Dive-depth distribution of loggerhead (*Carretta carretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific: Might deep longline sets catch fewer turtles?

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The Hawaii-based longline fishery operates over a large area in the central North Pacific, from the equator to latitude 45°N, between longitudes 130°W and 180°W. In 2000, 125 vessels were active in the fishery, producing total landings estimated at 24 million pounds and exvessel (wholesale) revenues of $50 million. The target species include bigeye tuna *(Thunnus obesus)*, yellowfin tuna (*T. albacares*), and albacore tuna (*T. alalunga*), and swordfish (*Xiphias gladius*).

Caught incidentally with these target species are leatherback (*Dermochelys coriacea*), loggerhead (*Carretta carretta)*, olive ridley (*Lepidochelys olivacea*), and green (*Chelonia mydas*) sea turtles.

Over the period 1994–99, it was estimated that an annual average of 418 loggerhead, 112 leatherback, 146 olive ridley, and 40 green sea turtles were caught in the Hawaii-based longline fishery (McCracken[1]).

Historically, the Hawaii longline fishery has set longlines considerably shallower than 100 m to target swordfish (*Xiphias gladius*) or substantially deeper than 100 m to target bigeye tuna. Incidental hookings of loggerhead turtles have been reported in the Hawaii longline fishery observer data, which cover about 5% of the total annual effort. Analyses of these data found that loggerhead turtles were caught only when gear was set shallow enough to target swordfish, primarily in the northern portion of the fishing ground. No loggerhead sea turtles were caught when longline gear was set deep to target bigeye tuna, primarily in the southern portion of the fishing ground. These analyses suggest that a ban of shallow sets in the fishery since 1 April 2001 may reduce future incidental catches of loggerhead sea turtles. However, analyses based only on observer data suffer from the limited observer coverage and the dependence between depth of setting and area fished. For example, swordfish are targeted at night in the north, whereas tuna are targeted during the day in the south. To better understand the depths inhabited by sea turtles, we used diving depth distributions collected from satellite-linked dive recorders attached to two loggerhead and two olive ridley sea turtles caught and released in the Hawaii-based longline fishery. Although other studies on the dive depths of olive ridley and loggerhead sea turtles have been conducted in the Pacific, these have been conducted with sea turtles in coastal areas rather than in the oceanic central Pacific (Sakamoto et al., 1993; Beavers and Cassano, 1996).

Materials and methods

We attached Wildlife Computer Argos satellite-linked depth recorders (SDR-T10) to two loggerhead and two olive ridley sea turtles that had been caught with commercial longline fishing gear. One loggerhead and one olive ridley were hooked in the mouth and were released after the hook and line had been removed. The other loggerhead and olive ridley sea turtle had deeply ingested hooks, and for both of these turtles the fishing line was cut close to the mouth but the hook was not removed. Trained observers on the fishing vessel attached transmitters to the carapace of each of the four sea turtles, using fiberglass cloth strips and polyester resin patterned after the method presented in Balazs et al. (1996). The observers noted that all four sea turtles swam vigorously away after release.

[1] McCracken, M. L. 2000. Estimation of sea turtle take and mortality in the Hawaiian longline fisheries. Southwest Fish. Sci. Cent. Admin. Rep. H-00-06. 29 p. Southwest Fish. Sci. Cent., Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.

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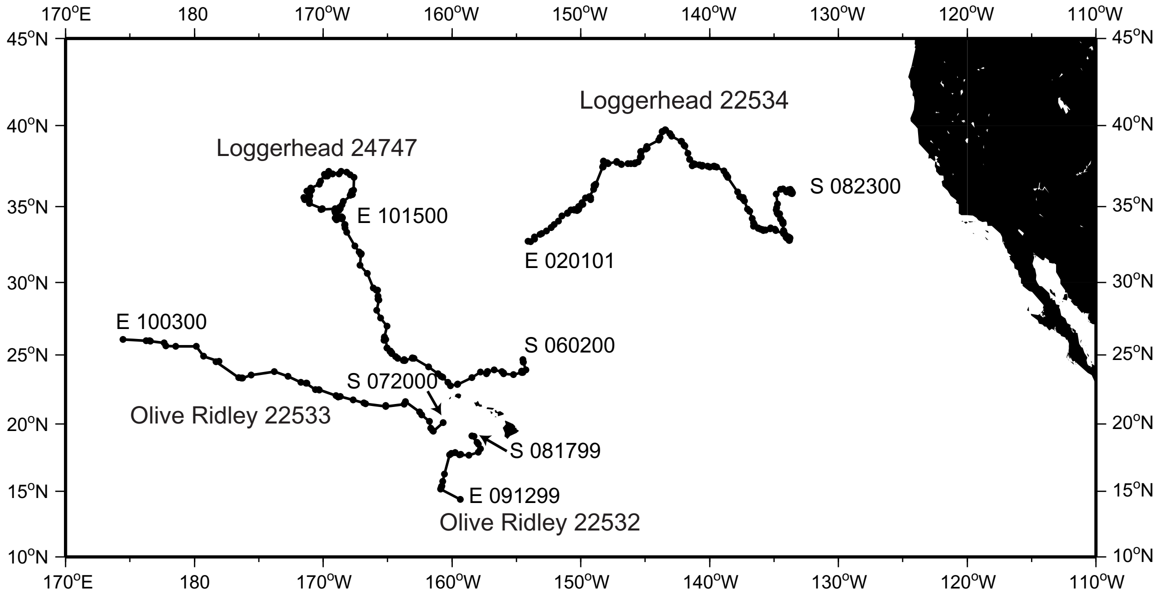

