Final Report

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Delivery of Stanford/TAG Electronic Tag Data to ICCAT
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Executive Summary

We are providing 392 electronic data sets to ICCAT from the Stanford University Tag-A-Giant (TAG) research program. This electronic tagging program is now in its 20th year, spanning deployments from 1996-2016. TAG is a partnership involving researchers from Stanford University, Monterey Bay Aquarium, Duke University Acadia University, fishers, and hundreds of citizen scientists who donated fish or tags to the program. TAG researchers initiated electronic tagging of Atlantic bluefin tuna in 1996 off the US coast of North Carolina, and continue to deploy tags in 2016 throughout the North Atlantic, Gulf of Mexico and Mediterranean Sea. We have delivered 392 data sets of archival and satellite tag data sets in accordance with a contract that permitted approximately two months of work on the data. The tag data files include all meta data, processed tracks, and the raw files from the tags. We have, to the best of our abilities in the time provided, put these data in an organized set of folders located in a Stanford cloud based BOX app that ICCAT and NOAA scientists have downloaded. The data set was obtained at a significantly high cost and effort, and it is with great pride we present these data to ICCAT. We provided deliverables 1-3, and the standard data types requested when we decode an electronic tag. We provided descriptions of the data in Table 1 and Table 2 (Deliverable 3), the manufacturer files, information on deployment and recapture or pop up, and a description of the files we produce upon decoding of the tags. A description of files is in Appendix 1. These files will vary between tag type, manufacturer, and tag models, and individual tag performance. Thus early tags on the list (1997-1999) may have had less data taken in a lower resolution (time series), then later model tags. Because we have three manufacturers (Lotek, Wildlife Computers, Northwest Marine Technology), and over 7 models of tags (developmental models), caution has to be taken interpreting files and data sets. We have provided manufacture files, and then processed location, temperature and depth files where available.

Introduction

Electronic tagging of Atlantic bluefin tuna, *Thunnus thynnus*, has emerged as a powerful tool to reduce the uncertainty in scientific knowledge of this species and to provide information on the spatial and temporal patterns of distribution necessary for proper fisheries management (Block *et al.*, 1998, 2001, 2005; Teo *et al.*, 2007a,b, Walli *et al.*, 2009, Wilson *et al.* 2010, 2015). Tagging, genetics and microconstituent analyses together provide the capacity to demonstrate that discrete eastern and western Atlantic bluefin tuna populations exist, move to separate spawning grounds, and mix on foraging grounds (Rooker *et al.*, 2008, Boustany *et al.*, 2008). Our research has shown that bluefin exhibit spawning site fidelity and foraging ground homing (Block *et al.* 2005, Rooker et al. 2008, 2014, Secor 2015). These migration behaviors demonstrate mixing across the North Atlantic, and provide information that influence fisheries stock assessments and population estimates as well as management decisions.

We have provided to ICCAT the direct results of 20 years of electronic tagging and deployments by TAG scientists. These data were collected by the Block lab, and the TAG scientific team, and partners with funding supplied from private philanthropic and federal agencies over the past 20 years. These tag data will be vital for the study of both the eastern and the western Atlantic fishery. Our archival tagging data provides the ability to track individual movements of fish primarily tagged in the western Atlantic fishery, but the tracks, and their duration (1-5 years) informs fisheries management about the eastern fishery too. In addition, our data supports modeling efforts that are currently examining the effects of stock mixing and efficacy of alternative management regimes as well as novel fisheries independent techniques for estimating mortality. These datasets will also improve our understanding of preferred habitats for spawning and enable dynamic management of the closed areas for bluefin tuna longlining in the Gulf of Mexico, which in theory would also reduce mortality on spawning sized bluefin.

Despite the rapid advances in our understanding of bluefin tuna biology, key questions remain about population mixing, recruitment dynamics, maturity schedules, abundance trends and the actual number and size of the independent populations accessed by the western Atlantic fishery. Electronic tagging datasets can improve management models by providing accurate information on key parameters of life history traits related to movements, maturation, fisheries and natural mortality (Kurota *et al.*, 2009, Taylor *et al.*, 2011, Kerr *et al.*, 2012), as well as providing information on critical habitat selection. Additionally, it is possible to use mark recapture frameworks to estimate fisheries mortality and abundance of individual year classes (Kurota *et al.*, 2009, Whitlock *et al.*, 2012). This information reduces the biological uncertainty in assessment models, thus improving their overall accuracy. The TAG scientists used these data to develop our own version of a spatially explicit model called MAST (Taylor *et. al.*, 2011) that demonstrates the importance of incorporating the spatial and temporal movements, as well as population mixing, observed with electronic tags. MAST modelled the seasonal movements of the eastern and western Atlantic bluefin tuna spawning stocks through five discrete fishing grounds in the north Atlantic Ocean (i.e., the Mediterranean Sea, northeast Atlantic, northwest Atlantic, Gulf of St. Lawrence and the Gulf of Mexico) and accounts for interannual and seasonal trends in the mixing rates of the two stocks on these fishing grounds. This model inspired more recent efforts to map complex mixing of the bluefin tuna populations for assessment science.

