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ABSTRACT FULL TEXT

Migratory Movements, Depth Preferences, and Thermal Biology of Atlantic Bluefin Tuna

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Supplementary Material

Methods

Archival tags are miniature computers, incorporating 8-bit microprocessors, 256 Kbytes to 2 Mbytes of memory and 4 environmental sensors. Attached or inserted in a free-swimming animal, they record data from the organism and the surrounding environment. Pressure and internal temperature sensors are located in the tag, which is surgically implanted into the peritoneal cavity of the tuna. Ambient light and temperature sensors are embedded in a 6-12 cm stalk protruding from the tag which remains external. Two conventional tags placed externally notify fishers of the archival tag inside the fish and a US$1000 reward upon return.

Two types of tags, one built by Northwest Marine Technology Inc. (NMT, Shaw Island, WA, USA) and a second constructed by Wildlife Computers Inc (WC, Redmond, WA) were deployed. Temperature sensors had a resolution of 0.05°C and were scaled to either 0.2°C or 0.1°C over the range of temperature measurements. For WC tags, pressure sensors had an 0.5 m resolution and were scaled 1 m (to 200 m depth), and then 4 to 8 m up to 800 or 1000 m. For NMT tags, depth resolution was 1 m (to 125 m depth) and 3 m to 700 m. WC tags sampled pressure, ambient and internal temperature at 120 s; NMT tags used 128 s intervals. Two generations of the WC, Mk7 archival tags were used in the experiments. The light sensor in the 1997 deployments had a broad response (400 nm to 1100 nm) and in 1999 deployments, a

filter was incorporated, narrowing the range of sensitivity to 450 nm ± 50 nm. The light sensor in the 1999 deployments recorded light over 10 decades. The fluorescent light detector of NMT tags incorporated a filter in the same range. Both types of tags compensated for temperature-related clock drift and upon recovery, tags were corrected for clock and depth drift over the entire deployment.

For both types of archival tags, surface light measurements required for determining local noon or midnight, were calculated from ambient light intensity collected at 120 s or 128 s intervals using light extinction coefficients determined daily. Longitude was calculated from local noon or midnight, calculated from the light data, using standard astronomical algorithms. Longitude data was filtered for anomalous positions (positions on land or two consecutive positions over 3° apart). A daily distribution of sea surface temperatures (SSTs) is calculated from the ambient temperature record of the archival tag. For each known longitude, the latitude at which this distribution best matched the SST distribution from Advanced Very High Resolution Radiometer (AVHRR) 18 km satellite data, was considered to be the latitude. These data were obtained from NASA Physical Oceanography Distributed Active Archive Center at the Jet Propulsion Laboratory, California Institute of Technology.

In North Carolina, all fish were caught using rod and reel. For archival tag implantation (n=279), methods were as previously reported (*1, 2*). Briefly, fish were pulled onto the deck, blindfolded and their gills irrigated with seawater. Betadine coated tags were surgically placed inside the peritoneal cavity. The mean curved length of archival-tagged fish in 1999 and 1997 was 209 cm and 192 cm, respectively. Age was calculated using a length-weight regression (*3*). The growth rate of 29 archival-tagged fish upon release and recapture was 0.033 ± 0.016 cm day^{-1}. The two release locations for the 279 archival tagged fish were: 35°N / 75°W ± 0.3° and 34°N / 76°W ± 0.5°. All archival-tagged bluefin tracks initiate in a winter month (Julian year day 1-95), off the coast of North Carolina.

49 archival tags were reported recaptured by fishers from 7 nations. In 12 archival recaptures, conventional tag numbers and in some cases, the archival tag number, were reported, but the electronic tag was not returned. Four returned archival tags failed, and 3 archival tags were drawn into the body cavity of the fish yielding no positional data but extensive depth and internal temperature records. Thirteen archival-tagged bluefin tuna were recovered in the western Atlantic from the same release date 07-March 1997. Post-recapture gonad samples for sex identification and curved fork length were taken when possible. Fish 512 was determined to be a female upon histological examination.

