

George - with my compliments, Kim

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Movements of tiger sharks (*Galeocerdo cuvier*) in coastal Hawaiian waters

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Abstract Externally and internally implanted sonic transmitters were used to track the movements of eight tiger sharks (*Galeocerdo cuvier*) ranging between 200 and 417 cm total length (TL), captured by hook-and-line on the south coast of Oahu, Hawaii, between 1993 and 1997. Attachment of the transmitters was facilitated by the fact that captured sharks exhibited tonic immobility when restrained and inverted at the side of the tagging vessel. Three common themes emerged from the horizontal movements of the tracked sharks: (1) offshore movements away from the island, (2) extended periods of directed, "straight-line" swimming, (3) orientation to the Penguin Banks – a shallow bank located ≈ 35 km from the release point. In shallow water (< 300 m) the sharks swam predominantly close to the bottom, in open water (> 300 m) they swam within the mixed layer at depths of ~ 80 m. One shark dove briefly to 335 m. The average estimated swimming speed of sharks traversing open water was 0.29 body length (BL) s^{-1} . Two sharks were recaptured after termination of the tracks; one of these sharks was recaptured twice, with a total time at liberty of 377 d. The data suggest that Hawaiian tiger sharks move within large home ranges and that they can efficiently navigate between distant parts of their range, even when this requires crossing open ocean waters.

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Introduction

In Hawaii, the long-term rate of shark attacks on humans is low, averaging ≈ 2.0 confirmed attacks per year over the past several decades (Wetherbee et al. 1994). Between 1958 and 1997, only three confirmed fatal shark attacks were reported. However, two of these fatal attacks occurred within a 12 mo period in 1990 and 1991, and several other, non-fatal attacks occurred during the same period (Wetherbee et al. 1994). This series of attacks rekindled widespread public debate about the appropriateness and the feasibility of shark-control programs. Because most shark attacks in Hawaii are probably attributable to tiger sharks (*Galeocerdo cuvier*; Randall 1992), most of the discussion focused on the behavior of this species. In fact, an improved understanding of the behavior of tiger sharks has pertinence beyond Hawaii, since tiger sharks are circumglobal in distribution and are considered one of the world's most dangerous species (Baldrige 1973; Compagno 1984; Randall 1992).

Previous shark-culling programs conducted in Hawaii between 1959 and 1976 included prolonged, statewide fishing that killed nearly 5000 sharks of several species (Tester 1969; Wetherbee et al. 1994) but, despite killing over 500 tiger sharks in these programs, there is no evidence that this widespread fishing effort had an effect on the rate of attacks on humans in Hawaii (Wetherbee et al. 1994). Consequently, much of the recent debate focused on whether there are alternative methods of addressing the perception that unchecked shark populations pose a threat to public safety. For instance, rather than culling large numbers of sharks from throughout the region, could fishing effort focused on a specific area result in a lasting, localized depletion of dangerous sharks in that area? A related question is whether fishing for sharks at the site of an attack soon after it occurred would be likely to capture the shark responsible for that attack.

An understanding of the movement patterns of tiger sharks in Hawaiian waters is critical to evaluation of the potential effectiveness of localized fishing; it would be easier to reduce the numbers of strongly site-attached sharks occupying stable home ranges than wide-ranging individuals with no affiliation to a home range. However, there have been no studies of the daily movements of tiger sharks or other potentially dangerous sharks in areas where there are large numbers of humans in the water. Acoustic telemetry has been used to track the movements of white sharks, *Carcharodon carcharias* (Carey et al. 1982; Strong et al. 1992), mako sharks, *Isurus oxyrinchus* (Carey et al. 1981; Casey and Kohler 1992; Holts and Bedford 1993), scalloped hammerheads, *Sphyrna lewini* (Klimley and Nelson 1984; Klimley 1993) and blue sharks, *Prionace glauca* (Sciarrotta and Nelson 1977; Carey and Scharold 1990), but these tracks occurred far offshore or away from swimming beaches.

One tiger shark was tracked with an acoustic pinger for 48 h around French Frigate Shoals, in the North-western Hawaiian Islands (Tricas et al. 1981), but French Frigate Shoals is a low, dry, uninhabited atoll, whereas the main Hawaiian Islands are high, wet, and have large human populations. The topography of the islands is pertinent because freshwater streams and estuaries have great impact on the geography of coral reef ecosystems and therefore on the movements of their inhabitants. Also, human and agricultural refuse is much more prevalent around populated coastlines and is often transported down rivers and estuaries. This anthropogenic material can be a source of food for tiger sharks (Lowe et al. 1996) and could potentially influence their behavior and movement patterns. The distribution and behavior of other shark species differs between the

high and low Hawaiian Islands (Wetherbee et al. 1996, 1997).