The rebuilding of the western, Gulf of Mexico spawning population also requires managers to have knowledge about how the population is influenced by environmental variation, and how susceptible mature bluefin will be to both fisheries bycatch and environmental changes. Tracking data provides evidence on where the fish are, what sectors of the fishery they are vulnerable to, and where protected areas will have the greatest impact (Wilson et al. 2015, Hazen et al. 2016). Management of Atlantic bluefin tuna at the population level requires knowledge of survival, growth and reproduction, movements and habitat utilization as well as changes that occur through ontogeny and based on gender. Electronic tags provide information on these parameters, as well as informing locations of critical spawning and foraging hot spots which can then be target areas for protection as these regions represent areas where catchability increases due to aggregation behavior. Electronic tags also provide information on geographic and physiological ranges, responses to oceanographic forcing, and human impacts (e.g. oil spills). Understanding the risk of marine species to anthropogenic stressors requires information on the patterns of habitat use and movements of marine animals as well as the spatial and temporal patterns of their stressors.

The TAG program is the longest continuous running electronic tagging program for Atlantic bluefin. TAG is a partnership involving researchers from Stanford University, Monterey Bay Aquarium, Duke University and Acadia University. TAG researchers initiated electronic tagging of Atlantic bluefin tuna in 1996 in the western North Atlantic in the Carolina winter fishery after spending two years to develop tags at the Tuna Research and Conservation Center. We initially worked in 1994-1996 with Northwest Marine Technology, and Microwave Telemetry in the early years to build the original electronic archival tag (NMT tags), and first pop up satellite tags (Block et al.1999). Two distinct tags were tested and trialed in the period from 1994-1997, and both eventually became stable electronic tag products with a large number of sales. Then, in 1996-1997, Dr. Block initiated worked with Dr. Roger Hill, and Wildlife Computers to develop two tags with this new company, one was the original mk7 archival tag, and the second was the PAT, pop up satellite archival tag. To date, over 1300 electronic tags have been deployed in the western Atlantic or Gulf of Mexico on adolescent and mature fish. From western tagging only, detailed location and behavioral time series data for individual Atlantic bluefin tuna of ages 5 to 30, have been obtained (Block *et al.*, 2001, 2005, Teo *et al.*, 2007a, b, Walli *et al.*, 2009, Lawson *et al.*, 2010, Wilson *et al.*, 2010, Wilson *et al.*, 2015), producing nearly 40,000 tracking days of data. Approximately 77% percent of these tags (n=983) were deployed in the coastal waters off North Carolina (1996-2012),18% of the tag deployments have occurred off Canada (2007-2013), 4% in New England and 3% in the Gulf of Mexico (1999-2003). Electronic tagging is expensive, long-term deployments are difficult to achieve, and mortality can be a concern. Most recently, we have focused our recent deployments at in the Canadian fall fishery in the Gulf of St. Lawrence, which provides access to GOM and Mediterranean spawning populations (Wilson et al. 2015, Hazen et al. 2016).

We, with approximately two and a half months of funding from ICCAT, have organized 392 data sets, in a cloud based folder and have provided direct access to ICCAT in this contract (Deliverables 1-3). These data are provided to the best or our abilities as a private laboratory, and not a business (CLS). We have ensured that NOAA and ICCAT scientists have access to the electronic tag data (some with known origin of spawning origin), for improving stock assessments. The published papers provide access to the mathematics and in particular we draw attention to Teo et al. 2004, Block et al. 2005, Block et al. 2011, Winship et al. 2012 and Wilson et al. 2015 for methods that are associated with our track models. Everything we do is published in the peer-review literature with methods that can be accessed there.

