

# Diel movement patterns of ocean sunfish *Mola mola* off southern California

Daniel P. Cartamil, Christopher G. Lowe\*

Department of Biological Sciences, 1250 Bellflower Blvd., California State University, Long Beach, California 90840, USA

**ABSTRACT:** Ocean sunfish *Mola mola* are a seasonally common inhabitant of southern Californian waters, and comprise the largest bycatch component (29% of total catch) of the California drift gillnet fishery for swordfish. We used temperature and depth-sensing acoustic transmitters to quantify the fine-scale movement patterns of ocean sunfish near Santa Catalina Island, California. Eight ocean sunfish were tracked continuously over 24 to 72 h periods, during which oceanographic data were collected every 2 h. Geographical position and depth of tracked fish were analyzed in relation to oceanographic data and time of day. Ocean sunfish traveled a mean distance of  $26.8 \pm 5.2$  ( $\pm$ SD) km d<sup>-1</sup>. Horizontal movements were characterized by a significant decrease in rate of movement (ROM) during the first 6 h of night (median ROM =  $0.76$  km h<sup>-1</sup>) (SD = 0.31) as compared to the remaining nighttime period (median ROM =  $1.00$  km h<sup>-1</sup>) (SD = 0.39), whereas daytime ROM (median ROM =  $1.22$  km h<sup>-1</sup>) (SD = 0.58) was significantly higher than either nighttime period. Horizontal movements were highly directional, with angular concentration values ( $r$ ) as high as 0.765 over the duration of entire tracks. Nocturnal vertical movements were confined to the surface mixed layer and thermocline, while diurnal vertical movements were often characterized by repeated dives below the thermocline. A significant relationship was found between maximum dive depth and the post-dive period spent in the mixed layer, suggesting that ocean sunfish may behaviorally thermoregulate between deeper daytime dives. The observed depth-distribution patterns of ocean sunfish indicate that lowering the depth of gillnets in the water column could significantly reduce bycatch of this species in the California drift gillnet fishery.

**KEY WORDS:** Acoustic telemetry · Pelagic tracking · Drift gillnet fishery · Bycatch · Thermoregulation

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## INTRODUCTION

The ocean sunfish *Mola mola*, a large pelagic zooplanktivore (Fraser-Bruner 1951), frequently comprises a large percentage of the bycatch in drift gillnet fisheries. A survey of the Spanish drift gillnet fishery in the Mediterranean Sea indicated that ocean sunfish represented between 71 and 93% of the total catch between 1992 and 1994 (Silvani et al. 1999). In the eastern Pacific, ocean sunfish numerically comprise 29% of the total catch of the California drift gillnet fishery for swordfish—far outnumbering the target species (D. Petersen, National Marine Fisheries Service [NMFS], unpubl. data). Reducing bycatch of abundant non-target species is becoming a high priority in fisheries management due to increased concerns over

ecosystem-wide fishery effects (Larkin 1996, Sherman & Duda 1999, Pitcher 2001). However, development of bycatch reduction strategies is dependent on knowledge of fish movement patterns and distributions relative to fishing methods.

Presently, very little is known about the biology or behavior of ocean sunfish. They inhabit subtropical to temperate pelagic waters worldwide (Fraser-Bruner 1951, Miller & Lea 1972), and are the largest known teleosts, with total lengths of up to 3 m and weights of almost 2000 kg (Gudger 1928). Surprisingly, ocean sunfish attain these massive proportions on a diet reported to consist primarily of gelatinous zooplankton (Linton 1901, Fraser-Bruner 1951, McCann 1961, MacGinitie & MacGinitie 1968, Hooper et al. 1973, Sommer et al. 1989). Morphologically, ocean sunfish possess

\*Corresponding author. Email: clowe@csulb.edu

many distinctive traits, such as a stiff truncated body, use of the dorsal and anal fins for primary propulsion, and a rudder-like caudal fin, or clavus (Fraser-Bruner 1951). These characteristics have led to much speculation regarding the locomotory abilities and behavior of ocean sunfish. For example, Myers & Wales (1930) reported that ocean sunfish are active swimmers, whereas Gudger (1928) and Dawson (1965) describe them as sluggish, inefficient swimmers, passively carried by water currents. Dean (1913) suggested that ocean sunfish morphology was more characteristic of deeper water species, although they are most frequently observed during daylight hours 'basking' at the sea surface, behavior some authors have attributed to illness (Fraser-Bruner 1951, McCann 1961, Schwartz & Lindquist 1987) or solicitation of cleaner fish (Threlfall 1967, Love 1996). In addition, observations of the drift gillnet fishery indicate that ocean sunfish are caught at night in gillnets set at depths between 12 and 50 m (D. Cartamil pers. obs.). The large number of ocean sunfish caught in these nets indicates that the nighttime depth distribution of ocean sunfish must at least partially include this range.

