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### Title

MIGRATORY MOVEMENTS OF PACIFIC BLUEFIN TUNA OFF CALIFORNIA

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**PROJECT TITLE: MIGRATORY MOVEMENTS OF PACIFIC BLUEFIN TUNA  
OFF CALIFORNIA**

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**INTRODUCTION:**

The genus *Thunnus* of the family Scombridae includes three species of bluefin tunas (Atlantic bluefin tuna – *T. thynnus*, Pacific bluefin tuna - *T. orientalis* and southern bluefin tuna - *T. maccoyii*). The bluefin tunas were first recognized as two independent species (Northern and Southern bluefin) based on subtle differences in morphological characters. Northern bluefin tunas are now recognized as morphologically, geographically and genetically separate species located in the Atlantic and Pacific oceans.

The Pacific bluefin (*T. orientalis*) is the only species which remains unmanaged; this lack of management persists despite intensive fisheries on both sides of the Pacific. The current life history model indicates that these fish spawn in the western Pacific (Sea of Japan, Philippine Sea and East China Sea). Either late in the first year or early in the second year, a portion of the population migrates to the western coast of the United States and Mexico, a journey of over 8700 km (Bayliff *et al.*, 1991). The young fish that have migrated into the eastern Pacific are thought to remain there for several years, feeding on sardines and anchovies in regions of intense upwelling (Bayliff *et al.*, 1991, Bayliff, 1993). While these tuna are fished only seasonally off California and Mexico, they may be a year-round resident (Bayliff, 1991). The migrants then travel back to the western Pacific to spawn. Why some bluefin remain in the western Pacific while others migrate across the ocean basin is unresolved. How long they stay in the eastern Pacific, what habitats are most important, what triggers their return to the west is unclear.

**PURPOSE:**

In this program we used electronic tagging technologies to examine the movements and behaviors of Pacific bluefin in eastern North Pacific. The research focused on the movements of bluefin within the North American exclusive economic zones (EEZs). Discerning distribution and residency times within the U.S. and Mexican EEZs will provide the baseline knowledge required for future efforts to allocate of these highly migratory species in both nations.

The project was designed to obtain the following information:

- 1) The distribution, diurnal behaviors, and physiological ecology of Pacific bluefin tuna in the major oceanic habitats of the west coast of North America.
- 2) How migration patterns vary geographically and temporally among the different age classes.
- 3) The existence of migration corridors, and rates of movement along these corridors.
- 4) The existence of regions of high residency (hotspots) where multiple fish aggregate or individuals spend long periods of time.
- 5) The environmental characteristics of hotspots or migratory corridors.
- 6) How environmental conditions affect the distribution of Pacific bluefin tuna in the US and Mexican EEZs.

#### **APPROACH:**

To determine the movements and habitat preferences of Pacific bluefin tuna, a number of electronic tagging technologies are being used, including pop-up satellite (PAT) tags and implantable archival tags. Electronic tags that archive or transmit stored data to satellites have rapidly advanced the mapping of habitats utilized by highly migratory fish in pelagic ecosystems. Both types of tags, PAT and archival, record light and allow an estimate of geoposition to be achieved to a maximum accuracy of 0.5° for latitude and 0.25° for longitude, or a mean error in position of about 40-50 km (Welch and Eveson 1999, Teo et al. 2004). Recorded temperature and depth data provide information on both the vertical and horizontal movements in addition to collecting information on the local environment. The archival tags also record internal temperature providing information on thermal physiology and foraging ecology.

We deployed a new generation of archival tag (Lotek LTD2310) in 182 bluefin tuna during 2002-2004. The archival tags had 8 Mbytes of memory and were capable of recording data from 4 sensors (light intensity, pressure, ambient and internal temperature) for up to five years. In addition, we tested the placement of a second generation of tags (Lotek LTD1100) externally. This is a lower cost tag that was being considered for deployments. For tag recovery an international recovery program has been in place since the program was initiated and is implemented by the Inter-American Tropical Tuna Commission which has field offices through out Mexico, and Central America. A \$500 reward is provided for recovered tags, thereby enhancing the recovery rates over conventional tags.