The overall objective is to improve our knowledge of habitat use, spawning fish migrations and stock mixing in the western North Atlantic and Gulf of Mexico. The successful rebuilding of Atlantic bluefin populations requires an understanding of their spatial structure, population mixing and seasonal movements (Taylor *et al.,* 2011). Atlantic bluefin have been historically challenging to study due to their size, speed and range. Integrated population assessment models depend upon data that incorporates spatial and temporal mixing of the western (GOM) and eastern (Mediterranean) breeding populations. New information on genetics, maturity and microconstituent analyses are also considered essential. Our tagging studies and those of our colleagues (Lutcavage *et al.*, 2000, Galiuardi and Lutcavage, 2012) have demonstrated that all age classes of Atlantic bluefin are capable of transits across ocean basins. The enormous scale of these migrations has made it difficult to follow these fish over long durations. Understanding the connectivity between eastern and western populations of bluefin tuna is critical to management efforts. Uncertainty about fidelity to spawning grounds, the timing and age of maturity, the size at which bluefin tuna move into spawning grounds (breeding and maturity schedules), temporal timing of spawning, duration of occupation on the spawning ground and exit dates from the spawning grounds, has resulted in a lack of clarity in fisheries stock assessment models (population assignments).

Deliverables:

1) We have delivered all the Block laboratory papers on electronic tagging using these data as requested in Deliverable 1.
2) We provided the 185 electronic tags, organized in order of the electronic tag number and deployment date in July. In Table 1 the list of tags, deployment and recovery information, pop up deployment and ARGOS recovery dates is provided as requested.
3) In early September we provided deliverable 3, the remaining data sets for a total of 392 data sets.
4) We provided data in the format our laboratory team prepares data sets. And we provided a description of all files.

Background/ and Analyses with the TAG Electronic Data Set

The ICCAT contract's objective was to deliver electronic tag data sets that had revealed significant information about tuna movements. The data set we delivered is 392

electronic tags put in fish from 1997-2015. The electronic tags deployed through the tag program were primarily archival tags (n=800), and then an additional 500 PAT tags, many of which were short term deployments as we developed the tags. To date, we have recovered approximately 20% of the archival tags, surgically placed in western Atlantic tagged bluefin tuna, and have acquired data from about 78% of the pop up satellite archival tags. From western tagging only, detailed location and behavioral time series data for individual Atlantic bluefin tuna of 5 to 30 years of age have been obtained (Block *et al*., 2001, 2005, Teo *et al.,* 2007a, b, Walli *et al*., 2009, Lawson *et al.*, 2010, Wilson *et al.*, 2010, Wilson *et al.*, 2015), producing nearly 38,000 tracking days of data. To date no other bluefin population on the globe has the collection of spawning area tracks and behavioral results that the TAG data set is generating. Many of the obstacles of tagging large spawning sized individuals have been overcome in the past five years.

For this contract that had a very tight timeline we delivered what we feel are the most informative data sets, n=392. There are additional data sets we have, that we can deliver in the future, but some require either more effort to decode position, and plot, or are of too short a duration to be of high interest (less then 90 days). We do have a Mediterranean data set, that ICCAT has acquired through our partners (WWF), and we have some additional tags reported in our recent paper on Mediterranean tagging that are not included herein (Cermeno et al. 2015). Thus, there may be an additional 200 tags to recover data from, and we continue to put tags out in 2015-2016. Finally we have an acoustic tag data set (130 tags, 30,000 detections), that has yet to be published and is also soon to be available.

We provided Deliverables 1-3, the standard data types and plots we use when we decode an electronic tag. We provided descriptions of the data (Table 1 and Table 3), the manufacturer files, information on deployment, and recapture or pop up, an then a description of the files we standardly produce upon decoding of the tags. These files will vary between tag type, manufacturer, and tag model. Thus early tags on the list (1997-1999) may have had less data taken in a lower resolution (time series), then later model tags. Because we have three manufacturers (Lotek, Wildlife Computers, Northwest Marine Technology), and over 7 models of tags (developmental models), caution has to be taken interpreting files and data sets. We have provided manufacture files, and then processed location, temperature and depth files where available.

Geolocation with the TAG Electronic Tag Data

The TAG team also improved and validated geolocation code from these tags to increase the precision and confidence of our Atlantic bluefin tuna tagging data sets. Algorithms to estimate the geographic location of tagged animals from environmental data archived on tags (light, depth and water temperature) have proven successful for estimating the movement paths of tuna and other marine species (Smith & Goodman, 1986; DeLong *et al.*, 1992; Metcalfe & Arnold, 1997; Block *et al.*, 2001; Gunn & Block, 2001; Block *et al.*, 2005; Shaffer *et al.*, 2006; Pedersen *et al.*, 2008; Thygesen *et al.*, 2009). Light-based geolocation methods rely on archived measurements of solar irradiation, with the timing of sunrise/sunset providing information on longitude and day length providing information on latitude (Smith & Goodman, 1986; Hill, 1994; Welch & Eveson, 1999; Ekstrom, 2004). The precision of light-based geolocation estimates of latitude have been improved using archived data on other environmental variables such as depth and sea surface temperature as well as bathymetry (Beck *et al.*, 2002; Teo *et al.*, 2004; Nielsen *et al.*, 2006; Lam *et al.*, 2008). Quantifying the uncertainty in location estimates is vital for drawing proper biological inferences from tracking data. Location estimates from tags should be validated to assess their accuracy and precision. Validation requires knowledge of the true location of the tag. Many studies have assessed the accuracy and precision of Argos and geolocation estimates using tags placed at known locations (e.g., Welch & Eveson, 1999; Musyl *et al.*, 2001; Ekstrom, 2007; Nicholls *et al.*, 2007).

