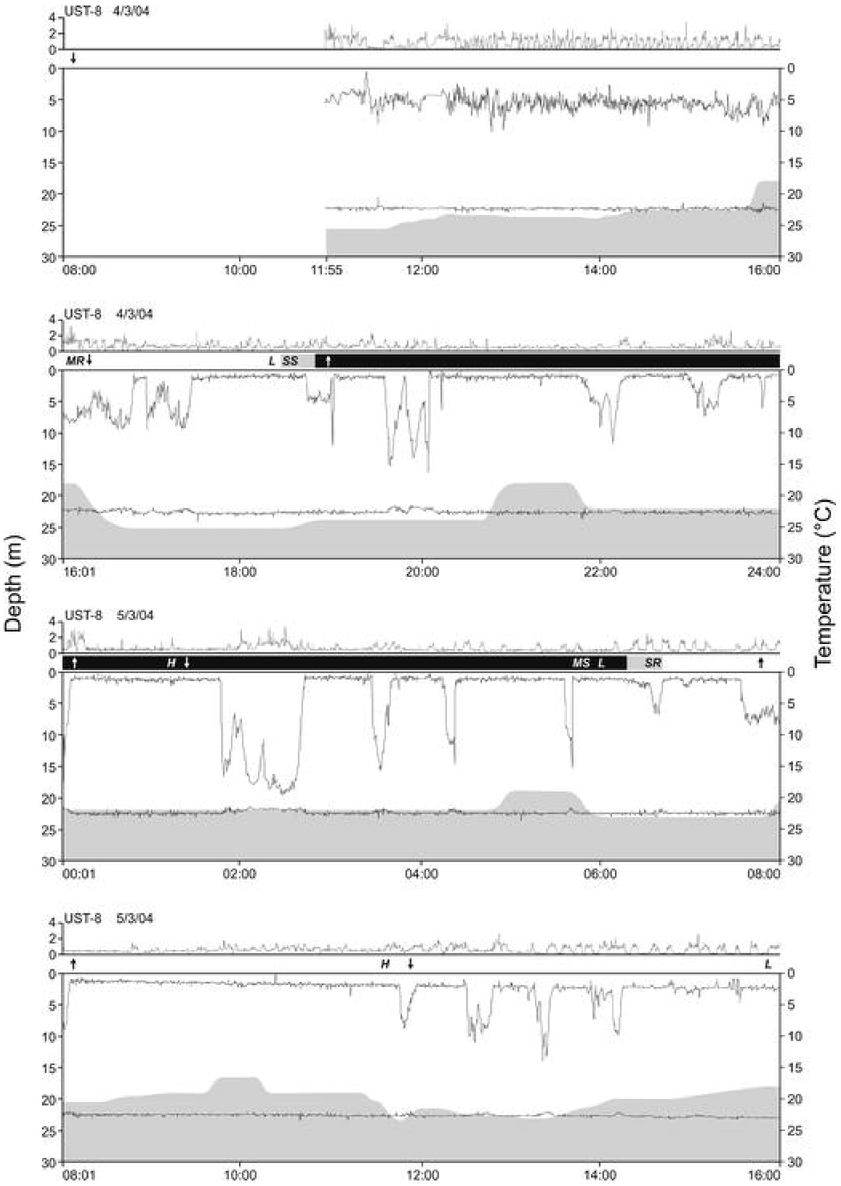


Fig. 7 Vertical track, ambient water temperature and speed of UST-7. Bar legend as per Fig. 1