In addition to the archival tags, 10 pop-up satellite tags (Wildlife Computers) were deployed on Pacific bluefin. These tags are attached externally where they record ambient temperature, depth, and light levels. At a preprogrammed time the tag releases from the fish, floats to the surface and transmits the recorded data to satellite. The data are summarized prior to the satellite transmission in the form of depth and temperature histograms, temperature vs. depth profiles and light data for subsequent geolocation

estimates. By using these devices, the fish does not need to be recaptured to recover the data and tags can be attached externally. Consequently, these tags are particularly useful in areas where the fish may be too large to bring aboard the fishing vessel and where the chances of recapturing fish are low.

For tagging, bluefin tuna were obtained using two methods, from a recreational fishing vessel and from the tuna farms off Ensenada, Mexico. Developing two tagging platforms was critical as bluefin schools are highly mobile and are often difficult to find. The recreational fishing vessel the *F/V Shogun* was chartered for three 14-day cruises in the summers of 2002, 2003 and 2004. From the *F/V Shogun*, bluefin tuna are caught using recreational tackle and brought to a swim step at the stern. Each tuna is then lifted in a vinyl sling onto a surgery table where the tag is implanted or secured externally. After tagging the fish are placed in an open-ocean tow pen where they are held until the entire school of tagged fish can be released together. When working at the tuna farms off Mexico, the fish are caught on hook and line and brought onto a surgical table on a small vessel secured between the holding pen and a tow pen. After tagging the tuna are placed in the tow pen. Once tagging has been completed the pen is towed offshore and the fish are released as a school.

The tags are implanted or secured externally through a quick surgical procedure. Once on the surgical table their eyes are covered with a wet blindfold, they are ventilated with seawater and length is measured. For the LDT 2310, the tag is quickly implanted in the body cavity through a small 1-inch incision that is closed with two stitches. The external tags are secured using a nylon anchor inserted at the base of the second dorsal fin. After tagging the fish is marked with special conventional tags.

Although our original plan called for the large-scale use of PAT tags, the high recovery rates (>40%) of archival and conventional tags (35%) indicated that archival tags were more appropriate.

## **RESULTS:**

### ***Tagging efforts:***

In the initial year of tagging (2002) we tested the efficacy of different tagging methods to discern how to effectively release live bluefin with electronic tags. During a cruise funded by the Monterey Bay Aquarium's Tuna Research and Conservation Center (TRCC), aboard the recreational fishing vessel the *F/V Shogun*, we adapted methodologies developed for large bluefin (Block et al. 2001) to smaller bluefin and built new devices for handling these smaller fish. Techniques for tagging large numbers of small tunas quickly, to take advantage of a rapid rate of hook ups over short duration, were also developed in this first tagging effort. In 2002, a total of 69 archival tags (49 Lotek LTD2310 and 20 Lotek LTD1100) and 7 Wildlife Computer PAT tags were deployed in five days of fishing. The mean size of the Pacific bluefin tuna released on this cruise was 103 cm curved fork length (CFL). Building on the results from 2002, a total of 110 archival tags (LTD2310) were deployed from the *F/V Shogun* over six days in the summer of 2003. The mean size of the Pacific bluefin tuna released on this cruise was 95 cm CFL. When schools of juvenile Pacific bluefin are found off southern California and Mexico, working from a recreational fishing vessel allows for large numbers of tuna to be tagged with hook and line over a relatively short time period.

As previously mentioned, one challenge of tagging bluefin tuna from a sport-fishing vessel arises from the difficulty in finding bluefin schools. Ship time is extremely expensive and Pacific bluefin tuna schools are often difficult to locate. Thus, alternative methods for large-scale deployments were explored. In October of 2002, Dr. Barbara Block led a team to Ensenada, Mexico to work with tuna ranchers on penned tuna. Here 22 fish were tagged with LTD 2310 archival tags. Using this method as many as 50 Pacific bluefin can be tagged in a day. Thus, if bluefin prove difficult to locate at sea, as they were in 2004, access to penned fish provides a valuable contingency plan for large-scale deployments.