The specific focus of the current study was to determine the short-term movement patterns of large tiger sharks captured close to areas of high recreational ocean use in Hawaii and to use the results to evaluate whether localized fishing effort could cause local depletions of tiger-shark populations. Based on the fairly restricted movements of the shark tracked at French Frigate Shoals (Tricas et al. 1981) and what was previously thought to be the behavior of tiger sharks in coastal waters (Compagno 1984), we hypothesized that tiger sharks near Oahu would display predominantly coastal behavior and possibly exhibit repeated diel movements to the same parts of the reef; i.e. they would display mesoscale site-fidelity.

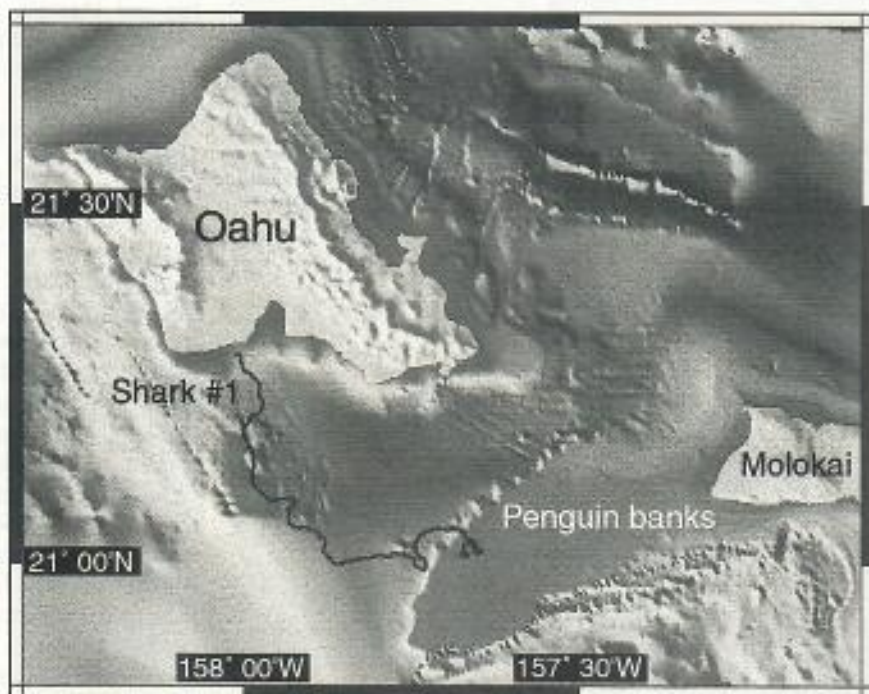
Materials and methods

Collection

Fishing for tiger sharks (*Galeocerdo cuvier*) was conducted at various locations along an 11 km section of the south shore of Oahu, Hawaii (see Fig. 1). The eastern edge of this fishing area is < 5 km from resort beaches that are heavily used for swimming and other water sports. Longlines were set near the bottom in water 17 to 75 m deep, \approx 3.5 km offshore. Branch lines comprised of \approx 10 m of polypropylene rope and 1.5 m of stainless-steel braided cable-leader were attached by snap-connectors to the main line at intervals of \approx 40 m. Each branch line terminated in a 12/0 hook baited with tuna heads or other fish parts. The lines were set at dusk and retrieved the following morning after soak times of between 8 and 13 h.

When a shark was caught, the branch line was unsnapped from the main line to facilitate manipulation. The branch line and leader, together with a rope noose placed around the caudal peduncle,

Fig. 1 *Galeocerdo cuvier*. Track of Shark No. 1, which departed capture area immediately after release and traversed Kaiwi Channel between south coast of Oahu and Penguin Banks (35 km from release site). At time track was terminated, the shark was meandering on the "flats" on top of bank



were used to restrain the captured shark at the side of a 6.0 m skiff. While still in the water, the shark was rolled onto its back and, after a period ranging from a few seconds to a few minutes, this inversion resulted in onset of tonic immobility (Gruber and Zlotkin 1982; Henningsen 1994). The shark was then measured and sexed, and an acoustic transmitter was attached externally or surgically implanted. Only sharks that appeared active on the line and were cleanly hooked in the mouth with no signs of significant injury or bleeding were used for the tracking experiments. The hooks were removed from the sharks prior to release and commencement of tracking.

Acoustic tracking

External acoustic transmitters (16 mm diam, 75 mm long, weight in water ≈ 10 g) with a nominal life span of 3 d were attached to the dorsal musculature with a stainless steel barb (e.g. Klimley and Nelson 1984; Holland et al. 1990b; Holts and Bedford 1993). Internal transmitters (47 mm diam, 197 mm long, weight in water 135 g) with a nominal life span of 8 to 12 mo were placed intraperitoneally through a 12 cm incision in the abdominal wall. Internal transmitters were coated with a 7:3 mixture of bee and paraffin wax to reduce immunological response and physical irritation. Incisions were sutured with nylon thread. Surgical implantation was completed within an average of 10 min of restraining the shark. Several of the external and internal transmitters were equipped with depth sensors. Four sharks were fitted with external transmitters and five with internally implanted transmitters. Because one shark was tracked twice, the nine tracks reported here were obtained from a total of eight different animals (7 males and 2 females) ranging between 200 and 417 cm TL.