UST-8 (estimated at 18 kg) was tagged at 1055 hours and tracked for 52 h 6 min (Fig. 8), having spent 96.5% of time above 10 m, mostly within 1–2 m of the surface. The fish was released in good condition. During the night it often rested motionless near the surface, propelled only by the current for short periods (~30 min) and would then resume swimming against the current for a short period. However, the net displacement was in the direction of the current. The track led in a long arc to the southwest. Total track was 78.7 km and maximum linear displacement from start point was 37.0 km. Notably, this fish moved continuously away from the capture location to a relatively shallow area not previously known as an aggregation site. Other sailfish were observed surface feeding in this shallow area during tracking of UST-8. Moon phase was waxing gibbous with 95% of visible disk illuminated.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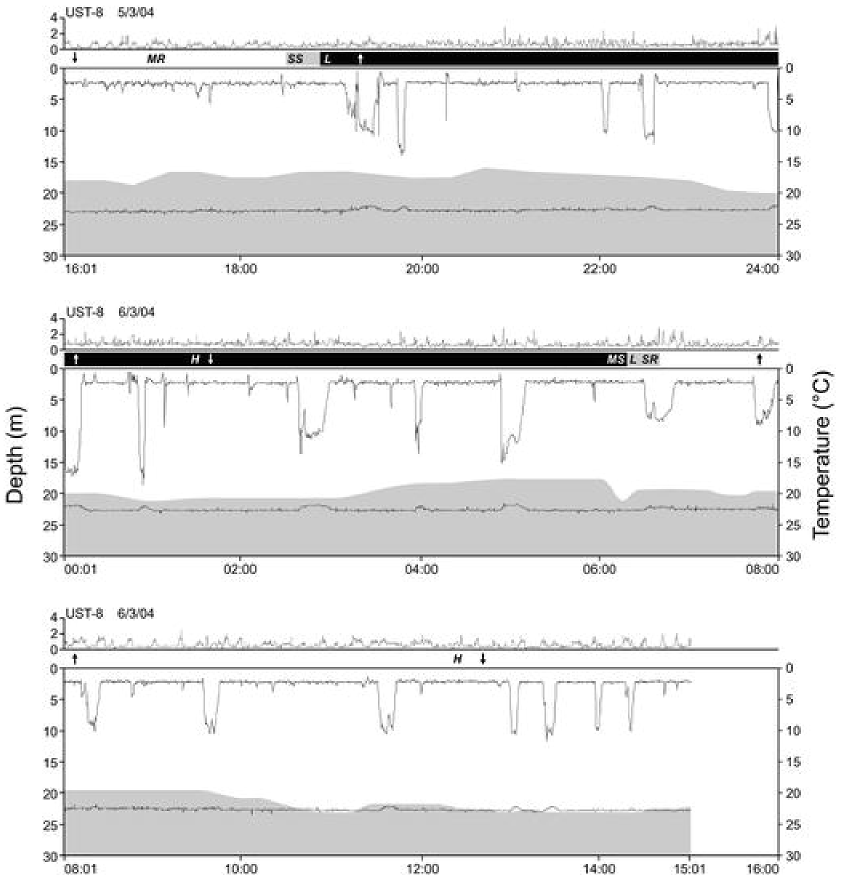

Fig. 8a,b Vertical track, ambient water temperature and speed of UST-8. Bar legend as per Fig. 1

UST-9 (estimated at 20 kg) was tagged at 1228 hours and tracked for 25 h 25 min (Fig. 9), having spent 72.5% of time above 10 m. This fish struggled during tagging procedures and regurgitated numerous sardines. It appeared stunned and tired when released and swam away slowly on an arcing course SW for around 4 h before turning NNW and swimming a straight course for the next 8 h, at which time it stopped completely and went into resting behavior (as described earlier) near the surface (Fig. 9). Resting lasted for about 1 h followed by swimming activity at depth and then resting again for over 1 h. Later it continued on a counter-clockwise arc, tracking to the south moving at depth, but interspersed by shorter periods of inactivity near the surface. Starting at 0800 hours and lasting for around 4 h, UST-9 traveled between schools of sardines and was probably feeding based on observations of the sardines' evasive behavior at locations of the tagged fish. Other sailfish were also observed feeding in the area during this period. Total track distance was 41.9 km and maximum linear displacement from start point was 12.6 km. Moon phase was waxing crescent with 18% of visible disk illuminated.