**Tag Recoveries:**

The results from recovery of tags (Table 1) indicate that the experimental protocols are highly successful. To date, a total of 76 tags have been recovered. Bluefin tuna were primarily recaptured off California and Mexico from the net pen fishery, either when they were first caught in the purse seine or during harvest. A few bluefin were also recaptured in gill nets, or caught by sport fishers. Bluefin tuna have been recovered from deployments on both the *F/V Shogun* and at the net pens indicating good survivorship using both methods. Fish have been at large for a mean track length ranging from 334-438 days for the two years.

**Table 1. Recovery of Archival Tagged bluefin tuna**

Year	Lotek 2310	Lotek 1100	Total Deployed	Total Recovered	% Recovered	Mean Track (days)
2002	71	20	91	29	32%	438
2003	110	0	110	47	43%	335

**Data:**

To date, over 20,000 cumulative days of data, recorded at one to two minute intervals, have been recovered on the movements and behaviors of Pacific bluefin tuna. This overwhelming amount of data is currently being processed using methods under development in the Block lab. For a typical track over 280 days of geolocation data are available. Most fish from which tags were recovered, remained along the coast of Mexico and California. These fish exhibit distinct seasonal movement patterns. In the summer months, they spent the majority of their time in the coastal waters off Mexico and Southern California. In the fall and winter, these bluefin moved north into the coastal waters of Northern California and from there, moved offshore in the winter months. Figure 1 shows the geolocation data for bluefin A0991 illustrating the extent of geographical movement typical for fish that remained in the eastern Pacific. In the summer this bluefin moved as far south as the tip of the Baja Peninsula Mexico and in the winter moved as far north as Point Arenas, north of San Francisco, CA. This fish was released off Mexico on 11/12/2002 from the tuna pens and recaptured by a purse seiner on 6/12/04, after which it remained in a net pen until 9/27/04.

