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Linking oceanography and bluefin tuna movements in the Northwest Atlantic

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Extended Abstract

For highly mobile predators such as Atlantic bluefin tuna (ABFT), appropriate oceanographic structure and biophysical interactions create dynamic feeding opportunities. The location and persistence of appropriate watermass features along their migration routes should influence ABFT residence times, energy stores, larval and reproductive success, and vulnerability to capture. Bluefin tuna may seek specific physical conditions to aid physiological functions such as thermoregulation and food assimilation. Gutenkunst et al. (2007) previously identified two movement modes, traveling and foraging, on coastal foraging grounds. However, time and spatial scales were limited (e.g., 48 h, 150 km tracks). Recent advances in satellite and electronic tagging technology and light based geolocation have revealed the scope and complexity of ABFT distributions.

Using spatial and behavioral results obtained from adult ABFT tagged with popup archival satellite tags for up to one year in the NW Atlantic, we examined the relationship between persistent oceanographic features and behavior type and depth patterns, and interplay of ABFT depth patterns and behavior. By developing a complete picture of habitat utilization of ABFT, we hope to better understand long term shifts in their distribution and abundance, and contribute to population rebuilding efforts through better understanding of their ecosystem. Our approach utilizes a framework useful for combining geolocations with depth data and the physical environment.

Behavior Type Determination

Measurements of behavior type and path straightness have become popular indicators of animal activity in different area and at different time periods and have been extensively used in the marine environment (*e.g.* Gutenkunst et al. 2007, Jonsen et al. 2007, Weng et al. 2008). Determination of straightness can be done geometrically using either angular or vector based methods (Gutenkunst et al. 2007, Weng et al. 2008), or can be estimated through state space methods (Jonsen et al. 2007)

Daily behavior type (localized or long range) was derived from a speed-biased approach (Gutenkunst et al. 2007) for 32 ABFT tagged and released off Nova Scotia in 2005 and

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2006 (Galuardi et al. 2009). Behavior type was determined as a measure of straightness (Weng et al. 2008) illustrated as follows:

$$\textit{Eq. 1} \qquad \frac{\Delta D}{\Delta L} / \Delta T$$

Where D is the geodetic distance between a start and end point and L is the cumulative length of consecutive daily geodetic distances. Calculation of ΔD and ΔL was done using the gmt (Magnusson 2007) and adehabitat (Calenge 2006) libraries for R (R Core Team, 2008). We examined ΔT of 1 - 15 days and concluded that 15 days was most appropriate for distinguishing two behavior types.

Oceanographic Data

We used a blended microwave and infrared sea surface temperature (SST) product (MWIR, Remote Sensing Systems, Inc.) to determine SST frontal density and to sample SST along the individual tracks. MWIR is a blend of AMSR-E microwave and MODIS Aqua infrared measurements of SST and is produced globally once per day. The use of MWIR eliminates gaps from cloudy areas and allows determination of SST along coastal regions. We produced 8-day 9km composites based on the daily imagery. Along track samples of chlorophyll a (chl a) and frontal density were sampled from blended, 8-day, 9km, SeaWifs/MODIS Aqua composites (Goddard Space Flight Center, NASA). For each SST and chl a composite, we used frontal detection methods of Ullman & Cornillon (1999), producing time series of binary images (Figure 1). This was carried out for the period tagged fish were at liberty (August 2005 – October 2007) and the range covered the North Atlantic from 100^{o}W – 0^{o}W and 20^{o}N – 55^{o}N. From these, frontal density relevant to each day's geolocation could be determined.

Sampling scheme

Geolocations were previously estimated for this ABFT dataset using an SST inclusive Kalman filter routine and bathymetric correction (Galuardi et al. 2009, Royer and Lutcavage 2009). For each day, 100 draws were taken from a multivariate normal distribution centered on each day's geolocation, and weighted by that day's variance/covariance matrix (Figure 2). These samples were used to draw values for SST, SST fronts, chl a and chl a fronts. For the SST and chl a samples, values were summarized into mean and variance components for daily locations. The binary frontal samples were summarized as a percentage for each day (i.e. 20/100 samples on a front = 20%), yielding a frontal density for areas at a scale relevant to individual's movements.