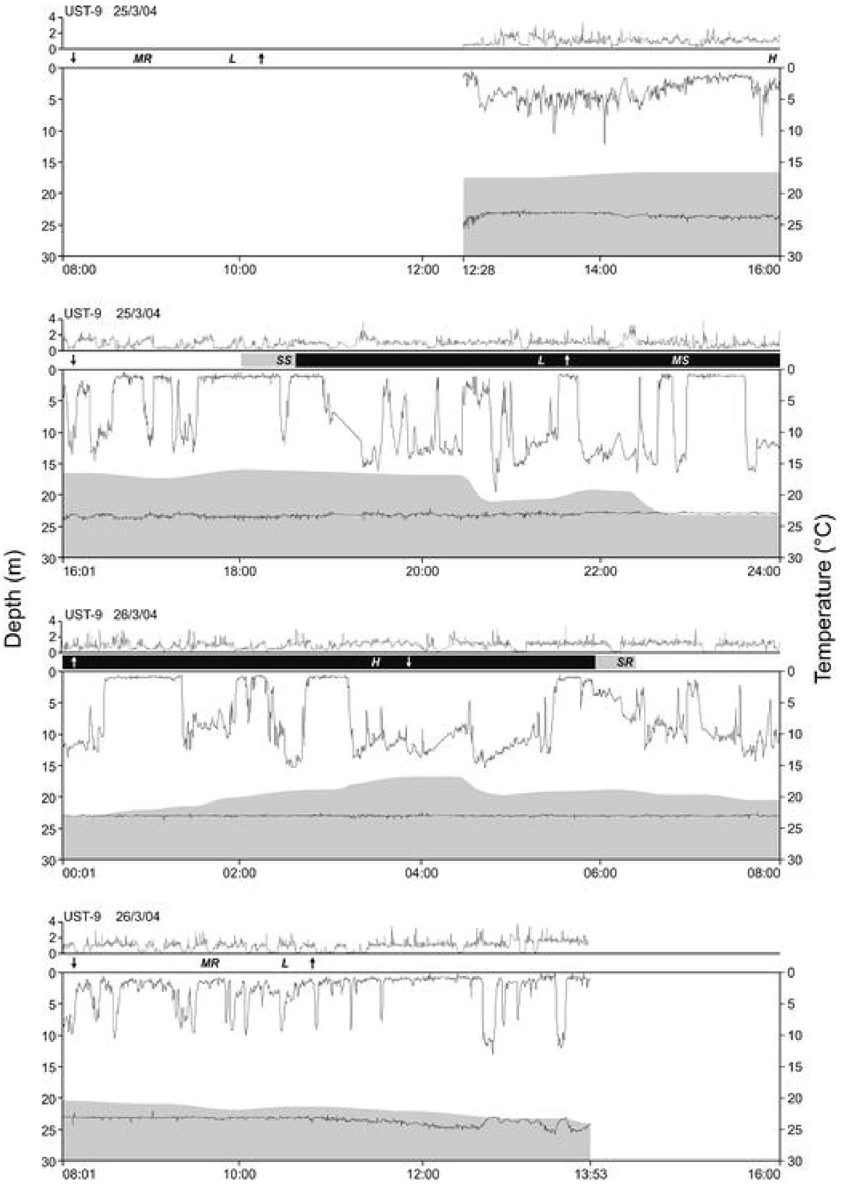

Fig. 9 Vertical track, ambient water temperature and speed of UST-9. Bar legend as per Fig. 1

Summary of PSAT tracks

PSAT-1 was deployed on 15 March 2002 and was at-large for a total of 58 days before being recaptured by commercial gillnet. Total linear displacement from start point was 150 km NNW. The mean depth of swimming and water temperature during this period were 3.4 m and 25.6°C, respectively (Table 2).

PSAT-2 was deployed on 27 March 2002 and was at-large for 68 days before being recaptured by commercial gillnet. Total linear displacement from start point was 543 km NNW. Mean depth of swimming and water temperature during this period were 5.2 m and 26.2°C, respectively (Table 2).