Based on the limited information available on ocean sunfish distributions, we hypothesized that they are vertical migrators, occurring near the surface by day and deeper by night. To test this hypothesis, we conducted an acoustic telemetry tracking study of *Mola mola* off southern California. Additional goals of this study were to ascertain the preferred depth range of ocean sunfish, and quantify fine-scale horizontal and vertical movement patterns relative to oceanographic factors.

## MATERIALS AND METHODS

**Acoustic telemetry and oceanographic measurements.** Ocean sunfish were spotted basking at the surface, or found in association with kelp patties. Once located, fish were captured by dipnetting and brought aboard the 6.6 m R/V 'Callinectes', where they were measured and externally tagged with a temperature and depth-sensing acoustic transmitter (Vemco, Model V22TP, 22 mm diameter  $\times$  100 mm length, frequencies 34 to 40 kHz). Transmitters were attached to a nylon dart (Floy Tag Mfg. FIM-96) via an 8 cm length of 100 lb (45.36 kg) test monofilament line. The nylon dart was inserted approximately 2 cm deep in the integument immediately anterior to the clavus, below the trailing edge of the dorsal fin. Preliminary dissections done in the laboratory confirmed that the integument in this region is thick enough to accommodate the dart without it entering the subcutaneous musculature and possibly affecting swimming behavior. The fish were then released at the site of capture after a handling time of less than 5 min.

Transmitters encoded depth and temperature information by varying pulse interval. The acoustic output of the transmitters was detected using a fixed directional hydrophone mounted through the vessel's hull, and decoded by a receiver unit (Vemco, Model VR-60) mounted above the boat console. Depth and temperature data, displayed on the receiver's LED screen, were recorded manually every 3 min along with the vessel's GPS-derived location. We attempted to maintain the farthest possible distance from the fish while still able to decode the acoustic signal at the lowest receiver gain setting. In calm sea conditions, transmitter range tests showed this distance to be approximately 300 m. Maximum range at maximum receiver gain was approximately 1 km. To accommodate for signal attenuation during periods of rough sea conditions, receiver gain was increased to avoid approaching the animal too closely. Thus, the boat was kept at a relatively constant distance from the fish, and for the purposes of data analysis, the boat's geographic position was assumed to be the same as the fish's (Brill et al. 1999).

A sonde unit (YSI, Model 6600) was deployed every 2 to 3 h, to a depth of 42 m, providing an environmental profile over the course of each track. For the last 2 tracks (Tracks 7 and 8), a longer cable allowed deployment of the unit to 70 m. Oceanographic factors measured with the sonde included depth, water temperature, light intensity and chlorophyll concentration.

**Data analysis.** Each track was plotted on a digital chart of the San Pedro Channel using ArcView GIS Version 3.2. Distances between successive positions were determined with the animal movement analyst extension (AMAE; Hooge & Eichenlaub 2000) for ArcView GIS. We calculated rate of movement (ROM) by dividing distance between successive points by the sampling interval. Daytime and nighttime ROMs were categorized for each fish based on local times of sunrise and sunset. Pooled daytime and nighttime ROM data from all fish were compared using a Mann-Whitney *U*-test. In order to examine patterns in ROM on a finer scale, distances traveled over 1 h periods were summed to provide hourly ROM and plotted against time of day.

Circular statistics were used to examine linearity of various tracks and track segments. For these analyses, we used AMAE to calculate mean bearing and angular concentration. Angular concentration (*r*) is a relative measure of linearity, ranging from 0 to 1, with a value of 1 representing absolute linearity (Batschelet 1981). Point-to-point bearings were determined with the 'path with distances and bearings' extension to ArcView (Jenness 2001), and analyzed using Rayleigh's *z*-test to determine significant linearity (non-randomness) of movement paths.

Vertical movements were examined by plotting each fish's depth readings against time of day to construct a depth profile for each tracking period. Temperature, chlorophyll concentration and light data obtained by sonde deployments were overlaid upon the depth profiles to evaluate the possible extent to which various oceanographic factors influenced the vertical movements of the fish.

Data obtained from the transmitter depth sensors were used to determine diel depth distributions. Percentage frequency of occurrence at depth was compared for all fish between day and night.

The descent and ascent rates, maximum dive depth, and durations of post-dive periods in the surface mixed layer were quantified for each discrete diving period. Diving periods were defined as vertical excursions from the surface mixed layer through the thermocline and back. The durations of post-dive periods were analyzed in relation to maximum dive depth using a linear regression. Dive descent and ascent rates were compared with a paired *t*-test.

