Convergent Evolution of Vertical Movement Behavior in Swordfish, Bigeye Tuna, and Bigeye Thresher Sharks

Vertical Niche Partitioning in the Pelagic Environment as Shown by Electronic Tagging Studies

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We are using acoustic, archival, and pop-up satellite archival tags (PSATs) to study vertical and horizontal movement patterns in commercially and ecologically important tuna, billfish, and shark species, as well as sea turtles. The work is part of a larger effort to determine the relationship of oceanographic conditions to fish and sea turtle behavior patterns. This information is intended for incorporation into population assessments, addressing fisheries interactions and allocation issues, as well as improving the overall management and conservation of commercially and recreationally important tuna and billfish species, sharks and sea turtles.

The research, sponsored by the Pelagic Fisheries Research Program and the NOAA Fisheries-Pacific Islands Fisheries Science Center, has shown that some large pelagic fishes have much greater vertical mobility than others. More specifically, we have found that swordfish, bigeye tuna and bigeye thresher sharks remain in the vicinity of prey organisms comprising the deep Sound Scattering Layer (SSL) during their extensive diel vertical migrations. In contrast, other billfish, tuna and shark species stay in the upper 200 m of the water column both night and day (Figs. 1, 2, 3).

The SSL is comprised of various species of squids, mesopelagic fish, and euphausiids which undertake extensive diurnal vertical migrations. Pelagic fishes that are able to mirror movements of the SSL can better exploit these organisms as prey. Also, the ability of swordfish, bigeye tuna, and bigeye thresher sharks to access great depths permits them to effectively exploit the SSL for prey even after they descend to deeper water depths at dawn [e.g., over 500 m] (Fig. 4).

Certainly, the ability to mirror the movements of vertically migrating prey confers selective advantages. However, other pelagic species, such as, yellowfin tuna, silky sharks, oceanic white tip sharks, blue marlin, and striped marlin do not make extensive regular vertical excursions.

Recent studies of tuna trophic ecology near the main Hawaiian Islands (Grubbs and Holland 2003) have confirmed that bigeye tuna generally select mesopelagic prey from the SSL, while yellowfin tuna feed primarily on epipelagic prey from the mixed layer even when the fish are caught in the same areas.
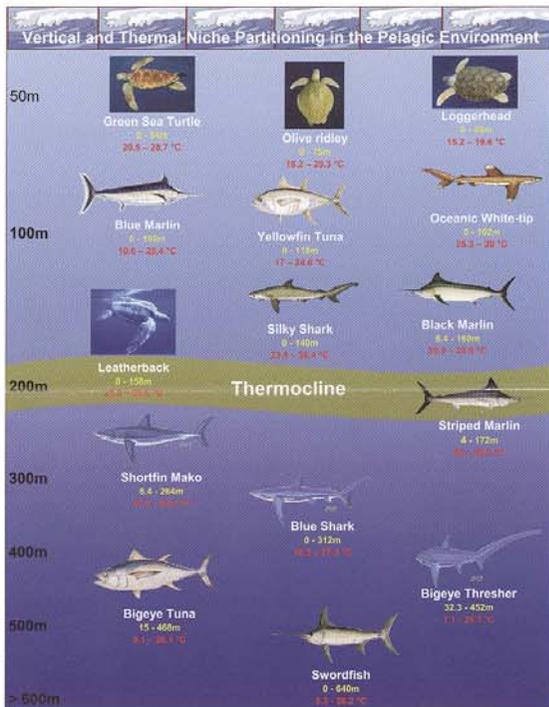
Figure 1. Values indicate the 95% depth and temperature preferences (combined day and night) for various pelagic species as indicated by electronic tagging studies funded by the Pelagic Fisheries Research Program of the University of Hawai'i, NOAA Fisheries, and Pacific Islands Fisheries Science Center.