Both PSATs recorded light levels for the purpose of calculating geo-location. The associated algorithms used to calculate location are at best accurate to 0.7° (78 km) for latitude and 0.32° (36 km) longitude, and deteriorate quickly when approaching a solstice or affected by ambient conditions such as wave action and turbidity (Hill and Braun 2001). Hence, PSATs are not well suited for accurately determining fine-scale daily movements within the confines of the Gulf and therefore no attempt has been made to calculate horizontal tracks.

Discussion

This study reports the first attempts at both electronic tracking of sailfish inside the Gulf and of tracking billfish within a marginal sea. The physical limitations of the Gulf, in terms of sailfish population management, underscore the need to have a thorough understanding of movement and habitat preferences that aid in conservation management. Two conspicuous characteristics of the Gulf that differ from other areas where billfish have been tracked are the shallow bathymetry and mixing of the entire water column. Other studies are typified by much deeper water (or nearby drop-offs) and by decreasing water temperature with depth, usually with a thermocline present (Jolley and Irby 1979; Holland et al. 1990; Holts and Bedford 1990; Block et al. 1992a; Block et al. 1992b; Brill et al. 1993; Pepperell and Davis 1999). In most circumstances marlins reside in deeper waters, whereas sailfish commonly inhabit shallow areas, often associated with land masses (de Sylva 1974; Williams 1990). A comparison of behavioral traits described in active ultrasonic tracking studies of billfish is shown in Table 3.

[Table 3 will appear here. See end of document.]

Horizontal movements

There was no consistent azimuthal direction of travel for ultrasonically tracked Gulf sailfish as reported for Atlantic sailfish (Jolley and Irby 1979), striped marlin (Holts and Bedford 1990; Brill et al. 1993), blue marlin (Yuen et al. 1972; Holland et al. 1990) and black marlin (Pepperell and Davis 1999), where fish were observed to generally move offshore following release. Hydrographic characteristics of the Gulf study area, particularly the absence of drop-offs or deep water, may be factors contributing to this difference. Tide flow was the only perceptible factor that may have influenced direction of horizontal movement. A visual comparison of horizontal tracks (Fig. 1) and the rising and lowering tides (Figs. 5, 6, 7, 8, and 9) suggests that the ultrasonic tagged sailfish in this study generally moved in the same direction as expected tidal currents, although currents were not actually measured in this study. One example is UST-7, whose drifting horizontal movement corresponded closely to tidal direction and timing. An exception is UST-5, whose short easterly track could be more accurately described as perpendicular to expected tidal flow. In another study, Brill et al. (1993) used a Doppler current profiler to measure currents during the ultrasonic tracking of striped marlin around the Hawaiian Islands and reported a strong tendency for horizontal movement to run parallel in the direction of the current.

Vertical movements

Gulf sailfish exhibited a marked preference for the upper water column (~85% of time spent above 10 m) even though maximum water column depth at all ultrasonic tracking locations was limited to 30 m, and latter portions of PSAT tracks occurred in areas reaching 80 m depth. Preference for near-surface waters is consistent with observations of striped marlin in California (Holts and Bedford 1990) and Hawaii (Brill et al. 1993). These studies correlated depth preference limitations with thermocline barriers present in those areas. Holland et al. (1990) and Block et al. (1992a) found a similar preference for warmer temperatures in the mixed layer for blue marlin, as did Pepperell and Davis (1999) for black marlin. Two Atlantic sailfish fixed with pressure sensors and tracked off Florida also showed preference for the upper water column in waters much shallower than the marlin studies, but twice as deep as the Gulf (Jolley and Irby 1979).

For Gulf sailfish tracks that included hydrological data, water temperature varied little throughout the water column and showed no thermoclines. The high and low values of individual temperature ranges (Table 1) are attributed to marked heating and cooling of the sea surface during day and night, respectively. Depth preference therefore does not seem to be temperature correlated for Gulf sailfish as it is for other istiophorids, which raises a question of why they spend so much time nearer the surface. Perhaps this trait relates to a visibility advantage for seeking prey or monitoring predators. Seasonal sea surface temperature variation in the Gulf is extreme and can range as much as between 15°C and 33°C (Sheppard et al. 1992). Analysis of mitochondrial DNA provides evidence that sailfish are most likely residing in the Gulf year-round (Hoolihan et al. 2004), thus suggesting this population has adapted to these large water temperature fluctuations.