## RESULTS

Eight ocean sunfish, ranging in length from 73 to 151 cm total length (TL; Table 1), were tagged and tracked off southern California. Seven of the ocean sunfish were caught off the northern coast of Santa

Table 1. *Mola mola*. Fish length and track data for 8 ocean sunfish tracked off southern California. TL = total length (from anterior tip of the fish to the trailing edge of the clavus). Angular concentration (*r*) is a relative measure of linearity on a scale of 0 through 1, with a value of 1 denoting a linear trajectory. **Bold:** movements that differ significantly from random ( $p < 0.05$ , Rayleigh's *z*-test)

Ocean Sunfish	TL (cm)	Dates tracked (mm/dd – mm/dd/yy)	Time tracked (h)	Track distance (km)	<i>r</i>
1	100	07/18 – 07/19/01	29	21.1	<b>0.765</b>
2	120	08/23 – 08/24/01	28	39.4	<b>0.606</b>
3	120	09/14 – 09/15/01	24	29.7	<b>0.573</b>
4	90	10/05 – 10/07/01	48	54.4	<b>0.326</b>
5	73	08/05 – 08/07/02	48	43.5	<b>0.734</b>
6	112	08/29 – 08/31/02	45	40.7	<b>0.666</b>
7	151	09/08 – 09/09/02	28	28.8	<b>0.584</b>
8	101	09/19 – 09/22/02	72	87.9	0.189

Catalina Island and 1 was caught approximately 50 km northeast of the island, close to the mainland coastline (Fig. 1). Six of the 8 tagged fish showed an immediate stress response consisting of 1 or more short-term deep dives, returning to more characteristic swimming depths after periods of 1 to 5 h. Therefore, data acquired during these periods were not included in analyses.

Overall, fish moved  $26.8 \pm 5.2$  ( $\bar{x} \pm SD$ ) km d<sup>-1</sup>. Horizontal movements were characterized by a significant decrease in ROM during the first 6 h of night (median ROM = 0.76 km h<sup>-1</sup>; SD = 0.31) as compared to the remaining nighttime period (median ROM = 1.00 km h<sup>-1</sup>; SD = 0.39), whereas daytime ROM (median ROM = 1.22 km h<sup>-1</sup>; SD = 0.58) was significantly higher than either nighttime period (Kruskal-Wallis test,  $p < 0.001$ ; Fig. 2). In many cases, horizontal movements were also highly directional, with *r* values as high as 0.765 over the duration of entire tracks (Fig. 3, Table 1).

Most of the tracked fish displayed a distinct diel pattern of vertical movement (Fig. 4). During nighttime periods, vertical movements were confined to the warmer near-surface waters (mixed layer) above or within the thermocline. The upper limits of the thermocline ranged from 10 to 20 m in depth, while the lower limits of the thermocline typically ranged from 30 to 40 m. Among all fish, only one descent below the thermocline was noted during nighttime periods. Daytime periods, in contrast, were often characterized by repeated dives below the thermocline, though the extent of this pattern varied among fish. These dives (generally to 40–150 m) were typically short in duration (mean dive duration  $11.2 \pm 9.5$  min), and were immediately followed by a return to the mixed layer, where

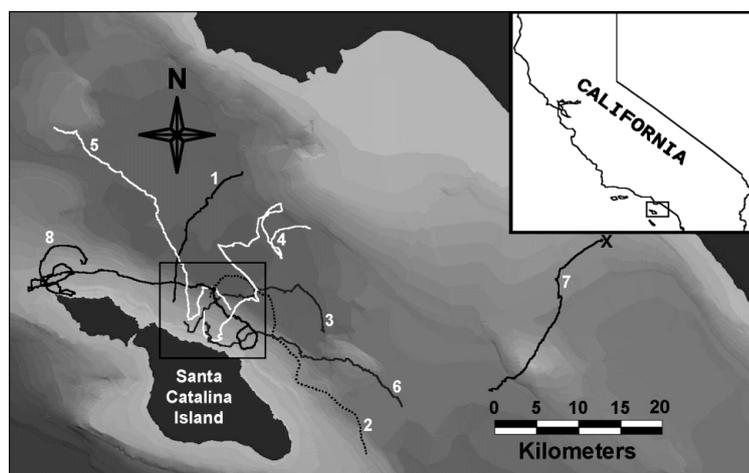


Fig. 1. *Mola mola*. Movements of 8 ocean sunfish tracked by acoustic telemetry, near Santa Catalina Island, California. Inset shows the general tracking area in relation to California. Darker gray indicates deeper water (max. depth: ca. 900 m). All tracks originated within the boxed area north of Santa Catalina Island, except for Track 7 (origin at X)