Figure 1

The start (S) and end (E) dates and track lines for the four turtles with satellite-linked dive recorders.

Data on daily location of the turtles were estimated from the signals received by the Argos receiver on a NOAA satellite. The position data were edited, and only the single most accurate daily position was plotted. The accuracy of each position was estimated by Argos as a function of the number and configuration of satellites and the number of transmissions received. Data on the dive behavior transmitted by the Argos receiver were not individual dive profiles but rather frequency distributions of time at depth, dive duration, and maximum dive depth, aggregated over four 6-hour periods and binned in specific depth or time intervals. The lower range of the depth bins (in meters) for the time-at-depth distributions were 1, 3, 5, 10, 15, 25, 35, 50, 60, 75, 100, 125, 150, 150+. Each time the turtle descended below 2 m, it was recorded as a dive. The lower range of the depth bins (in meters) for the dive-depth distributions were 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 100, 150, 150+. The 6-hour periods over which the time-at-depth and dive-depth data were pooled were programed in Hawaii standard time as 2100–0300, 0300–0900, 0900–1500, and 1500–2100 h. One period was night, another mid-day; one included dawn, the other dusk. Mean time-at-depth and dive-depth distributions for each turtle in each of the four time periods were computed as the average of all frequency distributions for each 6-hour period. Mean time-at-depth and dive-depth distribution for the combined four time periods for each species were computed as the average of the four mean time-at-depth and dive depth distributions for each turtle, then averaged by species.

Finally, after every 20 transmissions a special status message that contained technical data about the operation of the transmitter and the maximum dive depth of that day was transmitted. Both the loggerhead and the olive ridley sea turtles made some dives below 150 m; however, the histogram data did not indicate how much deeper than 150 m these animals dived. The maximum dives sent in the status messages were used to obtain some data on the deep dives.

Results

The positions of the four turtles showed that the turtles were occupying the characteristic habitats for each species: the loggerhead sea turtles were found in the northern portion of the subtropical gyre, and the olive ridley sea turtles were found farther south, well within the center of the subtropical gyre (Fig. 1). Loggerhead no. 24747, which was released with the hook removed, measured 83 cm (straight carapace length (SCL)) and transmitted data for 5.4 months. Loggerhead no. 22534, released with the hook deeply ingested, measured 61 cm SCL and transmitted data for 5.2 months. Olive ridley no. 22533, released with the hook deeply ingested, measured 57 cm SCL and transmitted data for 3.4 months. Olive ridley no. 22532, which was released after a hook was removed, measured 58 cm SCL and transmitted data for 0.8 months.

The time-at-depth frequency distributions for day and night periods for each of the sea turtles showed consistent diurnal and species differences in their dive-depth distributions (Fig. 2). The turtles spent more time at the surface during the day than at night and also dived deeper during the day (Fig. 2). We do not show the dive-depth distribution for the dawn and dusk periods, but these frequency distributions fell between the distribution for day and night periods.

Because it can often take as long as 20 hours to completely set and retrieve a longline, we examined time-at-