Salinity and specific conductivity levels exhibited a slight increase with depth (Fig. 4); a condition consistent with the expected oceanographic characteristics of the Gulf, where circulation is largely density driven as a result of high evaporation rates (Reynolds 1993). This increase is gradual and did not exhibit a marked halocline in the tracking area. Vertical and horizontal distribution (movement) of marine organisms can be influenced by haloclines, particularly when decreasing levels of dissolved oxygen are present (Jung and Houde 2003; North and Houde 2004). There were no fluctuations in dissolved oxygen levels with depth in the present study and no conclusive evidence linking salinity levels with preferential habitat for Gulf sailfish. However, it seems unlikely that the slight increase (~0.5 ppt) in salinity at depth acted as a deterrent to sailfish. It should be noted that average salinity levels in the study area are much higher (41.5 ppt) compared to levels (36.5 ppt) near the mouth of the Gulf.

Swimming speed

The average swimming speeds for Gulf sailfish (Table 1) are similar to those reported for striped marlin (Holts and Bedford 1990; Brill et al. 1993) and blue marlin (Yuen et al. 1972; Holland et al. 1990), but somewhat slower than speeds reported for Atlantic sailfish (Jolley and Irby 1979) and black marlin (Pepperell and Davis 1999) (Table 3).

Since small-scale horizontal and vertical movements in relation to vessel position were not considered in speed calculations, these numbers do not account for the true finer-scale swimming speeds of the tracked fish. In addition, other inherent limitations of ultrasonic tracking such as signal strength, sea conditions and crew alertness can lead to erroneous speed interpretation. For example, a tracked fish may pull away or be overtaken by the vessel as a result of incorrect vessel speed, prompting evasive action by the fish and erroneous speed measurements. Evasive behavior was reported during ultrasonic tracking of striped marlin (Holts and Bedford 1990) and black marlin (Pepperell and Davis 1999).

Block et al. (1992b) were able to measure the direct swimming speed of blue marlin with ultrasonic telemetry speedometers attached to the fish. Three blue marlin were tracked for periods of 25–120 h with monitored speeds ranging from 0.15 m s^{-1} up to bursts of 2.25 m s^{-1}, providing a more accurate depiction of normal swimming speeds (much higher speeds are attainable) than can be obtained from vessel positioning.

Resting

All of the four ultrasonically tagged sailfish tracked overnight in this study had periods of stationary behavior just below the surface for extended periods. No consistent pattern amongst fish was apparent. Similar behavior has been reported for striped marlin (Holts and Bedford 1990) and black marlin (Pepperell and Davis 1999). Although this activity cannot be conclusively attributed to actual sleeping, it certainly characterizes a stage of rest and energy conservation. Gulf sailfish are often observed resting at the surface during the day, usually in flat sea conditions, whereby they are stationary on the surface with dorsal and/or caudal fins visible. Often, groups of sailfish can be observed exhibiting this behavior; however it is not predictable and does not always occur when seas are calm. It does indicate that sailfish have the capacity to actively ventilate and pass water over their gills, and remain neutrally buoyant while stationary. Swordfish (*Xiphias gladius*) commonly make vertical deep dives into much colder waters and also exhibit occasional surface resting behavior. It has been suggested that this resting (basking) behavior may be a response to low oxygen levels encountered during deep excursions, or a method to warm the body after encountering colder temperatures at depth (Carey and Robison 1981; Carey 1990). In the present study dissolved oxygen and water temperature showed negligible fluctuation (Fig. 4) through the entire water column, so it is unlikely that this explanation for surface basking applies to Gulf sailfish.