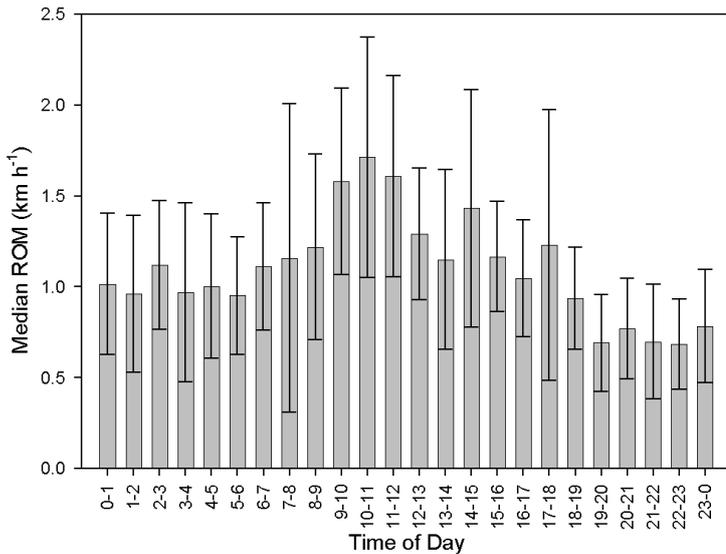


Fig. 2. *Mola mola*. Hourly rate of movement (ROM;  $\text{km h}^{-1}$ ; median  $\pm$  SD) of ocean sunfish tracked over a diel cycle

fish still spent the majority of the daylight period (Fig. 5). The maximum dive depth observed was 392 m. During these vertical excursions, the fishes experienced temperatures ranging from 21.0 to 6.8°C.

A significant relationship was found when maximum dive depth was plotted against duration of the post-dive period after the fish returned to the mixed layer (linear regression,  $R^2 = 42.1\%$ ,  $p < 0.001$ ; Fig. 6). There was no significant difference between the mean des-

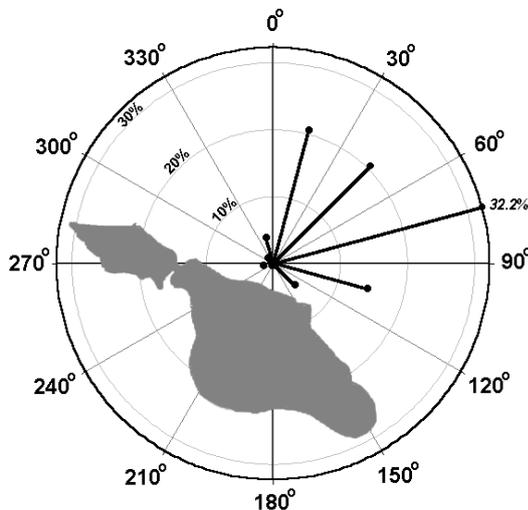


Fig. 3. *Mola mola*. Circular plot of Ocean Sunfish 1 movement, bearing concentrations over the course of a 29 h track. 0° represents due north. Individual bearings are pooled in 30° intervals, and concentric radial lines (light gray) indicate % of points within each interval. Angular concentration ( $r$ ): 0.765; mean bearing: 59.2°

cent rate ( $8.4 \pm 5.6 \text{ m min}^{-1}$ ) and ascent rate of dives ( $7.7 \pm 5.6 \text{ m min}^{-1}$ ; paired  $t$ -test,  $t = 1.40$ ,  $p = 0.166$ ). Additionally, no correlation was found between sizes of tracked fish (TL) and mean dive depths (Pearson's correlation coefficient:  $-0.183$ ,  $p = 0.69$ ).

The depths of the chlorophyll maxima were not correlated with fish depths (Pearson's correlation coefficient:  $-0.107$ ,  $p = 0.37$ ). Mean chlorophyll concentration at these maxima was  $4.8 \mu\text{g l}^{-1}$  (range 2.5 to  $7.9 \mu\text{g l}^{-1}$ ). Vertical excursions were typically initiated 10 to 15 min after civil twilight, corresponding to a light intensity of between 2700 and 8100 lux at 1 m depth.