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Figure 2. Values indicate the 95% depth and temperature preferences during the day for various pelagic species as indicated by electronic tagging studies funded by the Pelagic Fisheries Research Program of the University of Hawai'i, NOAA Fisheries, and Pacific Islands Fisheries Science Center.
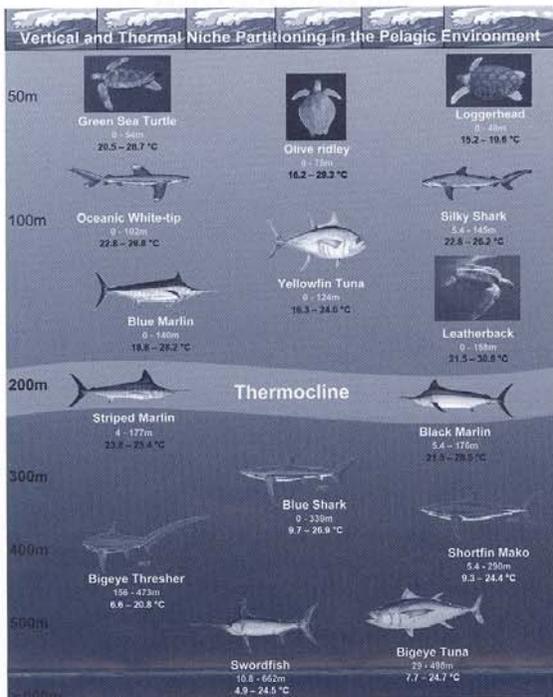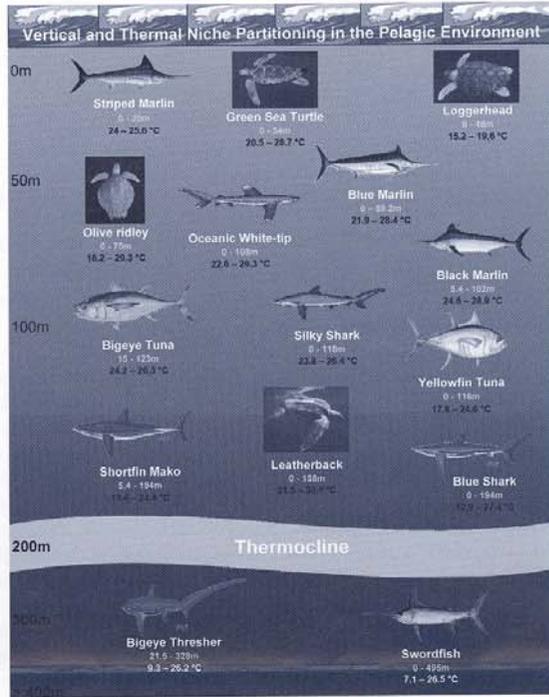

Figure 3. Values indicate the 95% depth and temperature preferences during the night for various pelagic species as indicated by electronic tagging studies funded by the Pelagic Fisheries Research Program of the University of Hawai'i, NOAA Fisheries, and Pacific Islands Fisheries Science Center.

We should point out that although the daily vertical movements of swordfish mirror the movements of the SSL, they are most likely following the vertical movements of larger cephalopods (the neon flying squid), which they exploit as a primary food resource. The larger squid, in turn, are following the movements of the SSL.

We have also found that one of the most ubiquitous large vertebrate species in the pelagic environment, the blue shark, occasionally displays vertical movement behaviors similar to those of swordfish, bigeye tuna, and bigeye thresher sharks (Fig. 1). Blue sharks appear to have no unique anatomical or physiological adaptations, and Carey and Scharold (1990) have characterized blue shark vertical movement patterns in terms of behavioral thermoregulation.

Nevertheless, our observations lead directly to the question, "Why are blue sharks so successful?" We hypothesize that at least part of the answer is their ability to undertake extensive daily vertical movements, which result in better forage utilization and more effective niche partitioning.