In the past two years, we developed a state-space framework for a statistical approach to analyze location data from archival double-tagging experiments (Figure 1-2; Jonsen *et al.*, 2007, Block *et al.*, 2011, Winship *et al.*, 2011, Wilson *et al.* 2015). This state-space framework has advantages over simple data comparisons because it acknowledges errors in all geolocation data, not just the less precise data around solstices, and it can accommodate a range of data types with different temporal resolutions without the need for data averaging, filtering or interpolation. A state-space models can be fitted to as many location data types as are available. Furthermore, because the state-space model incorporates an underlying model of animal movement, one can make appropriate inferences about true animal locations and movement while simultaneously estimating measurement errors. Thus taken together the geolocation validation and the new model output for tracks provides a measurement equation that accounts for the errors in the observed locations.

Both the archival tags and the miniPAT tags log ambient temperature, pressure and light intensity. Archival tags are obtained when the fish has been recaptured. Recapture and recovery occur when fishers call ICCAT, NOAA, TAG or the Block laboratory. In all cases $1000 has been paid to the fisher for return of the tag, and shipping costs by one of the three main recovery teams. In the case of the pop up tags, at a pre-programmed time, the tags release from the fish, float to the surface and transmit the recorded data to orbiting Argos satellites. Argos satellite costs have been paid by the Block lab. Time series data are logged on the archival tags based upon how they were first programmed, and the memory on the tags. In the early days, tags recorded data in 2' intervals due to memory restrictions. More recent tags built by Lotek (2310), recorded data in 4, 16 and 20 second itervals. A variety of problems occurred with archival tags, including sensor stalk failure (Wildlife Computers), and battery failure (Lotek). Most of these problems resulted in some shorter tracks, but occasionally tags did work for multiple years- providing up to 5 years of tracking data. Pop up satellite tags transmitted data through satellite and often had very course resolution data if the data sets was only transmitted data. So most of the tags do not have a time series record. Light curves are used to calculate sunrise and sunset times for both types of tags, and an accurate internal clock allows mathematical estimation of longitude and latitude based on time of local noon and day length using a custom program called SST lats (Block *et al.*,2001, 2005, 2011; Wilson *et al.*,2010, Teo *et al.*,2004, Stokesbury *et al.*,2004). A state-space switching model (SSM) developed in the past two years by Dr. Ian Jonsen of Macquarie University and James Ganong in the Block laboratory (Figures 1-3; Wilson et al., 2015), based on prior SSM model work (Block *et al.*,2011, Winship *et al.*, 2012), is used to generate a probablistic track. This SSM model algorithm incorporates a bathymetry filter that actively uses the deepest daily diving behaviors of the fish, to improve the fit of latitude position for these tracks.

In recent years, TAG has focused on electronic tagging of large bluefin tuna in the Canadian commercial fishery off Port Hood, Nova Scotia, Canada. The Canadian foraging aggregation has been permitted for electronic tagging by US scientists since 2007, and to date TAG scientists have placed 140 satellite tags on these fish (measured mean size 266.1 cm ± 22.2 CFL). Access at this location has been to the largest and most fecund Atlantic bluefin remaining in the North Atlantic. In addition over 80 acoustic tags have also been deployed here (Block *et al.*, in preparation). The region selected for the tagging experiments is a semi-enclosed sea connected to the North Atlantic Ocean via the Cabot Strait and the Strait of Belle Isle (Koutitonsky and Bugden 1991). 74% of the bluefin tuna whose tags remained attached until the peak spawning month (May, n=51) went to the Gulf of Mexico spawning ground, and four individuals carrying satellite tags went to the Mediterranean Sea. Ten additional Atlantic bluefin tuna that were of spawning size did not visit a known spawning ground during the spawning season. Use of larger mk10 PAT tags in the early years led to a significant number of premature releases. This has been resolved in the past three years with the use of the new Wildlife Computers miniPAT tags. These smaller tags remain attached with high retention rates to the pop-off date, providing a new opportunity for recovery of the satellite tag and the time series data. To date 25 archival data sets have been obtained by recovering satellite tags the year after they are deployed. From these data, we have learned that bluefin tuna that travelled to the Gulf of Mexico spawning ground from the North Atlantic always remained within the western management area and did not cross the 45 meridian (Figure 1). Population assignments of the individuals that move into spawning grounds have been verified using genetic microsatellite DNA assignments from fin clip analyses which were obtained during tagging. These results confirm GOM fish go to GOM spawning grounds, and have a GOM genotype; and fish that return to the Mediterranean spawning grounds have a distinctly different genotype, consistent with the Mediterranean population identification (Boustany *et al.,* 2008, Reeb *et al*., unpublished data).