Initial Results

Behavior type, SST and chl a frontal density were summarized across Longhurst region in the North Atlantic Ocean (Longhurst 1995). Initial results indicate that, generally, tracked individuals from 2005 exhibited more directed movements than those in tracked from 2006. The Gulf Stream, North Carolina (NC)/South Atlantic Bight and Central Atlantic regions, known to be rich forage areas, compromised the majority of observed locations and showed the greatest range of movement type (Figure 4). These forage regions had mean SST and chl a frontal densities between 11 -14% and 12 – 17% respectively (Figures 5 and 6).

Examination of Temperature vs. depth (T/Z) profiles indicated that ABFT switch vertical behavior in response to oceanographic (Longhurst) region (Figure 7). While there was variability within individuals (Figure 7), there was no clear relationship between horizontal behavior in relation to either variability in T/Z profile or by region.

Preliminary conclusions

Our analysis to date is exploratory in nature and forms a basis from which several hypotheses may be explored. Using statistical techniques such as mixed effects modeling will allow us to explore the significance of our preliminary results. It's possible that there is a significant interaction between horizontal behavior type and variability in depth, blurring any horizontal relationship with the oceanographic variable sampled here. This would be interesting from an energetics standpoint as it would indicate energy expenditure moving vertically vs. horizontally in various oceanographic regimes. It is also possible that the scale we chose may not be optimal forclarifying relationships between horizontal behavior type and the environment. It may be useful to test this in future endeavors.

Fine scale analyses in the Gulf of Maine indicate that the relationship between ABFT schools and SST fronts is inconsistent (Schick et al. 2004). We found this to be true for individuals, but found the relationship fairly consistent when aggregated for both SST and chl a frontal densities. Gutenkunst et al. (2007) analyzed prey patch size on a fine temporal scale in the Gulf of Maine using the basic behavioral mode derivation followed here. Thus, it may be possible to determine prey patch sizes on broader spatial and temporal scales using our proposed methods.

Acknowledgements

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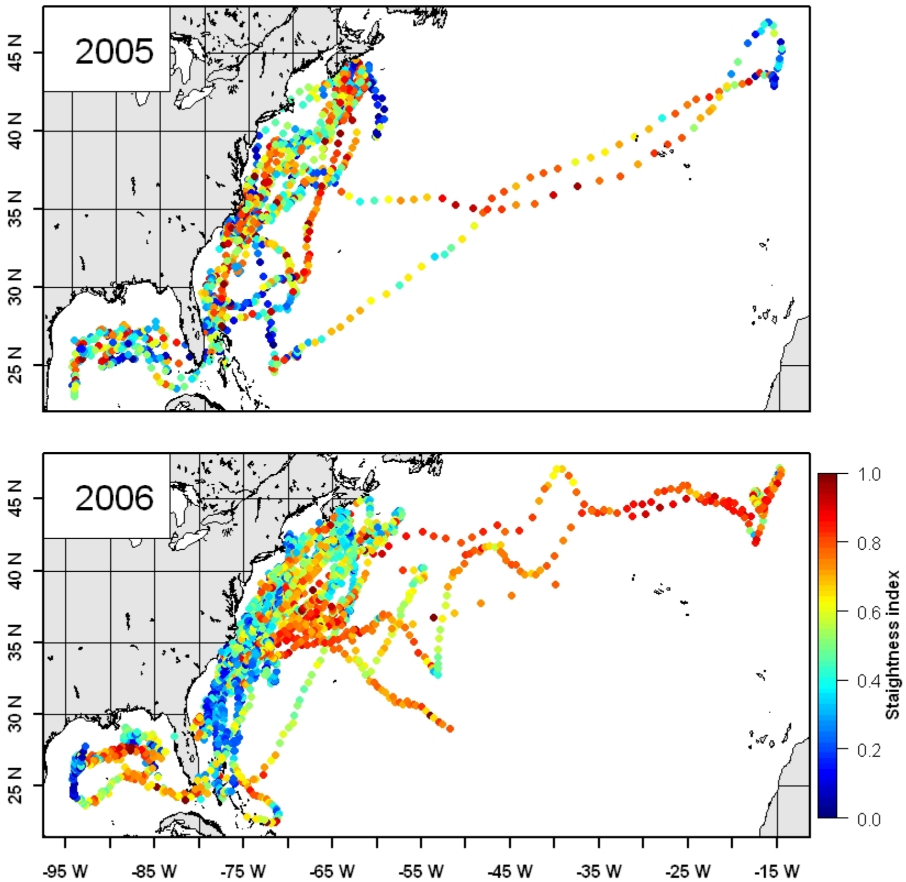