Diel behavior

All four sailfish tracked overnight (UST-6, 7, 8, 9) exhibited a greater proportion of time spent above 10 m during the day than at night (82.7 vs 70.0%) and undertook their deepest dives at night (Fig. 3), consistent with behavior observed by Holts and Bedford (1990) for striped marlin. However, this contrasts with findings for blue marlin (Holland et al. 1990) and black marlin (Pepperell and Davis 1999). Jolley and Irby's (1979) study of Atlantic sailfish tracked a single specimen overnight, which spent nearly all its time near the surface. UST- and PSAT-tracked Gulf sailfish exhibited similar 5-m depth profiles (Fig. 3), with slightly greater variability at night. There were no marked diel depth preferences as observed in swordfish (Carey and Robison 1981; Carey 1990; Takahashi et al. 2001), or any indication that Gulf sailfish perform deep 'bounce' dives at sunrise and sunset, as reported for some tunas (Lutcavage et al. 2000; Davis and Stanley 2001). One possible explanation for an increase in time spent at shallower depths during the day may be a preference for higher surface temperatures resulting from solar heating. Another plausible reason derives from the fact that feeding behavior is most prevalent during daylight hours. The predominant prey source in the study area consists of *Sardinella* sp. and sailfish characteristically drive them into tight groups at the surface to lessen their chance of escape, therefore possibly increasing the proportion of time spent in shallower depths during the day.

Recovery and post-release behavior

Assuming the PSAT 7-day depth profiles (Fig. 3) represent normal behavior, their similarity to the UST profiles suggests that ultrasonically tagged sailfish undergo post-release recovery within a relatively short period (hours) and are minimally affected by the proximity of the tracking vessel. During this study it was not apparent from either horizontal speed or vertical movement behavior exactly when post-release recovery occurred. One exception may be UST-1, which showed a speed increase 2 h after release, although the location where speed increased may have been influenced by water current. This contrasts with studies of blue marlin (Block et al. 1992b) and striped marlin (Holts and Bedford 1990) that noted fastest swimming speeds immediately after release. Pepperell and Davis (1999) reported no apparent difference in the post-release speed of black marlin compared with subsequent movement.

One of the ultrasonically tagged sailfish (UST-3) died shortly after release. It sank at a speed of 0.14 m s^{-1}, similar to the 0.17 m s^{-1} rate for a sinking striped marlin reported by Brill et al. (1993). The horizontal movement of UST-3 immediately prior to sinking was erratic, noticeably moving from one side of the vessel to the other. Such behavior might indicate a reaction from shark attack, an event reported for other ultrasonically tracked istiophorids (Jolley and Irby 1979; Block et al. 1992a; Pepperell and Davis 1999). The trauma of capture and tagging may be the primary factor that led to the fatality, but the precise cause remains unknown.

One sailfish in the present study (UST-5242) dived deep to 30 m immediately after release for a short period before ascending, whereas all of the other fish remained near the surface for various periods. This differs from observations of other istiophorid species showing most tagged fish descended immediately to deeper depths, possibly to benefit from cooler temperatures aiding in recovery. In Jolley and Irby's (1979) study of Atlantic sailfish, one of two specimens carrying pressure sensitive tags dived deep after release. Observations on striped marlin (Holts and Bedford 1990) and blue marlin (Holland et al. 1990; Block et al. 1992a) show fish diving and remaining deep while recovering for several hours. Pepperell and Davis (1999) reported black marlin deep diving after release and ascending to shallower depths more quickly than blue and striped marlin, suggesting such behavior may indicate a relatively fast recovery period for that species. Gulf sailfish remained mostly near the surface immediately after release, possibly indicating a rapid recovery; however, considering the uniformity of the water temperature, a released sailfish would not benefit by descending in an attempt to cool down. Interestingly, UST-8 tracked for 52+ h was recaptured in an Iranian gillnet after 125 days at liberty at a distance 547 km NNW of the tagging location. The button anchored ultrasonic tag had shed and the fish was identified from the conventional tag. This occurrence and the previously mentioned relocation of UST-3 after 4 days at liberty supports the favorable post-release recovery of sailfish captured with recreational fishing gear.