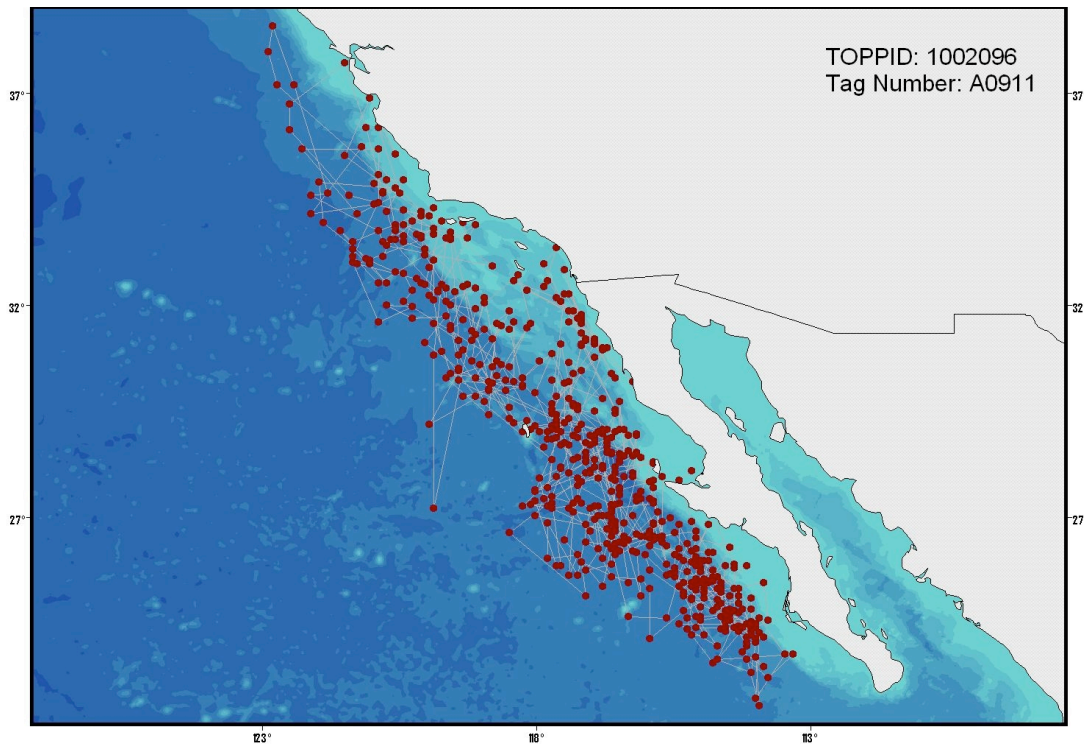


Figure 1. Geolocation data for one bluefin tuna A0991 tagged and recaptured off the coast of the Northern Baja Peninsula.

The movements along the North American coast were accompanied by distinct changes in diving behavior. Figure 2 shows depth, light and internal and external temperature as a function of time for bluefin A0991. Temperature and depth data provide insights into behaviors and habitat preferences beyond that offered by location data alone and this type of presentation allows for observation of large-scale patterns over the duration of the track. During the period in southern California, the bluefin tuna had a cycle of behavior that exhibited both diel and lunar periodicity. The horizontal line in depth (Figure 2A) that parallels changes in day length (Figure 2B) results from the deep dives typically observed at dawn and/or dusk, indicating the importance of light levels in triggering dive behavior. During the day, dives to 200 m and 10 °C were common. The lunar cycle in behavior is evident in the vertical banding pattern in the depth profile (Figure 2A), which becomes less distinct in the late summer and fall. As expected, the warmest temperatures were encountered in the summer months, which is reflected in both the external and internal temperature records (Figure 2C and D). A closer examination of internal temperature allows for identification of feeding events. The bluefin appear to be feeding near the surface during the dark phases of the moon, and then as the moon becomes full they increase the diving depth. In Northern California bluefin feed both at the surface and at depth. The ability to document feeding events is providing insights into the ecology of bluefin that were never before possible.