Figure 1. Behavior type for Atlantic bluefin tuna tracks (n = 11 in 2005 and n = 21 in 2006) over a 15 – day sliding window. Values towards zero indicate localized movements while those closer to one indicate directed movements.

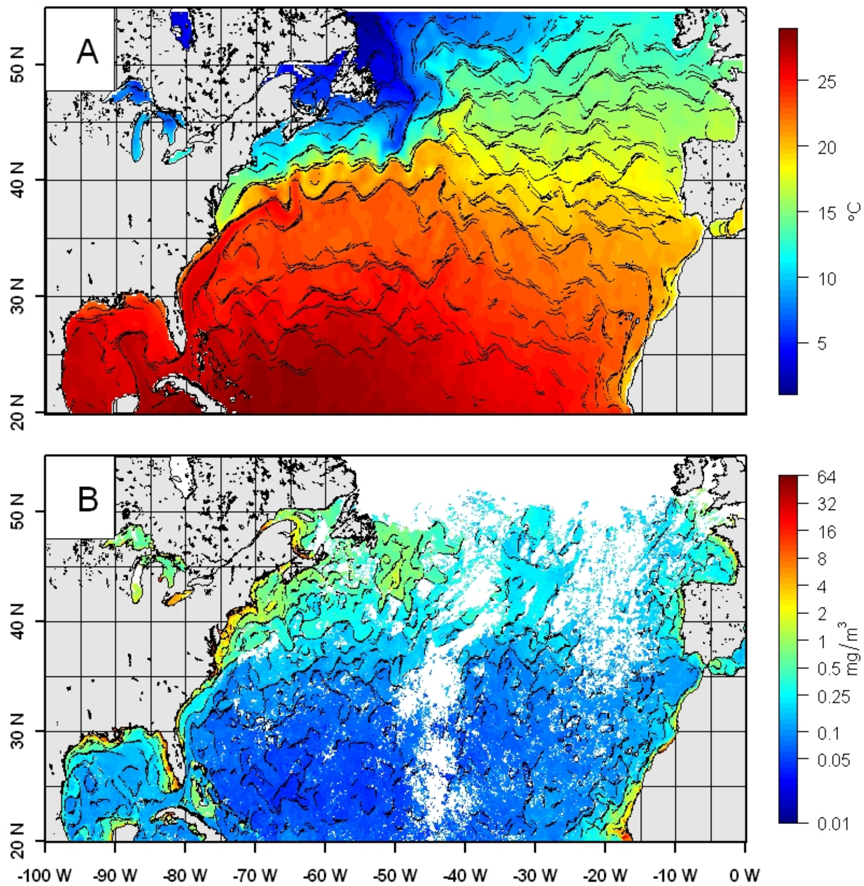

Figure 2. Example of fronts (black lines) for MWIR sea surface temperature (A) and SeaWIFS/MODIS blended 8-day Chlorophyll a (B) composites for the week of November 5, 2005. The algorithm used ignores cloudy areas (white areas in panel B) and land in the frontal determination.