Only tiger sharks > 2.0 m TL which were cleanly hooked were selected for acoustic tracking. All captured sharks were tagged with a standard "M" capsule tag bearing a reward message and contact phone-number (Casey and Kohler 1992). These external identification tags were anchored in the dorsal musculature near the dorsal fin. Acoustic tracking was conducted from a 12 m vessel equipped with a directional hydrophone and an acoustic receiver (VR-60, VEMCO, Nova Scotia), and GPS. The GPS and acoustic receiver were both linked to a computer for automatic data storage (Holland et al. 1985; Lowe et al. 1998). Vessel location was assumed to be the same as the shark's location; normally the vessel maintained a position ≈ 300 m away from the shark.

Results

Tracking of *Galeocerdo cuvier* took place between September 1993 and May 1997. Nine tracks were acquired, ranging in duration from 7 to 50 h (Table 1).

Horizontal movements

There were several behavioral characteristics shared by all or most of the tracked sharks. These included: (1)

extensive offshore movements, (2) periods of very directed (straight-line) swimming, and (3) movements toward and subsequent orientation to the Penguin Banks (a large, flat-topped, steep-sided, finger-like underwater extension of the island of Molokai located ≈ 32 km southeast of Oahu across the Kaiwi Channel; Fig. 1). To illustrate the horizontal movements of the tracked tiger sharks, three representative tracks are presented here in detail.

Shark No 1: external transmitter

This immature male shark was tracked for 30 h. Immediately upon release, it swam off the fringing reef surrounding Oahu and into the adjacent deep water of the Kaiwi Channel. This shark first moved south and then southwest until, after 20 h, it encountered the Penguin Banks at 06:15 hrs on the second day (Fig. 1). After initial contact with the slope of the bank, the shark moved parallel with the bank for 4 h before moving up onto "flats" (≈ 50 m deep) on the top of the bank. At the end of the track the shark was still meandering around in the same part of flats that it had occupied for the preceding 6 h. Its average speed over ground while crossing the channel was 3.6 km h^{-1} (0.5 BL s^{-1}).

Shark No 2: external transmitter

Upon release, this large female shark (probably mature: Randall 1992) stayed close to the bottom, and for 12 h made frequent turns as it moved back and forth along the reef slope adjacent to Barbers Point, Oahu (Fig. 2). About 0.5 h after sunset, this shark also headed out to sea and kept a very direct course across the Kaiwi Channel. When the track was terminated after 24 h, the shark was within 2 km of the Penguin Banks.

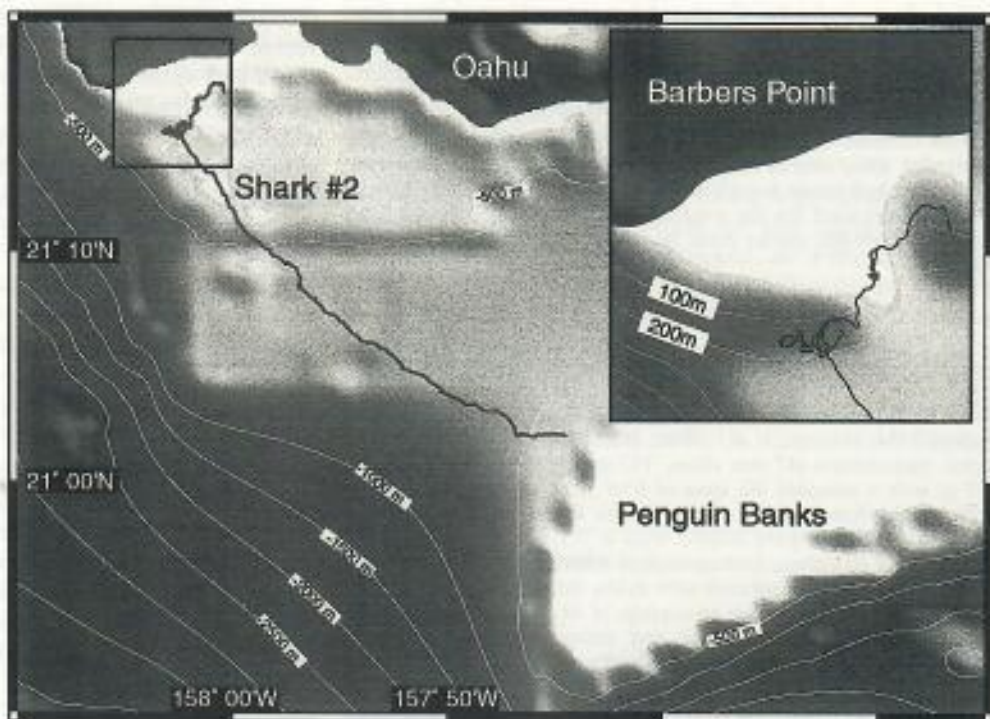
Shark No 5: internal transmitter

This large male shark was tracked on two different occasions separated by 314 d. The first track lasted 30 h, the second 31 h. During its first track (Track 5A), it moved directly offshore upon release and moved steadily southwest. When the track was terminated, the shark