Moon phase and tides

In the present study the times for moon rising, setting and moon phase (Figs. 5, 6, 7, 8, and 9) varied between sailfish tracks. These had no obvious effects on vertical movement or other behavior of tracked Gulf sailfish and generally agrees with findings in five tracked black marlin reported by Pepperell and Davis (1999). Also, no relationship between tides and sailfish behavior was apparent, except for the similarity between horizontal movement and direction of tide current (as described earlier).

Summary

Logistical constraints such as weather, time and expense are major restrictions on the practical feasibility of undertaking tracking studies on large pelagic fishes, explaining why this study and others involving billfish tracking are limited in number of specimens tracked and subsequent duration of tracks. These limitations might put into question the authenticity of description of ‘normal’ behavioral traits (e.g. depth preference) following the stress of capture and recovery. However, the cumulative information available from multiple studies and species (Table 3) reveals similarities that support individual findings. For example, all istiophorid billfish tracked have shown a preference for near-surface waters, although the reasons for this preference are not fully understood. Studies on marlin have shown that these animals exhibit a preference for warm near-surface waters, a behavioral trait assumed to avoid descending beyond certain temperatures imposed by thermoclines. Temperature barriers were not present in the Gulf study area, yet sailfish there still clearly preferred near-surface depths. It therefore seems that near-surface preference is an istiophorid behavior accurately assessed by ultrasonic tracking, even though causes for this trait may vary between species or locales.

Vertical movement and depth preference of Gulf sailfish are important considerations in fishery management decisions pertaining to gear selection and fishing effort. A large reduction in the population of Gulf sailfish has been linked to drift gillnet activities in Iranian territorial waters (Hoolihan 2004), where they represent incidental bycatch in a fishery targeting *Scomberomorus commerson*, *Thunnus tonggol* and *Euthynnus affinis*. The preference for near-surface waters revealed from ultrasonic and pop-up satellite tracking in this study indicate Gulf sailfish are particularly susceptible to this gear type. However, the prevalence of gillnetting suggests that time and area closures may be a more realistic management approach to reduce sailfish mortality. Genetic analysis revealing isolation of sailfish inside the Gulf from those outside (Hoolihan et al.

2004) indicates that less than one individual per generation mixes between the population inside and those outside, a factor that further reinforces the Gulf population's importance in terms of size limitation and biodiversity protection.

The present study represents only the second contribution to sailfish ultrasonic tracking since Jolley and Irby's (1979) pioneering work. It reveals behavioral traits of sailfish in a marginal sea environment with unique characteristics that differ from those reported in previous billfish tracking studies, and provides knowledge that can contribute to developing better informed management and conservation policies.

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Table 1 Summary of estimated body weight, track duration, distance, linear displacement, speed, range of depth and ambient water temperature for nine sailfish tracked with ultrasonic telemetry

UST no.	Deploy date (dd-mm-yy)	Anchor method	Estimated weight (kg)	Track duration (hh:min)	Total distance (km)	Linear displacement (km)	Mean speed (m s^{-1})	Depth (m) range (mean, SD)	Temp. (°C) range (mean, SD)
1	18–-04-02	H dart	16	09:53	25.4	12.1	0.71	0.9–15.3 (6.2, 2.59)	24.3–27.0 (25.6, 0.22)
2	21–-04-03	H dart	18	08:08	22.0	12.2	0.75	0.0–25.4 (6.5, 6.52)	22.7–27.0 (24.9, 0.65)
3	23–-04-03	H dart	18	03:33	Died	0.0	0.00	0.7–33.1 (27.7, 8.36)	21.9–27.7 (24.0, 0.76)
4	29–-12–-03	Button	23	03:53	7.4	7.1	0.53	0.4–12.6 (6.5, 2.92)	22.1–25.3 (23.3, 0.22)
5	02–-01-04	H dart	25	03:40	5.5	4.6	0.42	0.0–17.7 (2.0, 1.29)	21.1–25.1 (23.1, 0.27)
6	24–-01-04	Button	14	24:08	61.2	15.5	0.70	0.0–27.9 (7.8, 8.75)	21.0–23.8 (21.9, 0.29)
7	31–-01-04	Button	25	32:13	34.0	14.2	0.29	0.0–24.2 (5.2, 6.25)	20.0–23.6 (21.0, 0.32)
8	04–-03-04	Button	18	52:06	78.7	37.0	0.68	0.0–19.9 (3.0, 2.66)	20.2–24.4 (22.6, 0.25)
9	25–-03-04	Button	20	25:25	41.9	12.6	1.00	0.0–20.3 (5.8, 4.81)	21.3–26.3 (23.3, 0.45)