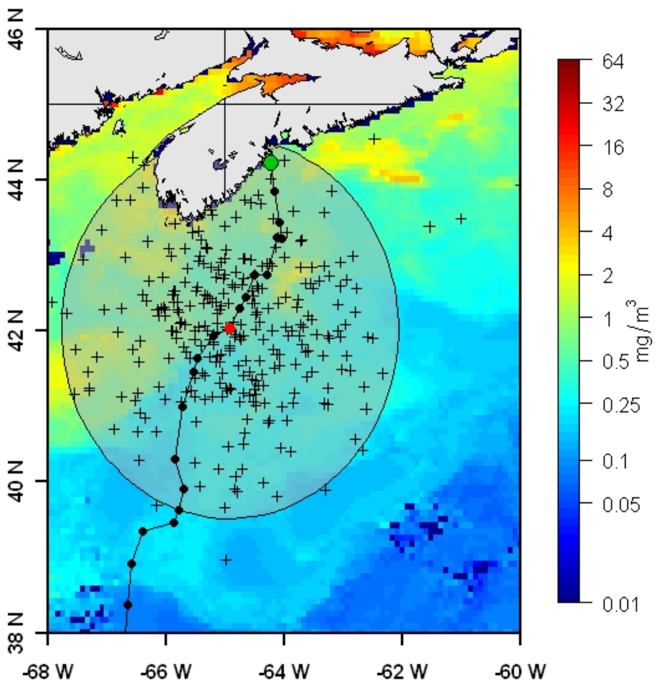

Figure 3. Chlorophyll a composite with samples (black crosses) drawn from a multivariate normal distribution centered on a mean daily position (red point) along the estimated track (black points) of an Atlantic bluefin tuna, conditioned on the covariance of the daily position (grey ellipse). The green dot is the starting point of the track near Riverport, Nova Scotia. This sampling scheme allows along track sampling while taking into account the variance in the location estimate.

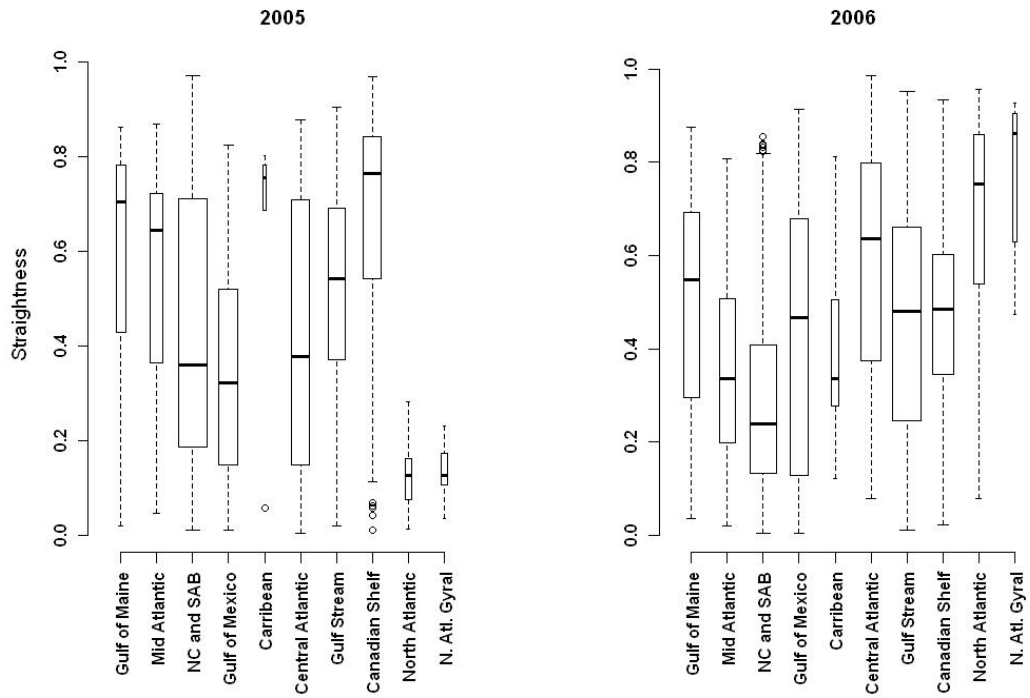

Figure 4. Summary of behavior type within Longhurst regions. Box width is proportional to the number of samples (days) in each region while year indicates tagging year (relevant for all boxplots presented in this study).