Table 1 *Galeocerdo cuvier*. Summary of acoustic telemetry tracks of tiger sharks off south shore of Oahu, Hawaii (M male; F female; Ext external; Int internal)

Track/Shark No.	Date started	Duration (h)	Total length (cm) and sex	Depth data recorded	Tag type
1	22 Sep 1993	30	200 M	Yes	Ext
2	22 Oct 1993	24	360 F	Yes	Ext
3	10 May 1994	20	217 M	No	Ext
4	6 Jul 1994	19	305 M	Yes	Int
5A	12 Oct 1994	30	304 M	No	Int
5B	22 Aug 1995	31	319 M	No	Int
6	20 Jan 1995	49	315 M	Yes	Ext
7	24 Oct 1995	7	342 M	No	Int
8	8 May 1997	50	417 F	No	Int

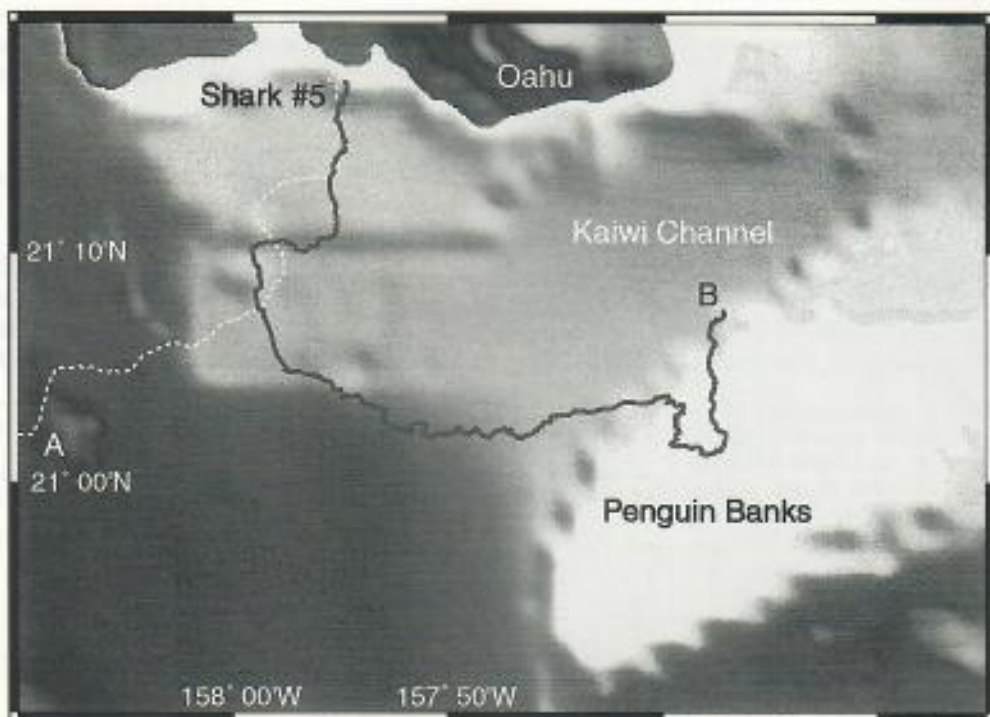
Fig. 2 *Galeocerdo cuvier*. Track of Shark No. 2, which meandered along reef slope adjacent to Barbers Point for 12 h (inset) before embarking on 12 h period of very directed swimming towards Penguin Banks



was located ≈ 23 km south of Barbers Point, Oahu. During its second track, (Track 5B), the direction of movement of this shark was similar to all but one of the other tracked sharks. That is, after it moved offshore, it adopted a heading that took it steadily towards the Penguin Banks (Fig. 3). The second track began when the shark was recaptured at the same location from

which it had been tagged and tracked 314 d earlier (Track 5A). Because the original internal transmitter was no longer operating, a second transmitter was inserted into the abdominal cavity. This time, the shark moved steadily offshore in a southeasterly direction for 22 h, reaching the Penguin Banks at 07:15 hrs the following day. When the shark reached the Penguin Banks,

Fig. 3 *Galeocerdo cuvier*. Two tracks of Shark No. 5. Track 5A (white dotted line) consisted of southwesterly movements to a point 23 km south of Oahu, where track terminated; Track 5B (black line) initially followed very similar path before shark turned east and proceeded to Penguin Banks



it moved up onto the flats where it meandered about until the track was terminated after 31 h.