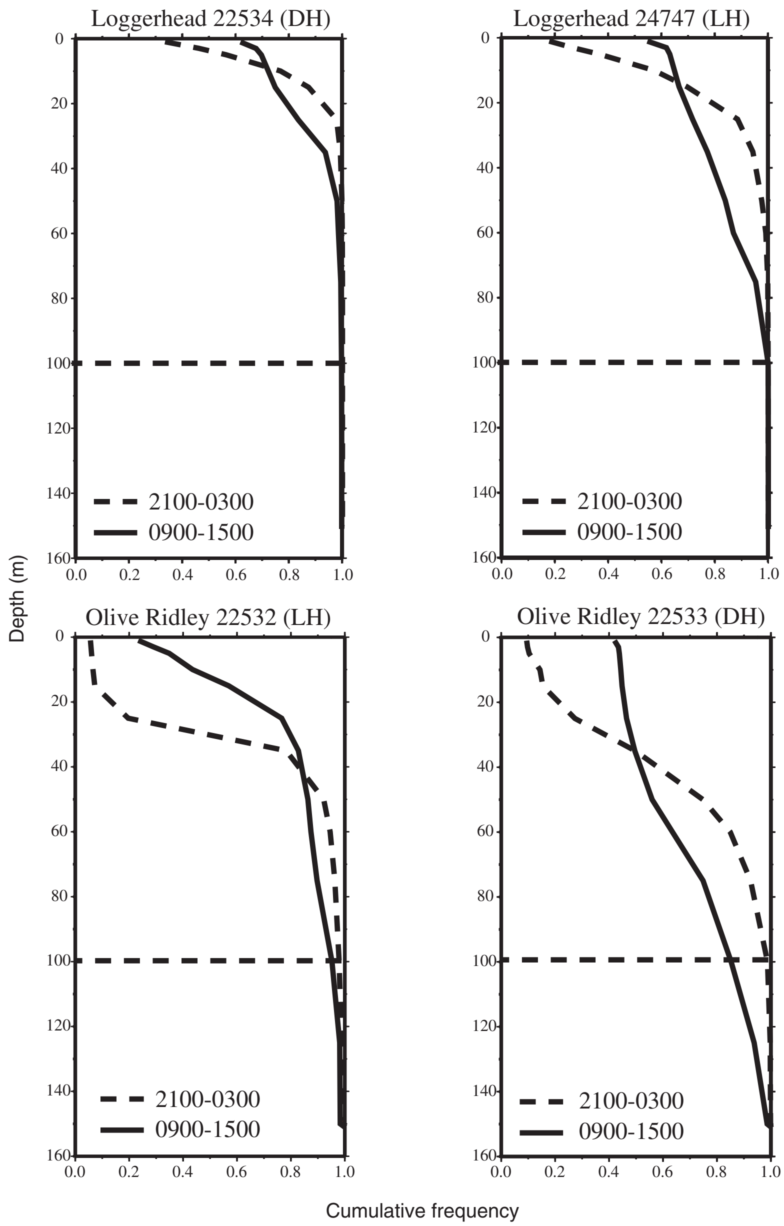

Figure 2

Time-at-depth cumulative frequency distributions for day (0900–1500 h) and night (2100–0300 h) periods for each of the four turtles. The 100 m reference depth is noted with a dashed line. DH indicates that the turtle was released with the hook deeply ingested, LH indicates that the turtle was lightly hooked and released with the hook removed.

depth and dive-depth distributions pooled over the four 6-hour time periods by species. The time-at-depth frequency distribution showed that the loggerhead sea turtles spent about 40% of their time in the top meter and virtually all their time shallower than 100 m (Fig. 3). We also examined the frequency distribution of the maximum depth of each dive and the deepest dive in a 24-hour period. The cumulative distribution of maximum depth of each dive indicated that most dives were very shallow: 70% of the dives were no deeper than 5 m (Fig. 3). The cumulative distribution of the maximum dive depth achieved over a 24-hour period indicated that for approximately 5% of the days, a dive exceeded 100 m (Fig. 3). Status messages reported that the deepest daily dive recorded was 178 m.