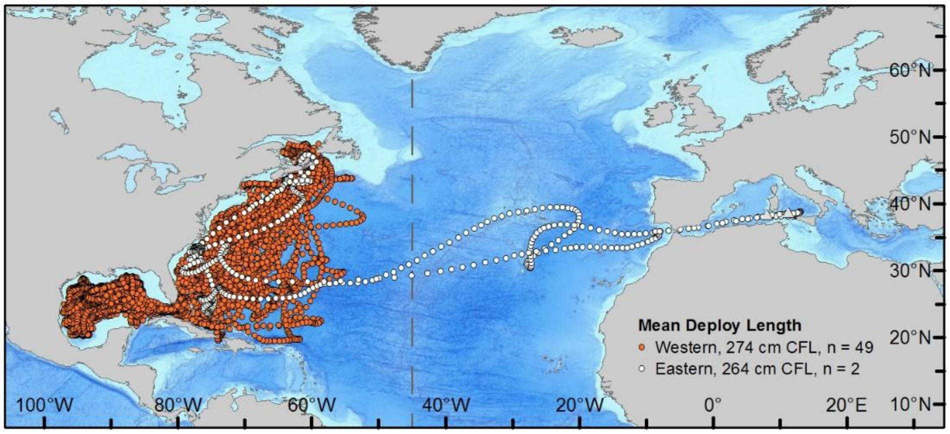

Figure 1. Geolocations from PAT satellite archival tags (n=51) deployed in Canadian waters that remained on fish. Circles are geolocations from light and SST based estimations and colors are tracks of satellite tagged bluefin tuna that are coded by their movement on to known spawning grounds (orange, Gulf of Mexico, white Mediterranean).

To study the GOM aggregation of spawning fish, which has resulted in a rapid increase in our capacity to track bluefin tuna moving to the GOM spawning grounds and back to the North Atlantic foraging grounds, required new techniques. We increased the retention time with the smaller miniPat tags which reduces the drag of the tag. We first tested the newly designed tags with double tagging experiments (MK10 versus miniPat). We designed a three-layer leader and two-point attachment system to keep tags on from deployment to recovery (Wilson *et al.*, 2015). Using these small tags, we have been able to get tracks that provide data on emigration from the Gulf of St. Lawrence foraging grounds to the Gulf of Mexico spawning grounds and back again over the past few years (Figure 2). We have established, through the eight seasons of Canada tagging reported in the ICCAT files, proper capture and tagging techniques that permitted successful handling on the deck of commercial fishing boats of fish up to 500-600 kg. By moving the fish on to the fishing boat deck, we can carefully place tags with two points of attachment that enable strong retention until scheduled pop up satellite endpoint dates. This is a critical step for obtaining valuable data sets from within the GOM. In addition, mortality studies were conducted to ensure the tag and release techniques were safe for these year classes (Stokesbury *et al.*, 2011, Block *et al*., 2013, Wilson *et al*., 2015). With the use of the miniPAT, we've shifted our focus to recovering every satellite archival tag to obtain the full archival time series. To date we've been successful in obtaining 18 full archival GOM records, that include putative spawning behavior over the past few years. Each record offers a detailed archive of 2-15s resolution data-on behaviors of giant bluefin that can be used to fully analyze oceanographic and behavioral records during spawning in the GOM.The satellite archival tag tracks from the GSL have provided 9-11 months data sets with detailed archival time series and oceanography over the period when bluefin tuna occupy the GOM spawning ground. more years to log a trip to the Gulf of Mexico fish.