Shark No. 5 was caught a third time, again at the initial point of release, 63 d after termination of Track 5B. In other words, it had returned from the Penguin Banks to Oahu where it was recaptured 377 d after initial capture and release.

All the other five tracked sharks moved offshore upon release, and three of these five made very directed movements towards the Penguin Banks. Thus, after departing Oahu, 6 of the 8 tracked sharks exhibited directed movements towards the Penguin Banks. The similarity of these tracks is remarkable (Fig. 4). Of the remaining two, Shark No. 3 also appeared to be moving towards the Penguin Banks when it was lost after 20 h in deteriorating sea conditions ≈ 5.1 km south of Diamond Head, Oahu. However, this shark was subsequently recaptured at the initial site of release 127 d after termination of the track. Thus, 2 of the 8 tracked sharks were recaptured (one twice) at their initial points of release.

Rate of movement

Movement rates (speed over ground) of sharks moving in shallow (<300 m) and deep water were analyzed separately because of the obvious differences in their behavior in these two environments. When the sharks were in shallow water, their behavior involved frequent turning and looping (e.g. Shark No. 2: Fig. 2). These meandering patterns were often too fine to be accurately traced by the tracking vessel, so estimates of swimming

speed were only derived from sharks in deep, offshore water where they displayed extended periods (>1 h) of straight-line swimming. The average estimated swimming speeds derived from 53 hourly-segments from six sharks in open water was 3.85 km h^{-1} (0.45 SD) or 0.29 BL s^{-1} (0.04 SD). There was no evidence of trauma-induced influence on the rate of movement following release. That is, there were no consistent patterns in change of rate of movement (speed over ground) with time elapsed following release.

Vertical movements

Depth data were obtained from four sharks, three with external transmitters and one with an internal transmitter. These sharks exhibited different vertical movements, depending on whether they were in deep water (>300 m deep) or associated with the fringing reefs of Oahu or the Penguin Banks. Most sharks moved offshore immediately after release, but Shark No. 2 spent the first 12 h of the track meandering close to the bottom near Barbers Point. As it departed the Oahu shoreline, it followed the reef contour down to a depth of nearly 200 m before ascending to depths between 6 and 118 m as it moved across open water (Fig. 5).

During transit across the Kaiwi Channel, Shark No. 1 made one dive to 335 m before returning almost to the surface (Fig. 6). The descending phase (from 70 to 335 m) took 5 min, and the round-trip down and back to 70 m lasted about 17 min. Another dive (to 290 m) occurred when the shark was close to the Penguin Banks. Upon reaching the banks, the shark stayed close

Fig. 4 *Galeocerdo cuvier*. Composite plot of all nine shark tracks, illustrating universal offshore movement following tag-and-release and predominant tendency for directed movements towards Penguin Banks (numbers are end positions of various tracks)

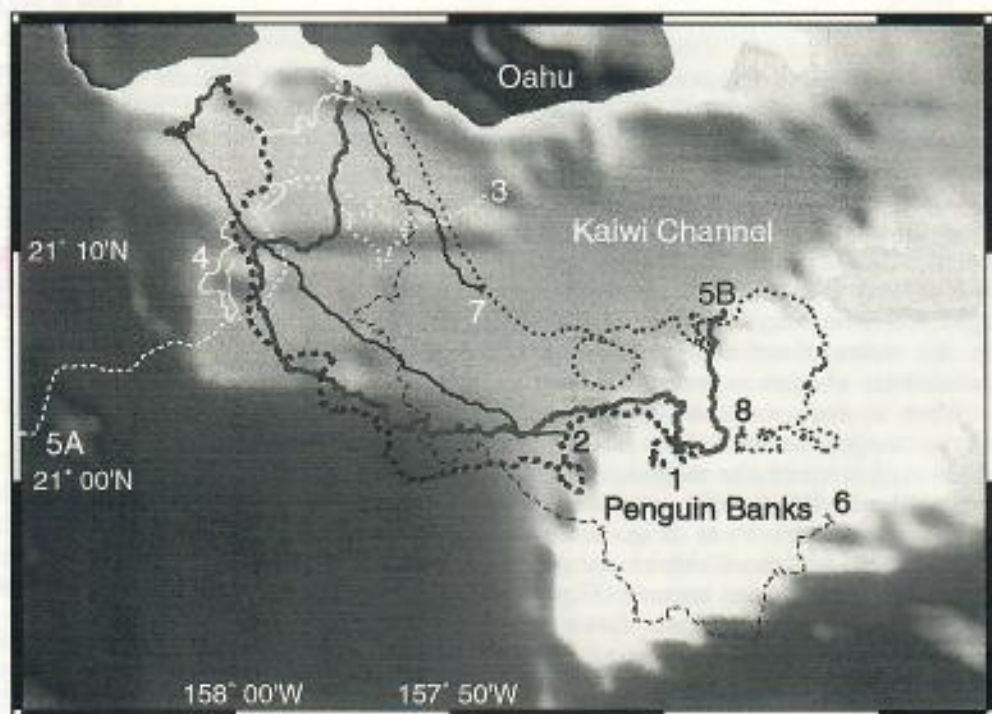


Fig. 5 *Galeocerdo cuvier*. Vertical movements of Shark No. 2 very close to bottom (heavy shading) while moving on reef near Barbers Point. Just after dark (light shading), shark followed reef slope down to 200 m as it left Oahu. Its movements thereafter were restricted to top 100 m as it crossed Kaiwi Channel