Childress and Nygaard (1974) have suggested that the organisms composing the SSL evolved the ability to migrate downward during the day into the cold oxygen minimum layer as a refuge against predation. Studies of crustaceans living in the cold oxygen minimum zone have shown that they are able to do so because of a suite of mor-

Scientists tagging a blue shark.

phological, physiological, and biochemical adaptations.

However, bigeye tuna, swordfish, bigeye thresher sharks, and neon flying squid have likewise evolved physiological abilities to invade the SSL organisms' predator refuge. We view this situation as a sort of "physiological arms race." The parallel behaviors of both fish and organisms comprising the SSL adjusting their vertical movement patterns appear to strongly correlate with moon phase.
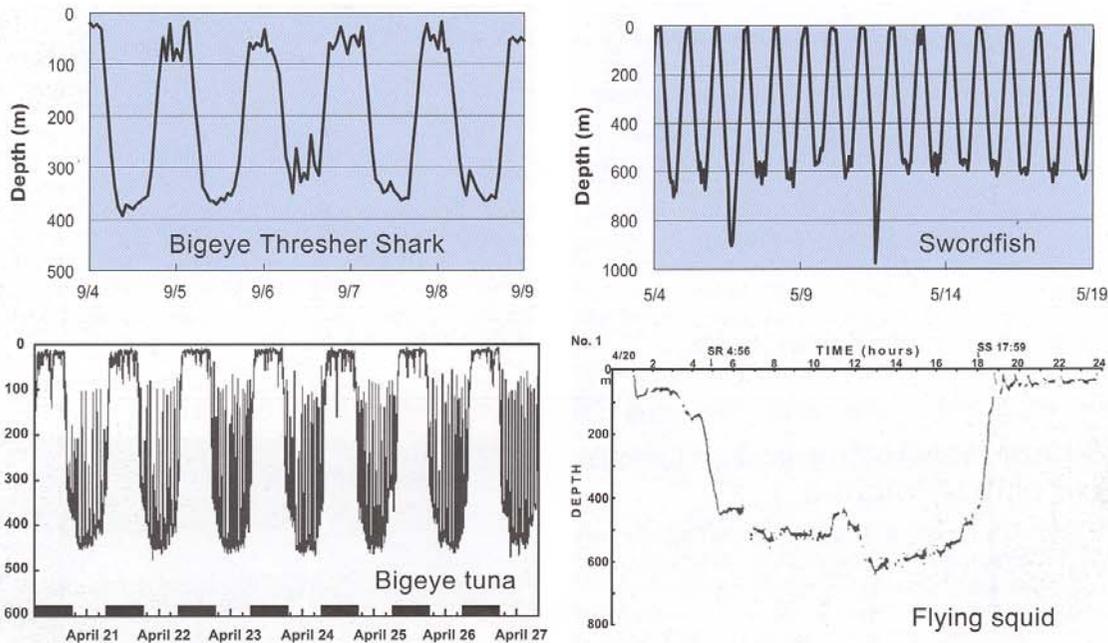
Figure 4. Illustrates the evident convergent dive patterns from disparate pelagic species. Note the regularity of the patterns and the "typical" pelagic behavior of diving deeper during the day and spending more time near the surface at night. Researchers believe this type of diving behavior evolved to mirror and exploit organisms comprising the Sound Scattering Layer.

For example, Musyl et al. (2003) demonstrated that adult bigeye tuna that were not associated with islands, seamounts, or FADs dramatically adjusted their nighttime dive patterns depending on the moon phase. That is, fish stayed deeper (ca. 80 m) during full moons and remained near the surface during new moons.

Researchers believe this behavioral modification helps "backlight" and silhouette prey organisms of the SSL. Furthermore, we suggest, as have others (e.g., Josse et al. 1998), that the vertical movements of large pelagic predators mirror the movements of their prey to the extent allowed by each species' physiology. Lastly, a logical hypothesis is to therefore suggest that the vertical distributions of pelagic fishes are influenced by both oceanographic conditions and the density and distribution of their prey.