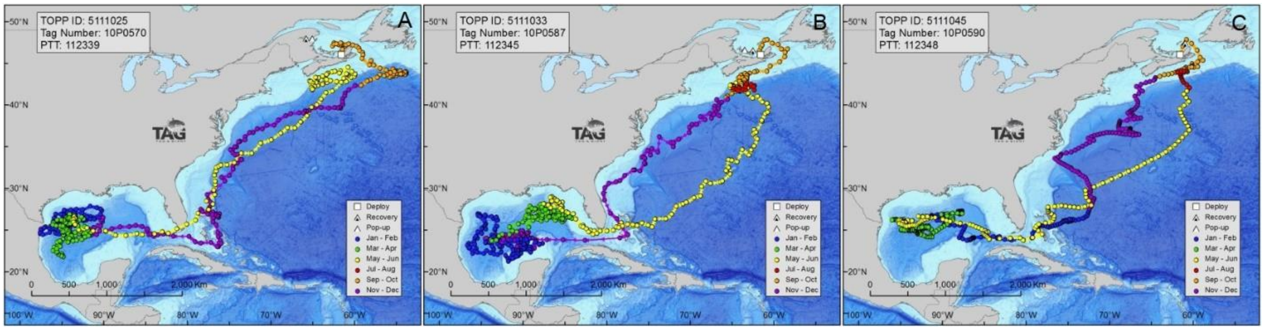

Figure 2. (A-C) Examples of pop-up satellite archival tag tracks run with a state space model. These tracks were obtained from tagging Canadian bluefin in the GSL with Wildlife Computer satellite archival tags. Tracks show trips from the release on the foraging ground to theGOM spawning areas and demonstrate the capacity to capture the complete roundrip from foraging to spawning grounds and back.

In addition to geolocation tracks, the satellite archival tags provided from our team are filled with detailed time series data on bluefin tuna location and behaviors including potential foraging activity, putative spawning behaviors, and oceanographic preferences. Tags record temporal data on the journey from the GSL foraging ground to the GOM, the exit date from the GSL, the entrance date in the GOM, spawning date location, initiation and termination of spawning behaviors in relationship to local GOM oceanography and exit date, as well as the length of time and path of the return trip duration to the foraging ground (Teo *et al.*, 2007a, 2007b, Wilson *et al.*, 2010, Block et al. 2013, Wilson et al. 2015).

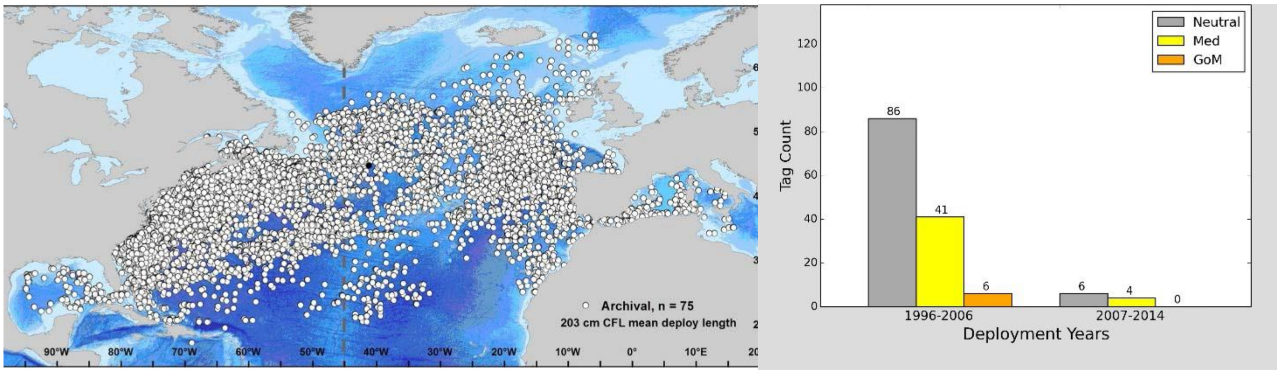

Figure 3. A) Positions (geolocations) of Atlantic bluefin tagged and released in North Carolina winter fishery with archival tags that recorded 30 days of tracking data or more (recovered from 1997-2012). The tags were deployed on fish with a mean measured length of 203 cm (CFL) from waters off Morehead City, and Hatteras, NC. Right panel -The tracks visiting a spawning area go primarily to the Mediterranean Sea (45) and fewer tracks recorded visitation to the GOM (6). Neutral track are most likely adolescent fish that had one year or less of data.