## DISCUSSION

### Horizontal movements

Ocean sunfish are commonly regarded as planktonic fish, primarily transported by oceanic currents (McCann 1961, Holt 1965, Lee 1986). However, those tracked in this study were observed to move a mean of  $26.8 \text{ km d}^{-1}$ , with the highest ROM (peak ROM:  $3.2 \text{ km h}^{-1}$ ) occurring during the daytime. Estimating the degree to which fish movement was attributable to ocean currents is problematic due to the complexity of near-surface circulation patterns in the San Pedro Channel (DiGiacomo & Holt 2001) and lack of current monitoring during tracks. Current circulation in the San Pedro Channel is dominated by the California Counter-current, a branch of the southeastward-flowing California Current that turns northward and flows inshore through the southern California Bight (Hickey 1992). The typical mean northwesterly current velocity in the San Pedro Channel during late summer and fall is 0.18 to  $0.36 \text{ km h}^{-1}$  ( $4.32$  to  $8.64 \text{ km d}^{-1}$ ; Bakus 1989, Hickey 1992). Only 2 of the 8 tracked fish traveled northwesterly, while 3 traveled perpendicular to the California Counter-current, and 3 fish followed a southeasterly trajectory. This clearly indicates that ocean sunfish are active swimmers, not substantially affected by the velocity or direction of the currents. While it may not be surprising that other pelagic species such as tunas show minimal influence by ocean currents due to their swimming abilities, it is interesting to note that the ROMs of ocean sunfish tracked in this study are similar to those found by Block et al. (1997) for yellowfin tuna *Thunnus albacares* ( $1.7$  to  $3.2 \text{ km h}^{-1}$ ) in the southern California Bight.

Ocean sunfish horizontal movements were often highly directional; 7 of the 8 fish tracked exhibited significantly non-random movements over the entire