Table 2 Summary of estimated body weight, release/recapture locations, day at-large, distance, speed, depth and temperature range for pop-up satellite archival tags (*PSATs*). Depth and temperature values are for the initial 7 days post-deployment

Tag no.	Deploy date (dd-mm-yy)	Estimated weight (kg)	Release location	Recapture location	Total days	Linear distance (km)	Mean speed[a] (m s^{-1})	Recording interval (hh:mm)	Depth (m) range (mean, SD)	Temp. (°C) range (mean, SD)
PSAT-1	15–-03-02	22.7	24°48′N 54°05′E	25°48′N 53°05′E	58	150	0.03	00:01	0.0–46.0 (3.4, 5.04)	22.1–33.7 (25.6, 1.70)
PSAT-2	27–-03-02	29.5	24°49′N 54°05′E	28°02′N 49°59′E	66	543	0.09	00:01	0.0–80.0 (5.2, 7.46)	19.7–30.3 (26.2, 1.52)

[a] Speed calculation is based on linear displacement from point of deployment to point of recapture

Table 3 Comparison of behavioral traits reported for active ultrasonic tracking of billfishes. Behavioral activity is symbolized by: +++ (usually), ++ (some), + (few), ± (rare) and – (never); *NA* information not available

Species	No. of successful tracks	Prefer near surface depths	Diel depth preference	Dive below thermocline	Preference to thermocline	Water temperature restriction	Resting (non-mobile)	Site affinity	Range of average swimming speeds ($m\ s^{-1}$)	Sources
Sailfish (*Istiophorus platypterus*)	8	+++	+[a]	–[b]	–[b]	+++	++	++	0.29—1.00	Hoolihan (present study)
Sailfish (*Istiophorus platypterus*)	8	+[c]	NA	–	–	NA	±	+	0.42—2.10	Jolley and Irby (1979)
Striped marlin (*Tetrapturus audax*)	11	++	+[a]	±	++	+++[d]	++	+	0.39—0.79	Holts and Bedford (1990)
Striped marlin (*Tetrapturus audax*)	6	++	NA	+	++	+++[d]	–	–	0.50—1.00	Brill et al. (1993)
Blue marlin (*Makaira nigricans*)	4	++	++[e]	+	++	+++[d]	–	–	0.62—0.98	Yuen et al. (1972)
Blue marlin (*Makaira nigricans*)	6	++	+[e]	±	+	+++[d]	–	–	0.62—1.12	Holland et al. (1990)
Blue marlin (*Makaira nigricans*)	6	++	+[e]	±	–	+++[d]	–	–	–	Block et al. (1992a)
Black marlin (*Makaira indica*)	6	++	++[e]	±	+[f]	+++[d]	++	–	0.42—2.10	Pepperell and Davis (1999)
Swordfish (*Xiphias gladius*)	6	++[e]	+++[e]	+++	–	–[g]	++	++[h]	–	Carey and Robison (1981)
Swordfish (*Xiphias gladius*)	5	++[e]	+++[e]	+++	–	–[g]	++	++[h]	–	Carey (1990)

[a] Prefers shallower depths at day

[b] Studies limited to shallow areas lacking thermocline
[c] Only two sailfish fitted with pressure sensitive transmitters
[d] Seldom ventures below the thermocline
[e] Prefers shallower depths at night
[f] Thermocline not usually evident in Pepperell and Davis (1999) study
[g] Commonly ventures below the thermocline
[h] Diel inshore (daytime), offshore (nighttime) movements returning to the same location each morning