In the North Carolina winter fishery (Figure 3), despite deploying over 700 archival tags (with a 22% return rate), only 6 archival tags recorded bluefin tuna visitation to the GOM. This emphasizes the value of the newly developed techniques, which enable a team to keep tags on long enough to capture a full broadcast spawning period in the GOM. Many more Carolina archival tagged fish go to the western Mediterranean Sea (46). Most record journeys only into the North Atlantic (Block *et a*l., 2005) characteristic of adolescent foraging migrations. Thus, the GSL release of bluefin tuna with satellite archival tags offers a unique opportunity for bluefin tuna scientists and modelers. Advances in tagging technologies (use of smaller satellite tags with stronger leaders) in the past two years, enable major steps forward in gathering long-term data sets on these mature fish. This opportunity will only remain while the fish of these year classes are accessible. Fishing in the GSL has been variable and in the 1990s many of these size classes were unavailable. The ability to access the GOM spawning ground with electronic tags deployed in this region, provides a unique opportunity to study adults on the GOM breeding ground. We can thus test predictive adult habitat utilization models aimed at improving the understanding of habitat selection in the context of the variable GOM oceanographic environment and enables studying the effectiveness of the time area closures to protect spawning bluefin tuna (Teo *et al.*, 2010). Additionally, the tags will provide explicit spatial use of GOM fish considered matures spawners, when out on the North Atlantic foraging grounds. To date, they have shown a particularly western distribution (Figure 1).

As outlined above, the advancement in satellite tagging techniques in the GSL waters now provides the latest information on the annual cycle for bluefin tuna of GOM origin as shown in Figures 1-2. From these new tag data we have learned several surprising results: a) entrance and exit into the GOM is occurring at a broader seasonal time period (November- June) than previously recorded from the implantable archival tags on the North Carolina aggregation (Figure 5); b) geographic hot spots in the GOM are increasing as larger fish are tagged and now show occupany in new areas of the GOM in US, Mexican and International waters (Figure 6), which potentially may be areas of longline bycatch; c) presumed spawning aggregations show focal spots on the US slope waters in April and May as previously reported (Block *et al.*, 2005, Teo *et al.*, 2007a, 2010), but are not precisely captured by the new closed areas. d) bluefin tuna exiting the GOM spawning ground can transit in less than 24 days to Canada (passing the North Carolina coast within a week of exit). Thus, a female bluefin who may have spawned in May or June in the GOM could have viable oocytes, or display atresia if the fish was caught coming into these regions upon exit. Many of these fish are exposed to other longline fisheries given their trajectories in the North Atlantic. Their tracks and position data (given their western spawning status) become quite valuable for overlaying with catch and effort information from offshore fisheries.

The tag data can now be used to create proxies (behavioral codes that utilize the time series data on an archival tag) to find behavioral records unique in the GOM, that may represent putative spawning. We know from prior work and the new results that bluefin tuna aggregate in US slope waters in the GOM in April, May and June (Block *et al*., 2005, Teo *et al*., 2007a, b). Diving behaviors often change in concert with the slope water GOM aggregations. This period is also associated with an environmental warming (as spawning occurs at the latter residency period in the GOM,) when SSTs are warmest. In addition, temperature-depth profiles of the water column appear to be stable during what appears to be the putative spawning time.

Habitat Utilization within the GOM

To date, the new TAG Canadian derived tracks from GSL deployments delivered to ICCAT on primarily mature tuna provide the highest level of information on how individual adult bluefin tuna use the GOM spawning area. Tracks show age of entry of bluefin into the Gulf of Mexico. The mean size of the bluefin tuna that recorded visitation to the GOM was 275 ± 14 cm (CFL ± SD, n = 41) and tagged bluefin entering the GOM ranged from 243 to 313 cm. Small fish are being tagged in Canada, so this is not simply an artifact of selecting large fish for satellite tags. Atlantic bluefin show usage of both eastern GOM and western GOM.. The mean exit date of Atlantic bluefin from the GSL that visited the GOM was 16 October ± 13 days (SD) (n=41). The mean travel duration from the GSL to the GOM was 94 ± 41 days (SD) (n=41). Atlantic bluefin entered the GOM over an extended period from 10 November to 4 April (mean entry date =

17 January ± 42 days (SD), (n=41) and exited from 5 April to 10 June (mean exit date = 20 May ± 16 days (SD), n = 17). Both entry and exit dates were available for 17 individuals. The mean residency period within the GOM was 118 ± 50 days (SD) and ranged from 46 to 197 days. The peak GOM residency, measured by the number of tagged bluefin in the GOM each month, occurred during the months of April and May. This is consistent with prior bluefin tuna spawning habitat data that also suggested that spawning activity in the GOM peaks in May (Block *et al*., 2005, Teo *et al*., 2007, Muhling *et al*., 2010).