We expect to continue this line of inquiry and to develop unique characters based on vertical movement patterns in order to examine the evolution of ecological relationships and vertical niche partitioning in the ocean. To aid in this endeavor, the following international team of collaborators has been assembled to investigate specific questions related to their area(s) of expertise:

- Fisheries Oceanography—Mike Laurs, Dave Foley, Keith Bigelow
- Habitat Based Stock Assessments—Pierre Kleiber, Keith Bigelow
- PSAT tagging studies and data analyses, pelagic fishes—Mike Musyl, Rich Brill, and Lianne McNaughton
- PSAT tagging studies and data analyses, marine sea turtles—Yonat Swimmer, Lianne McNaughton, Mike Musyl
- Fish Physiology—Rich Brill, Chris Moyes
- Individual Based Models—Hans Malte, Christina Larsen, Nini Jensen
- Sensory Physiology—Eric Warrant, Kerstin Fristches, Amanda Southwood
- Neural Anatomy—Tom Lisney
- Improvement of light-based geolocations—John Sibert, Anders Nielsen, Keith Bigelow, Mike Musyl
- PSAT Performance Evaluation—Geoff Arnold, Rich Brill, Mike Domeier, Molly Lutcavage, Mike Musyl, Yonat Swimmer, Steve Wilson
- PSAT and Archival database—John Sibert, Johnoel Ancheta, Dodie Lau, Mike Musyl

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Fishery Monitoring and Economics Program
Preliminary Longline Logbook Summary Report

The Pacific Islands Fisheries Science Center presents its preliminary 2004 second quarter report for the Hawai'i-based longline fishery, "Fishery Monitoring and Economics Program Preliminary Longline Logbook Summary Report, April-June 2004" online at http://www.pifsc.noaa.gov/currentevents.html. Results are derived from the logbook data and are based on non-confidential summaries which provide:

- Fleet-wide analyses of effort, catch, and catch-per-unit effort, or CPUE
- A summary of logbook data
- Interactions with protected species
- Fishing effort
- Catch and targeted CPUE values for tuna, billfish, blue shark, and miscellaneous pelagic species
- Historical annual effort and catch figures on the Hawai'i-based longline fishery from 1991-2003

Federal longline logbook data for trips completed in the second quarter by Hawai'i-based longline vessel operators have been received and processed and are summarized in this report. There may be data from trips that began late in the second quarter and continued into the third quarter that are not presented herein. Therefore, this report should still be considered preliminary.

The Hawai'i-based longline fishery has operated under new rules since April 2, 2004. These new rules eliminate the southern area closure and reopen the swordfish-directed component of the fishery.

The swordfish component of the fishery will be subject to restrictions on effort, hook and bait types, and a separate annual total for interactions with leatherback and loggerhead sea turtles

A tuna longlining operation. Image courtesy of NOAA.

in order to minimize adverse impacts on sea turtles. Other mitigation measures, such as dehooking devices, also will be required. Swordfish effort and catch totals are expected to increase from the current low levels.

Preliminary longline logbook summaries show that 106 vessels made 330 trips in the second quarter of 2004, representing two less vessels and 40 less trips than in the same period of the previous year.

All trips targeted tuna. The total number of hooks set in this quarter was 7.5 million, up from the record high 6.8 million hooks set in the second quarter of last year. Most (70%) hooks were set outside the U.S. Exclusive Economic Zone (EEZ) along with the main Hawaiian Islands (MHI) EEZ (20%), the U.S. possessions (8%) and Northwestern Hawaiian Islands (NWHI) EEZ (2%).

Bigeye tuna catch (22,990 fish) in the second quarter of 2004 was almost double that in the same period last year; 72% of the bigeye tuna was caught outside the EEZ. Bigeye tuna CPUE on