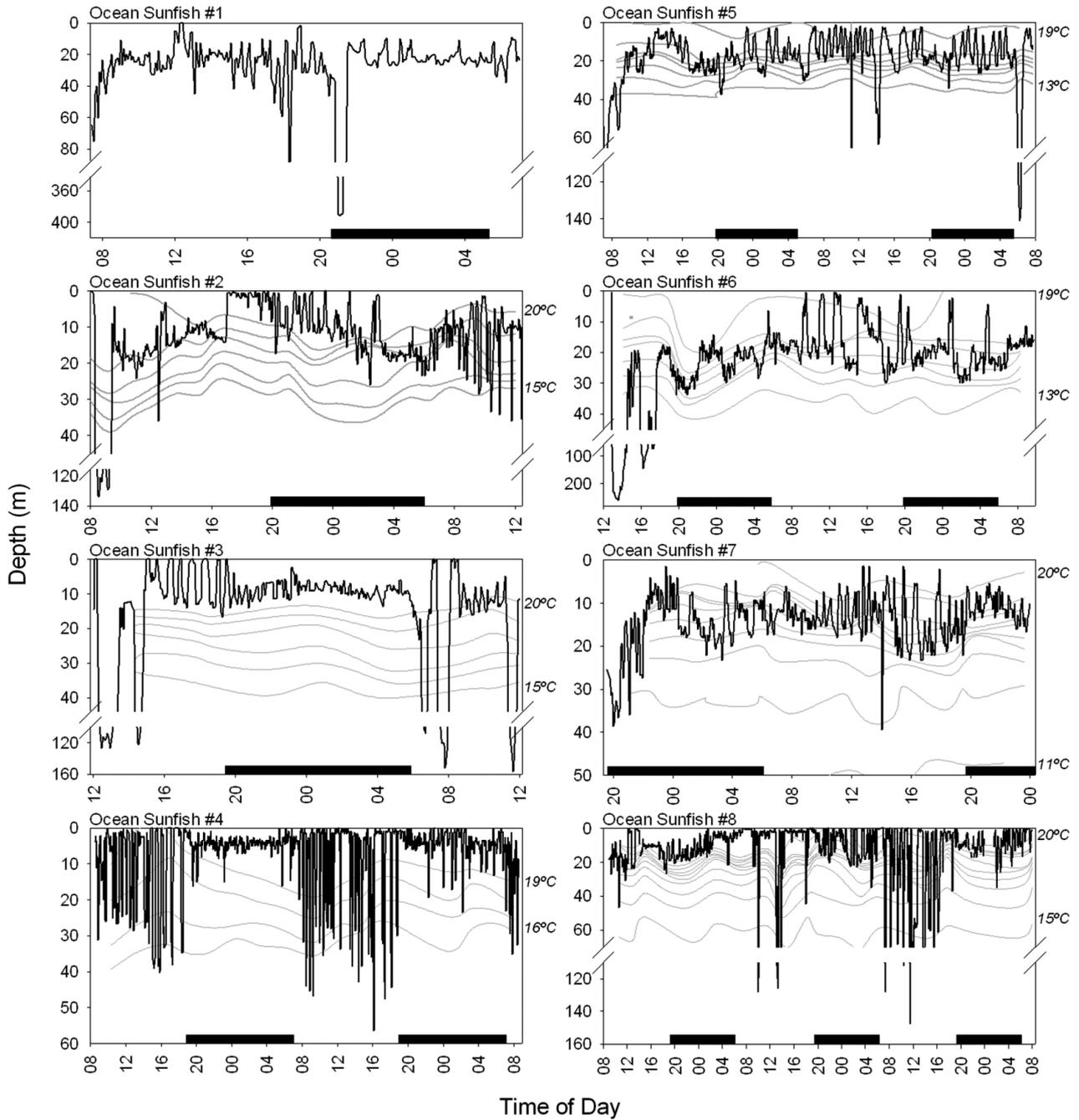


Fig. 4. *Mola mola*. Dive profiles of Ocean Sunfish 1 to 8 over the course of each track. Gray lines: 1°C isotherms; max. and min. temperatures are given on the right. No water temperature data were collected during the tracking of Ocean Sunfish 1. Black horizontal bars indicate nighttime periods

tracking period. Even in cases where the overall  $r$  for a track was low, extended periods of the track often retained high  $r$ -values. For example, Track 8 had a low  $r$ -value of 0.189 over a 72 h period. However, over the 30 h period from 14:00 h on 19 September 2002 to 20:00 h on 20 September 2002, the track had an  $r$ -value of 0.501, significantly non-random ( $p < 0.001$ ). Direc-

tional movements are common among pelagic fish studied, and have been noted in various pelagic sharks (Carey & Scharold 1990, Klimley 1993, Holland et al. 1999), blue marlin *Makaira nigricans* (Block et al. 1992), and yellowfin tuna (Holland et al. 1990b). While the orientation cues of directed movements are difficult to identify, some fish have been shown to orient to

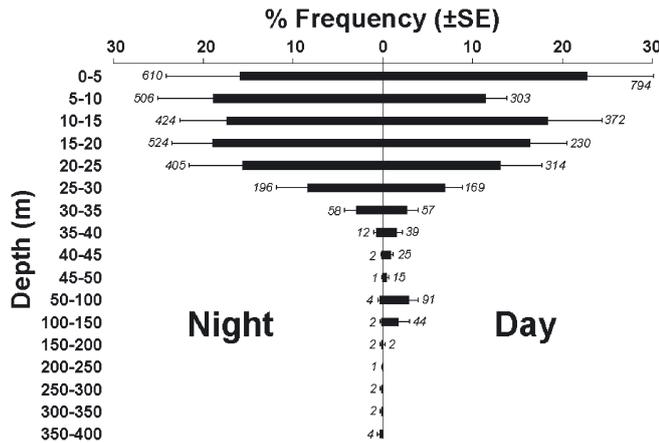


Fig. 5. *Mola mola*. Depth distributions (% frequency; mean  $\pm$  SE) calculated from individual fish at each depth interval. Depth readings of 0 to 50 m are pooled in 5 m intervals, and readings of 50 to 400 m are pooled in 50 m intervals. Total number of depth readings are given in italics. All nighttime depth positions below 40 m are from 1 dive to 392 m during Track 1

magnetic cues (Walker et al. 1984, Moore et al. 1990, Kobayashi & Kirschvink 1995). As no obvious or detectable celestial or ocean current orientation was observed, magnetoreception could explain the directed movements of ocean sunfish in the pelagic environment.

The general trend of movement was away from Santa Catalina Island, though the direction of travel was highly variable. It is unlikely that the high degree of directionality exhibited during these movements was influenced by the island itself, since directed movements continued even after fish were well offshore, over the deepest portions of the San Pedro Basin. Block et al. (1992) reported directed movements

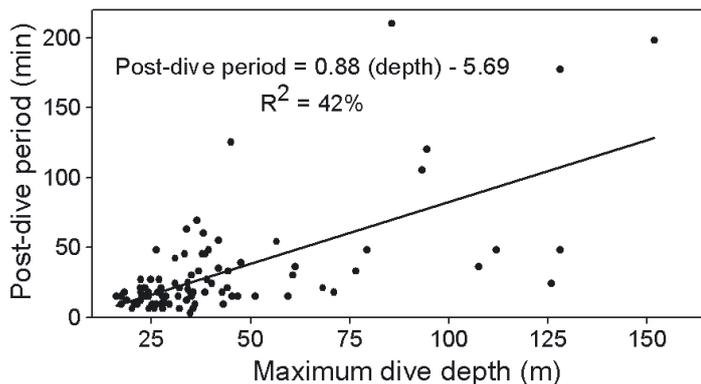


Fig. 6. *Mola mola*. Relationship between maximum depths of all dives and durations of corresponding post-dive periods in the mixed layer

of blue marlin away from the island of Hawaii, suggesting that these fish may be temporarily visiting the island during longer migratory movements. Although the temporal distribution patterns of ocean sunfish in the eastern Pacific are not well known, their seasonal occurrence in locales such as Monterey Bay and Santa Catalina Island, California, suggests migratory activity, presumably within a preferred temperature range (Myers & Wales 1930, Lee 1986). As such, Santa Catalina Island may represent a temporary 'stopping-over' location, due to abundant prey, warm water, and the presence of kelp beds and paddies (under which they are often cleaned by halfmoons *Medialuna californiensis*, and other fishes; Hixon 1979).