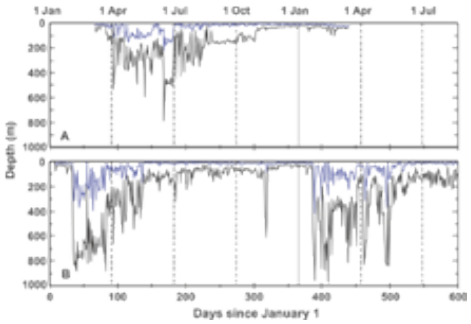
Pop-up satellite tags were deployed in North Carolina (n=71) using the same techniques as for archival-tagging (*1, 2*). Fish were tagged and released in the Gulf of Mexico after capture using longlines (n=15), and in New England via purse seine (n=9) and rod and reel (n=3). Sizes were estimated for purse seine and longline fish, all others were measured. The mean size of the measured pop-up satellite tagged Carolina fish was 204 cm curved length or ~8.4 years of age. Mean size in the Gulf of Mexico was estimated to be ~10 years of age and for New England ~9.6 years.

Supplemental Figure 1. Latitude and longitude track of bluefin tuna 408. This fish (203 cm measured curved fork length upon release) and spent three consecutive years in the western Atlantic (1997-2000) prior to a trans-Atlantic crossing into the Mediterranean Sea. While in the west, the fish moved each year between the Carolinas and the Gulf of Maine and offshore waters of Cape Cod. It was released on March 3

1997 at 35.09N, 75.26W and recaptured June 15, 2000 at 35.37N 12.53E by an Italian purse seiner.

Medium version | Full size version

Supplemental Figure 2. Maximum and mean depth of Atlantic bluefin tuna. An immature western resident bluefin tuna (A) shows a western resident pattern of movement based on geolocation that coincides with bathymetrically constrained diving when on the shallow Carolina shelf in early spring, deeper diving while off-shelf in the Gulf Stream and constrained diving when on the New England shelf in summer. This fish returns to the 40 m Carolina shelf in the winter and spring following tagging. This pattern of high fidelity to the North American continental shelf in the west was evident in many of the immature western recovered fish. (B) A western resident mature fish (~10.1 years of age) shows a similar pattern but makes excursions more frequently in deeper waters. Mean depth (blue) is calculated for each day from all 120 s measurements. Maximum depth (black) is the single deepest depth recorded in the 24-hour period.



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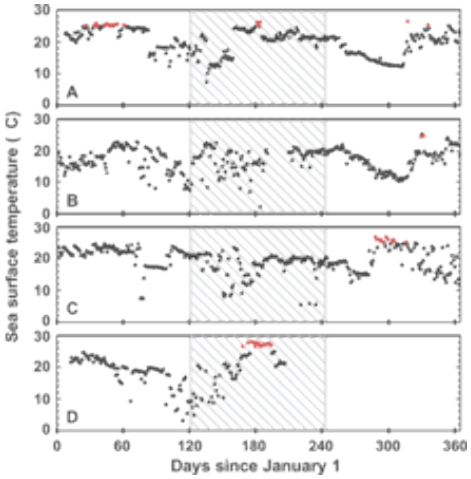
Supplemental Figure 3. A year in the life of four western resident bluefin tuna as viewed from sea surface temperature (SST) records. The maximum daily SST daily is shown. Any SST above 25°C is indicated by red. The proposed duration of the western breeding season is shown in the cross-hatched area. Temperature and pressure are sampled every 120 or 128 s. The maximum SST recorded in the zero-2 m depth interval daily is used. Bluefin are measured and length is used to estimate age (*3*). Bluefin in A-D displayed western resident geolocation tracks and are estimated to be fish of 10.1, 8.2, 7.0 and 9.2 years of age respectively at release. Bluefin in D (fish 507) displayed a pronounced, warm SST signal and oscillatory diving behavior similar to the individual fish in the Gulf of Mexico. However bluefin 507 was located in the Gulf Stream off Cape Hatteras, North Carolina in June.



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