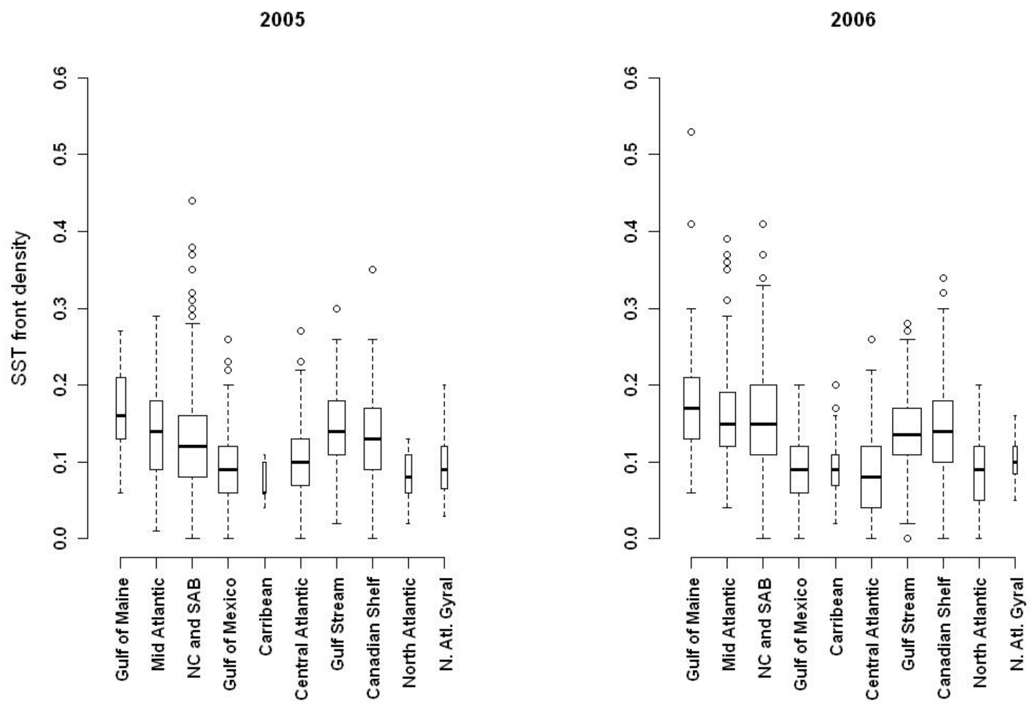

Figure 5. Summary of SST frontal density (%) within Longhurst regions sampled by ABFT between August 2005 and October 2007. Regions with highest frontal densities correspond with known forage areas for ABFT.