### Vertical movements

Six of the 8 fish showed an immediate deep-dive response after release, in which the fish often reached their greatest recorded depths before returning to more 'typical' behavior. This reaction was brief (<3 h) in most cases, and is well documented as a short-term stress response in various acoustically tagged pelagic fishes (e.g. Sciarrotta & Nelson 1977, Carey & Scharold 1990, Holland et al. 1990a, Block et al. 1992, Holts & Bedford 1993). There also may have been some inhibition of vertical movement for a short time following the initial stress-related dive, but it is unclear whether this was due to tagging stress. Carey & Scharold (1990), Block et al. (1997) and (1992) observed similar behavior in blue sharks, yellowfin tuna and blue marlin, respectively, wherein diving patterns were less well-developed over approximately the first 12 h of tracking. Although it is difficult to determine the degree to which capture stress impacts post-release behavior, the occurrence of diel vertical movement patterns may provide some indication of speed of recovery that may only be obvious over longer tracks.

Most tracked fish showed a distinct diel diving pattern with daytime periods characterized by brief, repeated dives below the thermocline. This diel pattern is likely induced by changes in light intensity. Changes in diel light intensity are thought to initiate similar bounce diving behavior in other pelagic fishes, such as blue sharks *Prionace glauca* (Carey & Scharold 1990), swordfish *Xiphias gladius* (Carey & Robison 1981), and some tunas (Holland et al. 1990b, Kitagawa et al. 2000). Various explanations have been posited for this behavior, most of which focus on prey acquisition as the primary motivation for diving activity.

The spatio-temporal dynamics of ocean sunfish prey suggest that the movement patterns of ocean sunfish could have evolved as a means of foraging on vertically migrating organisms. Ocean sunfish are widely

reported to feed primarily on gelatinous zooplankton, including salps, medusae and ctenophores (Linton 1901, Suyehiro 1942, Fraser-Bruner 1951, McCann 1961, MacGinitie & MacGinitie 1968, Hooper et al. 1973, Sommer et al. 1989), although the fragility and digestive state of these ingested organisms has often precluded identification to species. Many common gelatinous zooplankton found in southern California waters are vertical migrators, occurring near the surface nocturnally and retreating by day to various depths within the vertical distribution range of ocean sunfish (e.g. Bruland & Silver 1981, Mills 1982, Purcell & Madin 1991). Therefore, it is possible that ocean sunfish dive during daylight hours to feed on gelatinous zooplankton at their diurnal depths below the thermocline. To further test this hypothesis, concurrent data on prey depth distributions, species composition and evidence of actual foraging is needed.

The vertical movements of ocean sunfish could also serve to increase the probability of prey detection as ocean sunfish ascend or descend through the water column. Ocean sunfish routinely dove to depths in excess of 50 m, and might have experienced increased prey density as they moved through the chlorophyll maxima (high concentrations of phytoplankton), a zone often associated with high zooplankton concentrations (Harris 1988). The chlorophyll maxima during our study were most often situated between 20 and 30 m depth, though the abundance and species composition of zooplankton associated with local chlorophyll maxima during tracking periods was not determined.

Regardless of the function of daytime diving behavior, there appears to be a strong motivation for ocean sunfish to dive to the colder waters below the thermocline. However, ocean sunfish rarely remained below the thermocline for more than a few minutes, even though surface temperatures in more northern parts of their range can be colder than the temperatures experienced during these dives (Miller & Lea 1972, Lee 1986). Brill et al. (1999) suggested that due to physiological limitations, the magnitude and rate of change in water temperature, rather than absolute temperature, may limit vertical movements in yellowfin tuna, blue marlin and striped marlin *Tetrapturus audax*, and the same may be true for ocean sunfish. Periodic ascents to the warm mixed layer, therefore, may be attempts by the fish to rewarm its core body temperature (i.e. behavioral thermoregulation), as was suggested for swordfish *Xiphias gladius* (Carey & Robison 1981). Rewarming of the body could be advantageous in terms of increased mobility, digestion, assimilation and growth rates (Wurtsbaugh & Neverman 1988). Dive 'recovery times' (i.e. the post-dive period) of ocean sunfish spent in the mixed layer increased significantly as a function of maximum dive depth, further support-

ing this hypothesis (Fig. 6). While only 42% of the variance in post-dive time was accounted for by maximum dive depth, it is likely that the varying masses of the fish, varying degrees of thermal variation from the surface to the maximum dive depths, and the amount of prey available to the fish at depth may also explain some of the variability. Further studies where core body temperature is monitored during dive activity are needed in order to better understand potential thermoregulation in ocean sunfish.