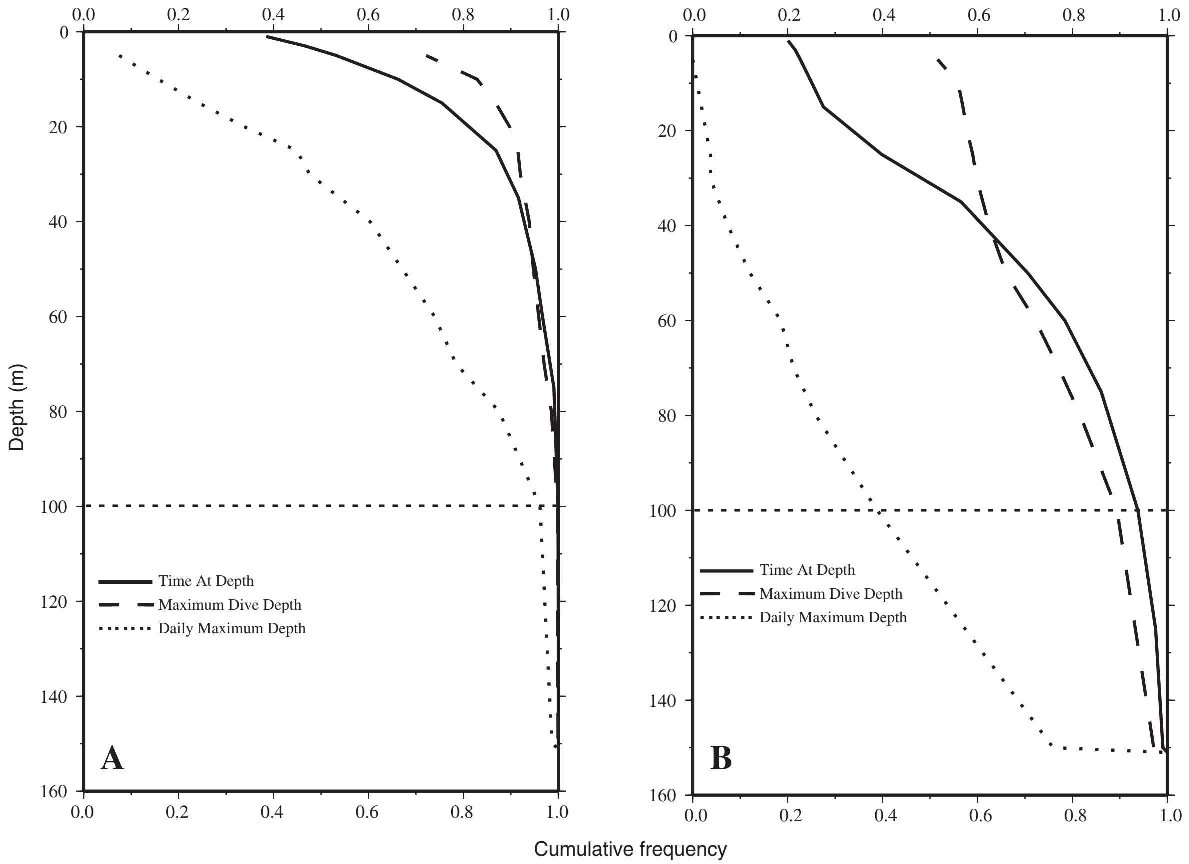

Figure 3

The time-at-depth, maximum dive depth, and daily maximum dive-depth cumulative frequency distributions for all periods combined: (**A**) the two loggerhead sea turtles combined; (**B**) the two olive ridley sea turtles combined.

By comparison, the time-at-depth and maximum depth-frequency distributions of the two olive ridley sea turtles showed considerably deeper depth distribution (Fig. 3). These sea turtles spent only about 20% of their time in the top meter and about 10% of their time deeper than 100 m (Fig. 3). Their daily maximum depth exceeded 150 m at least once in 20% of the days (Fig. 3). Status messages reported that daily dives of 200 m occurred—one dive recorded at 254 m.

Discussion

The loggerhead dive-depth distributions indicated that these animals tended to remain at shallower depths than that of 100 m. If shallow longline sets were replaced with deep longline sets, the incidental takes of loggerhead sea turtles should be reduced substantially. Further, even though olive ridley sea turtles dived deeper than loggerhead sea turtles, only about 10% of their time was spent deeper than 100 m. Therefore, their incidental catches should also be substantially reduced with the elimination of shallow longline sets. However, when deep sets are being made or retrieved or when current shear prevents the gear from sinking to its expected depth, hooks will be present in relatively shallow depths and could result in incidental catches of turtles.

Results to date in the fishery confirm the reduction in incidental catches of turtles that can be achieved from the elimination of shallow sets. Beginning in April 2001, shallow sets were prohibited in the Hawaii-based longline fishery. Data from the onboard observers in the longline fleet, which now comprise 20% of the fishing effort, showed that no loggerhead and only two olive ridley sea turtles were caught from April through December 2001.

The relatively shallow dive-depth distribution for loggerhead sea turtles in the central North Pacific is consistent with our understanding of their ecology; they forage and migrate along convergent fronts where they encounter a shallow aggregation of forage (Polovina et al., 2000). Although oceanic loggerhead sea turtles have a shallower dive behavior than that of olive ridley sea turtles, they appear to dive deeper in oceanic habitat than loggerhead sea turtles in coastal habitat. For example, the dive distribution of two loggerhead sea turtles between nesting periods off Japan indicated that virtually all their dives were shallower than 30 m (Sakamoto et al., 1993). The deeper-dive distribution of olive ridley sea turtles is also consistent with their oceanic habitat, which is south of the loggerhead habitat in the central portion of the subtropical gyre. The oceanography of this region is characterized by a warm surface layer, a deep thermocline depth, and an absence of strong horizontal temperature gradients and physical or biological fronts. It is likely that the deeper diving seen in the olive ridley sea turtles results from foraging at depths associated with the deep scattering layer.

Acknowledgments

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