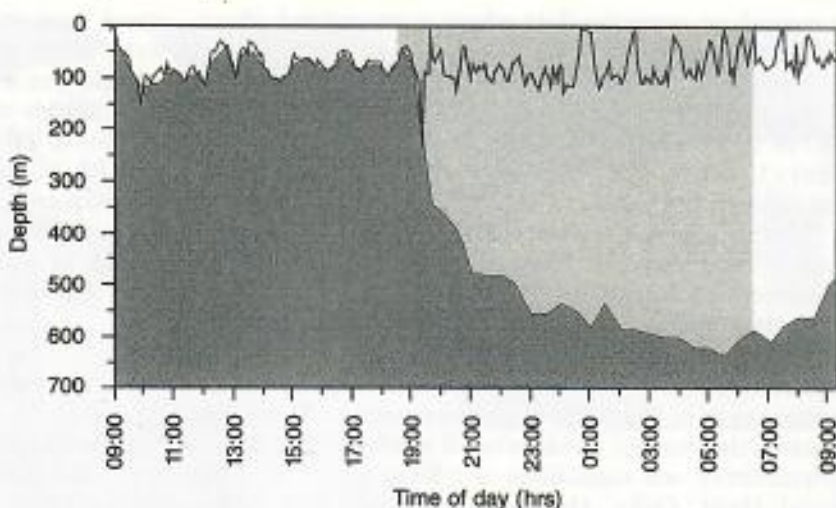
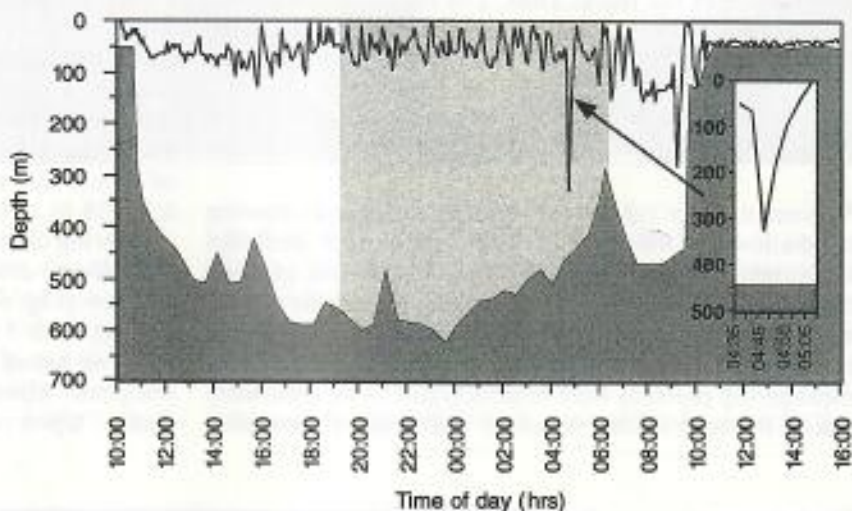


Fig. 6 *Galeocerdo cuvier*. Vertical movements of Shark No. 1, including two deep dives, one during nighttime to 335 m (inset) the other to 290 m as shark neared Penguin Banks



to the bottom and followed the contour of the bank slope for 1.5 h at depths of 120 to 140 m before going onto the top of the banks (50 m), where it remained close to the bottom.

While crossing the Kaiwi Channel, Shark No. 6 showed a statistically significant (Student's $t = -7.87$, $p = 0.005$, $df = 233$) diel shift in average depth from 50.5 m (19.3 SD) during the day to 72.4 m (23.3 SD) at night. There were no diel changes in depth demonstrated by the other three sharks carrying depth-sensitive transmitters whether in deep or shallow water.

When in open water away from reef structure, the sharks ranged between the surface and depths of > 330 m, but spent the majority of time ($> 72\%$) between 40 and 100 m, with a peak frequency between depths of 60 and 80 m (Fig. 7). When in shallow water (< 300 m), most sharks spent the majority of time very close to the bottom (Figs. 5, 6), including following the reef contour down to considerable depths as they made their transition to travelling across open water. Once in open water, the sharks moved closer to the surface. Shark No. 6 was some-

what different in showing frequent excursions between the bottom and the surface while in shallow water over the Penguin Banks.