The vertical movements of ocean sunfish may also be limited by dissolved oxygen concentration. Four of the ocean sunfish reached depths approaching 150 m during dives. During the months of August through October, average O<sub>2</sub> concentrations at 150 m in the study area are between 2.5 and 3.0 ml l<sup>-1</sup> (Wyllie & Lynn 1971), a range known to induce avoidance responses in many marine fish species (reviewed in Davis 1975 & Brill 1994). While the physiology of ocean sunfish is not well studied, oxygen concentration may also play a role in defining their habitat preferences. Therefore, as noted by Carey & Robison (1981), recovery time spent in the mixed layer by pelagic fishes may be related not only to temperature, but to recovery from hypoxia, particularly for deeper-diving fishes.

In contrast to the daytime vertical movements of ocean sunfish, nocturnal vertical distribution was confined to the waters within the thermocline, and more typically to the mixed layer. This nocturnal compression of depth distribution was concomitant with a significant decrease in horizontal ROM, a pattern not previously described for any pelagic fish species. One possible explanation for this behavior is that ocean sunfish actively forage in the mixed layer by night, but have little need for movement because vertically migrating prey are near the surface. However, zooplankton are typically patchy in distribution (Steele 1976, Mackas et al. 1985) and greater horizontal movement might be expected from a fish exploiting a patchy resource in order to increase prey encounter rates. Another possibility is that ocean sunfish become relatively quiescent in the warmer mixed layer by night, which may confer many of the same metabolic advantages as the aforementioned post-dive period. This hypothesis is supported by the lower nighttime ROMs, as higher ROMs are usually presumed to be associated with foraging in other pelagic fishes (Sciarrotta & Nelson 1977).

Curiously, the only instance in which a fish descended below the thermocline during the nighttime period was also the greatest depth recorded for any tracked fish. Almost 1 h after sunset, Ocean Sunfish 1 rapidly dove to 392 m (corresponding to an ambient water temperature of 6.8°C). Depth data were taken on a minute-by-minute basis during this dive period, and

indicated that the fish descended at a rate of  $53 \text{ m min}^{-1}$ , 6 times faster than typical descents observed during daytime dives ( $8.4 \pm 5.6 \text{ m min}^{-1}$ ), and ascended at a rate of  $25 \text{ m min}^{-1}$ . Based on the incongruous time period, swift descent rate, and the fact that other deep dives were typically associated with the initial post-handling stress, this dive could possibly represent a predator avoidance response. Ocean sunfish predators include large sharks (Fergusson et al. 2000, S. Kohin pers. comm.) and California sea lions *Zalophus californianus* (T. Thys pers. comm.), both of which are commonly found in the waters off Santa Catalina Island.

### Implications for drift-gillnet fishery management

An extensive drift gillnet fishery exists off the western coast of the United States, with most fishing activity concentrated off southern California. Typically, fishing gear consists of a 2.2 km (length)  $\times$  30 to 40 m (depth) large-mesh gillnet that hangs vertically in the water column at a minimum depth of 12 m to avoid marine mammal interactions. Drift gillnets are usually set at dusk and retrieved before dawn (D. Cartamil pers. obs.).

Because the nocturnal depth preference of ocean sunfish observed in this study was above the thermocline, it is not surprising that this species is often caught in the upper portions of gillnets (D. Cartamil pers. obs.). Ocean sunfish tracked in this study were found to spend 75% of the time within the upper 20 m of the water column at night. These data suggest that lowering the minimum depth at which drift gillnets are set could result in a substantial decrease of ocean sunfish bycatch. Based on our data, increasing the minimum mandated net depth to 20 m would likely result in a reduction of ocean sunfish bycatch of 20 to 25%. However, the depth distributions of swordfish and thresher sharks *Alopias* sp. in the eastern Pacific are not well known, and therefore it is difficult to predict the effect of lowering drift gillnets on catch rates of these target species.

Additionally, NMFS observer data indicates that the majority of drift gillnet-caught ocean sunfish are released alive (D. Petersen, NMFS, pers. comm.), and therefore there is a general belief among management personnel and fishermen that ocean sunfish populations are unaffected by drift gillnet interactions. However, many of the released fish show obvious signs of fishery-induced trauma, including loss of protective mucus coating, abrasions, bleeding, and gill discoloration resulting from air exposure (D. Cartamil pers. obs.). Therefore, an assessment of post-release mortality is needed in order to make informed decisions regarding drift gillnet fishery management.

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