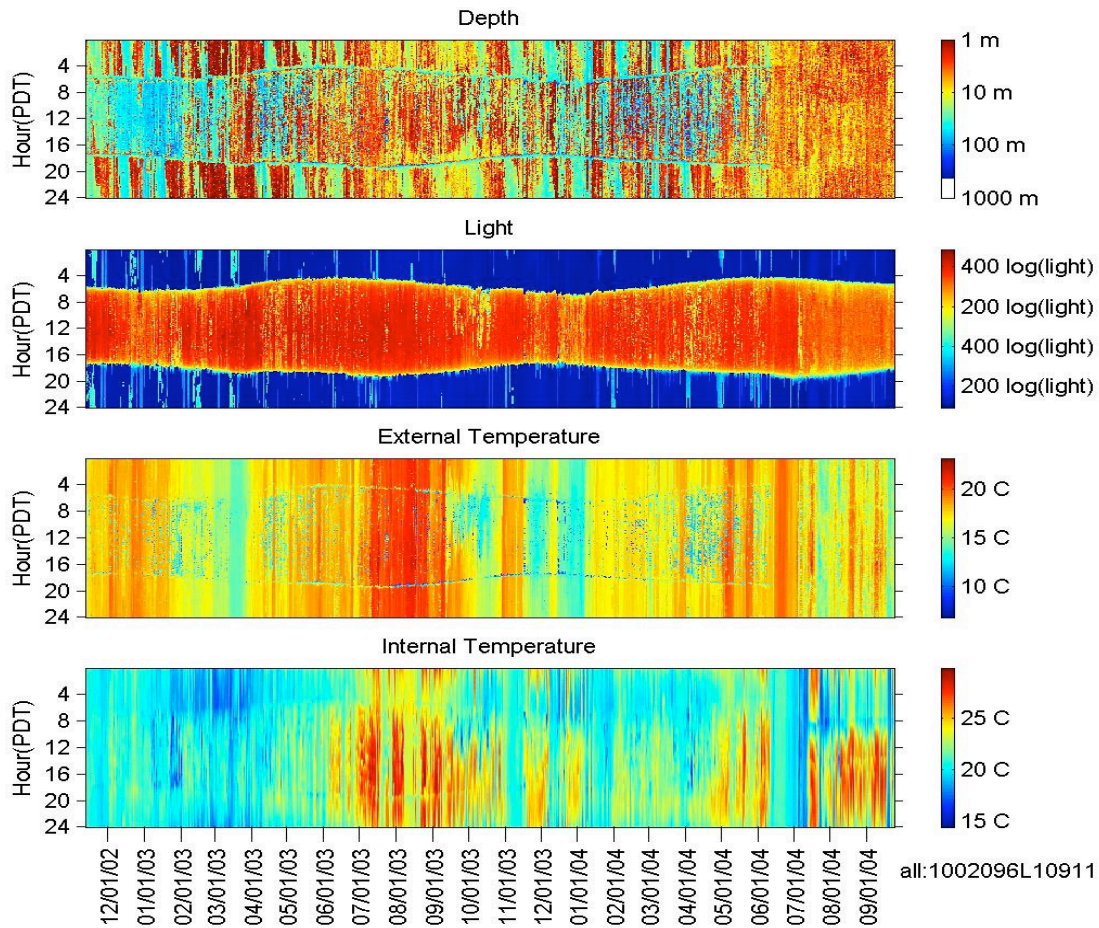


Figure 2. The A) depth, B) light levels, C) external temperature, D) internal temperature plotted for each minute of each day over the duration of the track for bluefin tuna A0991.

The electronic tags also provide data on the regional oceanography in addition to behaviors. In Figure 3, ambient water temperature is plotted as a function of depth for bluefin A0991. From this graph we can observe changes in sea surface temperature, the depth of the thermocline throughout the track and the extent of vertical movements. Most deep dives were to around 200 m although occasional dives deeper than 300 m were observed. Characterization of the water column through out this and other tracks is in progress.

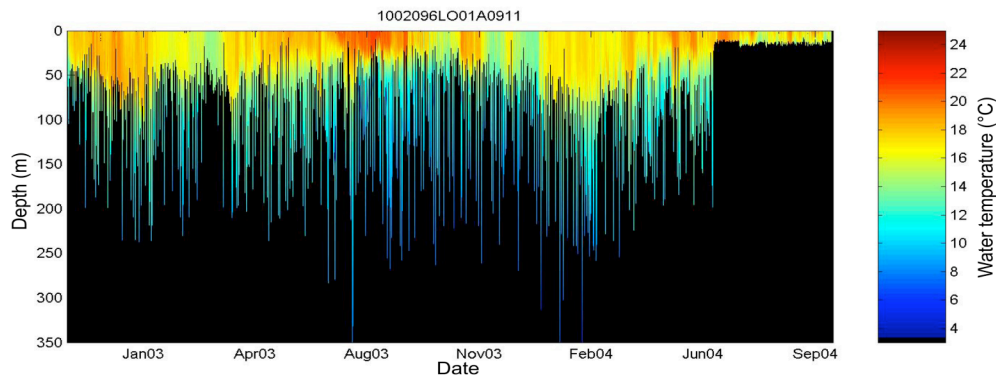


Figure 3. Ambient temperature-depth profiles during the track for bluefin tuna A0991.

Three bluefin tuna made trans-Pacific migrations and were recaptured near Japan. A single bluefin tuna tagged in November of 2002, and released from a pen in Ensenada, Mexico, was recaptured off the coast of Japan after 296 days at large. Following the tagging event this tuna remained off the coast of California and Mexico until early January, 2003 prior to moving west. The trip across the Pacific took approximately six months and the fish was recaptured in September, 2003. This fish stopped several times on the way back to Japan, remaining in specific areas for over a month, presumably to feed. Behavior such as this gives us great insight into aggregating sites for bluefin tuna that we would otherwise be unable to obtain due to their distance from land. A second bluefin traveled across the Pacific three times before being recaptured in Japan. Figure 4 shows the temperature with depth experienced by this fish. Note that the deepest dives to over 500 m were only observed in the waters close to Japan. These data represents the first archival tag data documenting the return of Pacific bluefin tuna from the eastern Pacific to the waters off Japan and the only evidence to date that fish may make multiple trans-Pacific crossings prior to returning to the western Pacific to spawn.