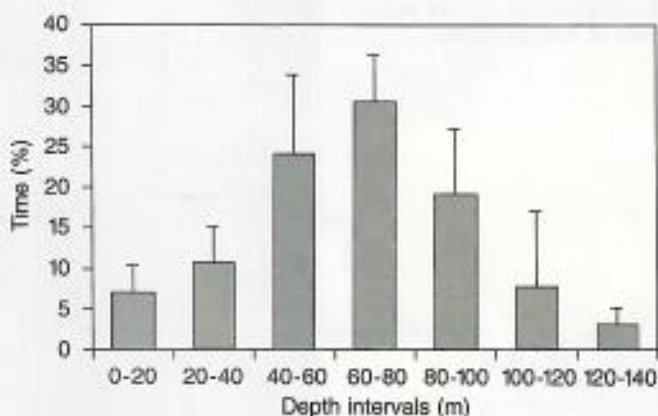


Fig. 7 *Galeocerdo cuvier*. Depth-frequency histogram of four sharks carrying depth-sensitive tags. Data are only for periods when the sharks were in deep (> 300 m) water. Depths combine daytime and nighttime movements

Discussion

The longline hook-and-line method used to capture *Galeocerdo cuvier* resulted in very low mortality rates for captured tiger sharks (<5%). This was probably because the long branch lines enabled the sharks to move continuously after being hooked. None of the sharks chosen for tracking died following release. The tonic-immobility response of sharks restrained upside down at the side of the boat greatly facilitated removal of the hooks and the attachment and implantation of the transmitters. This method probably significantly reduced the trauma experienced by the sharks. Certainly, they swam away vigorously immediately following release.

Many of the large females caught during this study were severely scarred and disfigured by bite marks probably associated with mating behavior, and the incision used to implant the transmitters did not appear to be qualitatively as severe as some of the naturally occurring wounds. Shark No. 5, which received two implanted transmitters (and was recaptured after both) displayed barely visible, completely healed wounds when recaptured. Similarly successful surgical internal-tag implantation has been used on gray reef and lemon sharks which, as in the current study, showed no differences in behavior when external or internal tags were used (McKibben and Nelson 1986; Gruber et al. 1988). Both types of transmitters were <1% of the sharks' weight in air. External transmitters could be applied much more quickly than surgically implanted transmitters but external transmitters have a shorter battery life and are more prone to detachment. Internal transmitters have zero drag, longer battery life, greater range and probably longer retention times.

The results of this study do not support our initial hypothesis that these sharks maintain coastal, mesoscale home ranges that they patrol on a daily basis. Consequently, the ultimate benefit of using long-life, implanted transmitters to achieve long-term monitoring of movement patterns was not realized in this study. The fact that the sharks made long-range, offshore movements precluded frequent crew changes or the re-acquisition of the sharks necessary to obtain long-term, repeated tracks.

The effect of tagging trauma on the movements of any tagged fish is difficult to evaluate. The end of recovery periods can sometimes be inferred from changes in swimming speed or depth (Gruber et al. 1988; Holland et al. 1990b; Lowe et al. 1998). In the present study, there were no instances of elevated swimming rate or other obvious trauma response following release. The striking similarity of initial heading among tracks indicates that sharks were probably not disoriented even in the periods immediately following release. In addition, all these sharks abandoned their highly directional movements once they encountered the Penguin Banks. That is, they did not maintain their straight trajectories

regardless of the habitat type through which they were moving. This suggests that the highly directional cross-channel movements were not simply trauma-induced flight behaviors. Also, Shark No. 2 meandered around on the south shore of Oahu for the first 12 h after release before heading across the Kaiwi Channel on a path very similar to that of the sharks that left Oahu immediately upon release. This delayed onset of cross-channel movement by Shark No. 2 reinforces the interpretation that the cross-channel movements of the other sharks represented a normal component of this species' behavioral repertoire. Whether or not these individuals would have made these crossings at these specific times and in the absence of being caught and tagged can not be known.

When in shallow water, the tiger sharks displayed horizontal movements similar to the previously described movements of shallow-water species of shark. That is, the tiger sharks turned frequently, had low overall rates of horizontal movement, and generally stayed close to the bottom. This limited range of movement is similar to that of lemon sharks in Bimini lagoon (Gruber et al. 1988) and for gray reef sharks in the lagoon at Enewetok atoll (McKibben and Nelson 1986).

In contrast, when the tiger sharks moved offshore, their horizontal movements became similar to those previously reported for pelagic species of shark and teleosts. In previous tracking studies, pelagic sharks such as blue sharks (Carey and Scharold 1990), mako sharks (Carey et al. 1981; Holts and Bedford 1993), and white sharks tracked in pelagic surroundings (Carey et al. 1982) have all demonstrated prolonged, highly directional and extensive horizontal movements similar to those displayed by the tiger sharks in this study as they traversed the channel between Oahu and the Penguin Banks.