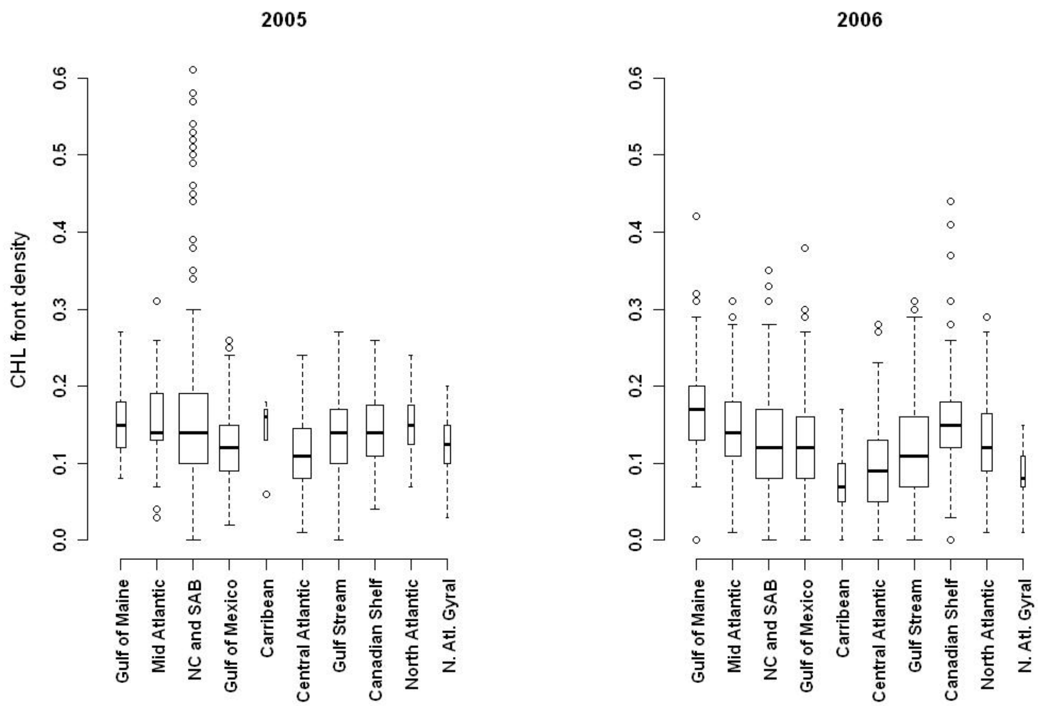

Figure 6. Summary of chl a frontal density within Longhurst regions sampled by ABFT between August 2005 and October 2007. Chl a frontal density was more homogenous for ABFT tracked in 2005 than those tracked in 2006.

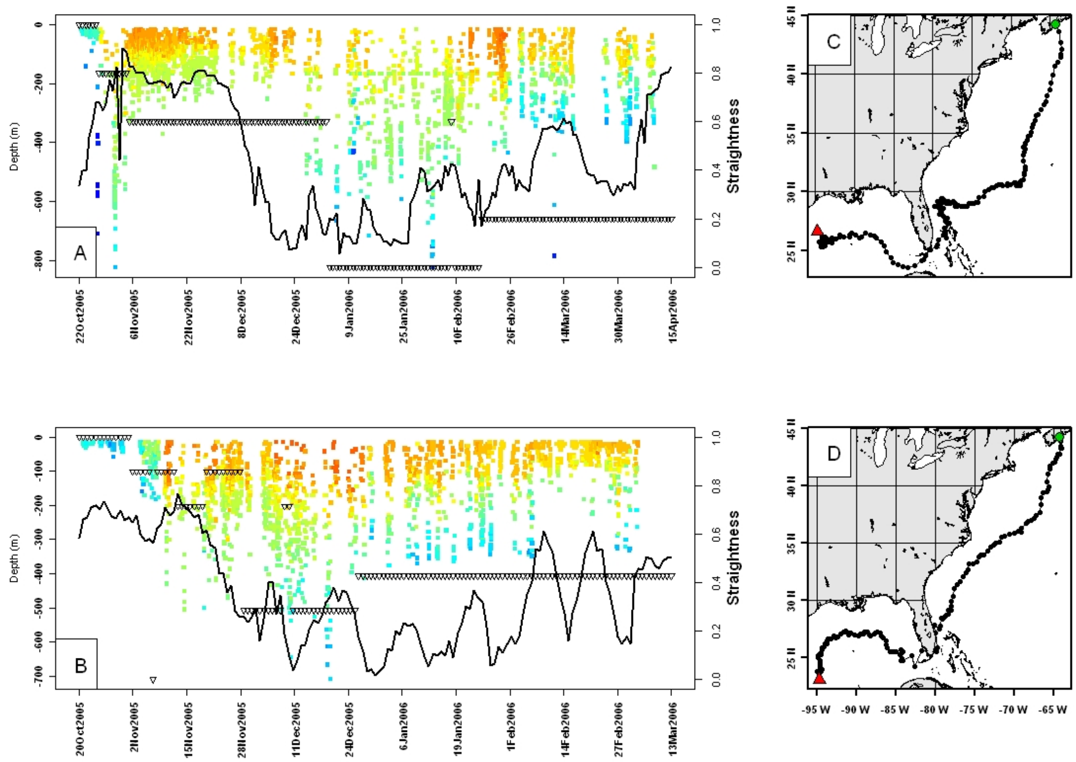

Figure 7. Example of two ABFT temperature depth profiles (A and B) and tracks (C and D). Thick black line in panels A and B indicate behavior type (straightness index) and triangles indicate different Longhurst regions. Green and red dots in panels C and D indicate tagging locations and pop-ff points respectively.