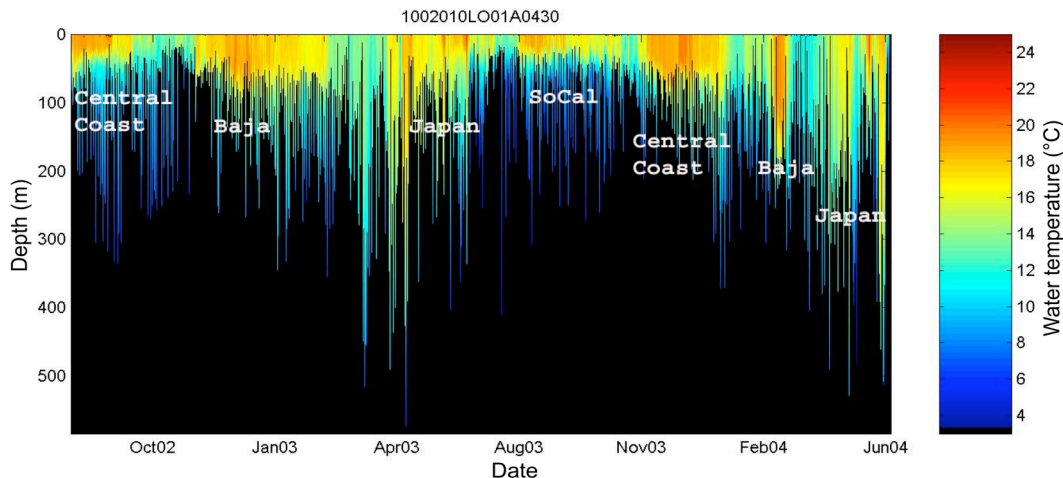


Figure 4. The ambient temperature with depth for bluefin tuna A0430 that transited across the Pacific three times before being recaptured in Japan.

The next step is to link movements to physical oceanographic conditions over a range of temporal scales from daily to annual. The software necessary to link the biological and oceanographic data is currently under development in the Block lab in conjunction with the TOPP program.

### EVALUATION:

To date, efforts in tagging and data collection for Pacific bluefin tuna have exceeded our expectations. One of our initial goals was to develop and test tagging methods and identify the most useful tagging technology for tracking Pacific bluefin tuna. Based on results to date, it is overwhelmingly clear that for examining large-scale movements of tuna, archival tags are the better technology given the high tag recoveries rates. For specific questions that can be answered in the first 10 months after tagging, pop-up tags may be used in the future. Given the recovery of data from fish that were tagged during the *F/V Shogun* cruises in 2002 and 2003 and from the tuna pens in Mexico, it is clear that both tagging methods provide good options for deploying a large-



volume of electronic tags. The tuna pens provide a valuable alternative when wild schools are difficult to locate.

While the program is still in the relatively early stages, we have already amassed an impressive dataset on the movements and behaviors of Pacific bluefin tuna both off California and Mexico, and during trans-Pacific migrations. We are able to track individual bluefin tuna over thousands of kilometers, which allows us to establish migration patterns, physiology, and behavior in relationship to their oceanic environment. In the long-term, these data will be used to develop and test models quantifying the abundance and distributions of bluefin and other marine vertebrates. This level of understanding is critical for the long-term management of Pacific bluefin tuna, especially given their highly migratory nature, high market value and the expanding net pen fishery off Mexico.

## **PUBLICATIONS**

Teo, S. L. H., A. Boustany, S. Blackwell, A. Walli, K. C. Weng, and B. A. Block. 2004. Validation of geolocation estimates based on light level and sea surface temperature from electronic tags. *Mar. Ecol. Prog. Ser.* 283:81-98

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