Directional swimming, with extensive periods of straight-line movement, has also been demonstrated by scalloped hammerhead sharks (*Sphyrna lewini*) making nightly excursions away from daytime aggregations associated with seamounts in the Gulf of California (Klimley 1993). These hammerhead excursions were apparently round-trip nocturnal foraging events and, after travelling up to 20 km, the hammerheads returned to their starting points after each excursion. In contrast, the uni-directional tracks of our tiger sharks did not exhibit diel cyclicity, and appeared to represent movements from one section of a home range to another.

Marlin and tunas have also shown pelagic navigational ability and, in fact, the behavior of yellowfin tuna (*Thunnus albacares*) moving along quite straight routes between widely spaced fish-aggregating devices (FADs) shows the most similarity to the cross-channel movements of these tiger sharks (Holland et al. 1990a; Marsac et al. 1996). In both cases (tunas between FADs, tiger sharks between Oahu and the Penguin Banks), the highly directional movements strongly suggest that these destinations had been previously visited by these individuals. They were able to navigate efficiently between

distant points even when this involved movements that were predominantly in the pelagic, offshore realm. The sensory mechanisms that underlie these directed movement patterns are not understood but, in the case of both the tunas and the sharks, a magnetic orientation capability may exist. This sensory modality may allow these animals to use the complex contours of the earth's magnetic field to find their way through open-ocean waters (Walker 1984; Walker et al. 1984; Klimley 1993).

A pelagic component to the movements of tiger sharks in the central Pacific has previously been indicated by the fact that tiger sharks are taken by tuna long-line fishing gear in locations far away from land (Polovina and Lau 1993). Also, in the Atlantic, tiger sharks tagged off of the east coast of the USA have been recaptured off the coast of Africa (Anonymous 1997), which indicates that at least some Atlantic tiger sharks leave the continental shelf. The current results suggest that open-ocean movements are not uncommon for both sub-adult and mature tiger sharks.

While in the pelagic phase of their movements, the vertical component of the behavior of these tiger sharks was predominantly in the upper 100 m, with distribution centered around depths of 60 to 80 m. This is the typical depth of the thermocline in Hawaiian waters (Holland et al. 1990a), and indicates that these sharks were predominantly in the mixed layer and possibly using the temperature discontinuity of the thermocline as a vertical reference point. Movements predominantly restricted to the mixed layer have also been demonstrated in mako and blue sharks (Sciarrotta and Nelson 1977; Holts and Bedford 1993), and Carey (1983) tracked a white shark in the Atlantic which appeared to use the thermocline as an orientation cue.

Tracks of pelagic sharks and teleosts show that individuals of most species move closer to the surface after nightfall (Holland et al. 1990a, b). In some cases, when pelagic fish are already very close to the surface they move deeper after nightfall, as did Tiger Shark No. 6 in the present study. This deeper nighttime behavior has been observed in mahimahi (*Coryphaena hippurus*; Holland unpublished results), and may be in response to changes in the surrounding fauna after nightfall.

There are also reports of blue sharks completely ignoring the thermocline and regularly and repeatedly diving to great depths. This has been interpreted as hunting behavior (Carey 1983). In the current study, the tiger sharks showed considerable vertical plasticity and an ability to dive quickly to deep depths. However, these dives were infrequent and may have served as an orientation mechanism for the sharks which helped to determine if they were leaving or approaching the shallow banks that, in this case, appeared to be their destination (for example, see vertical track of Shark No. 1 in Fig. 6).

The vertical movements of the tiger sharks tracked in this study correspond with those of the tiger shark tracked around French Frigate Shoals atoll by Tricas et al. (1981), which also remained close to the bottom when in shallow water and predominantly moved

within the top 100 m of water when it moved offshore.

The large distances moved by all the tiger sharks we tracked and the directness of most of the tracks indicate that these sharks routinely travel large distances, and that tiger sharks can learn to navigate efficiently between distant locations even when those locations are separated by deep open-ocean water. These data, together with the fact that 25% of the sharks were recaptured (one twice, and one after being tracked to the Penguin Banks), strongly suggest that a significant portion of the Hawaiian tiger-shark population maintains a large home range which can include more than one island and involves traversing offshore waters. In the case of the specific sharks tracked in this study, their home ranges include at least the south shore of Oahu and the Penguin Banks.

The apparently large size of the home ranges of these sharks and their high mobility both indicate that selective culling efforts focusing for short periods on a single section of coastline would probably not be effective in reducing the numbers of sharks visiting that particular section of coastline. That is, the shark there today may have come from a distant location in the preceding 24 h and may be a long way away tomorrow. Sharks moving past one particular area are likely to have other, remote components to their home range, and they may stay in those distant locations for prolonged periods of time. If this is the case, continuous fishing would be required to deplete the population of sharks that, sooner or later, would pass through any given location. Similarly, the high mobility of individual sharks tracked in this study indicates that fishing for a "culprit" after an attack is unlikely to be effective.

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