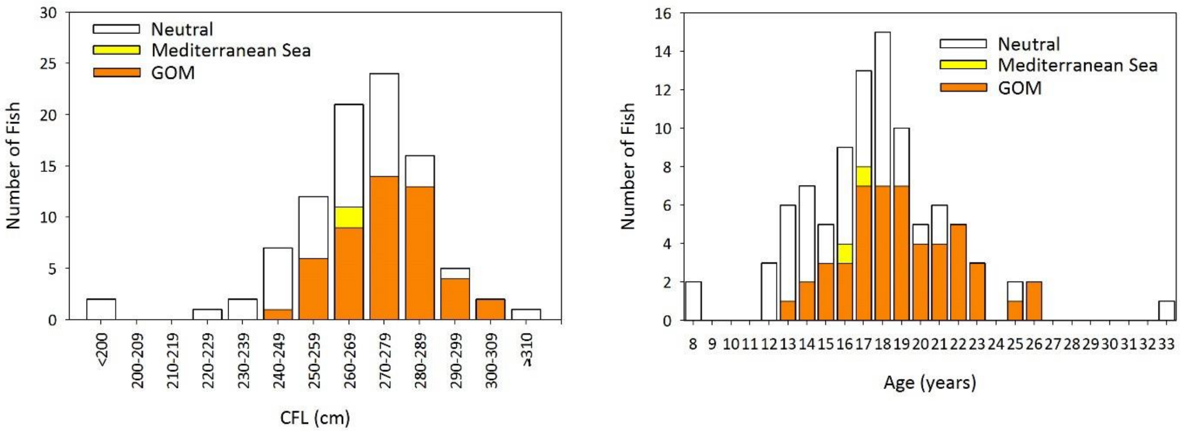

Figure 4. A) Number of bluefin tuna by size class (CFL in cm) that visited the GOM, Mediterranean Sea or neither location (called neutral) from releases in the Canadian GSL area; **B**) Number of bluefin tuna by age that visited the GOM, Mediterranean Sea or no known spawning ground (neutral). The western growth curve (Restrepo et al. 2010) was used to calculate the age of GOM and neutral bluefin and the eastern growth curve (Cort 1991) was used to calculate the age of the Mediterranean fish.

To examine the high use areas of the spawning regions in the GOM, the track data from TAG (Hazen et al. 2016), are utilized to identify the habitat visited by bluefin. The environmental correlates with behaviors on the tag we're analytically mapping as "spawning periods". The months of April and May are hypothesized to be the peak GOM spawning period based on electronic tagging data, catch data and larval surveys (Block et al. 2005, Teo et al. 2007a, 2007b, Muhling et al. 2010). The archival tagging data reveal locations in slope waters (Figuof the northern GOM: both in the western GOM, and the other in the eastern GOM in the vicinity of the Macondo well where our models identify spawning may be occurring. Complete round-trip tracks from the GSL foraging ground to the GOM spawning ground and back were initially obtained for 9 Atlantic bluefin tuna (more have been obtained since the first analyses). These fish exited the GOM from 12 May to 10 June (mean exit date = 24 May ± 9 days (SD), n=9) and returned to the GSL from 18 June to 2 August (mean entry date = 7 July ± 16 days (SD), n=9). Travel duration from the GOM to the GSL ranged from 21 to 77 days (mean duration = 43 ± 17 days (SD), n=9). These tracks provide the raw data for extensive analyses in relationship to environmental data- on where exactly spawning of adults occurs.

Electronic tagging also inform fisheries managers about the age at which bluefin tuna are moving into the GOM, presumably to spawn. Only tagging provides this individual movement information, residency and habitat preferences. Plotting the bluefin tuna age cumulatively over the entire period when bluefin were tracked with electronic tags provides information on when bluefin tuna enter the GOM and extends entry to as early as November, and exit through the month of June. The youngest tagged fish observed to have entered the GOM was age 10 according to the new growth models for western bluefin tuna (Restrepo *et al.*, 2010). Bluefin tuna smaller than 10 were tagged in the GSL, but did not move into the GOM (these fish remained in the North Atlantic). Monthly plots showed that April and May are the months with the highest number of electronic tracked bluefin present in the GOM. Although tagged fish as young as 10 years of age entered the GOM, the total distribution of all tracked fish reveal that only a small percentage of 10 year old fish entered the GOM (0% for November through April, 2.5% in May, 6% in June). For May, the month with the greatest number of tagged fish found in the GOM, the ages at which the majority of fish were found in the GOM were by measured length converted to ages >16 (66% for ages 17 and 19, 80% for age 18 and 100% for ages 20-23). Our tagging data show that bluefin tuna enter and depart the GOM at different times, and tagging provides the opportunity to examine the percentage of electronic tagged fish in the GOM over the entire period when fish were observed to have traveled there (November through June). Although the dataset is smaller, the data returned from tagging corresponds well with those calculated by Diaz (2010) for GOM catch records. Both data sets indicate that the year classes of fish on the spawning grounds in the Gulf of Mexico are large in size, and late in age. Such data can only be garnered with long retention times for tags on mature fish.

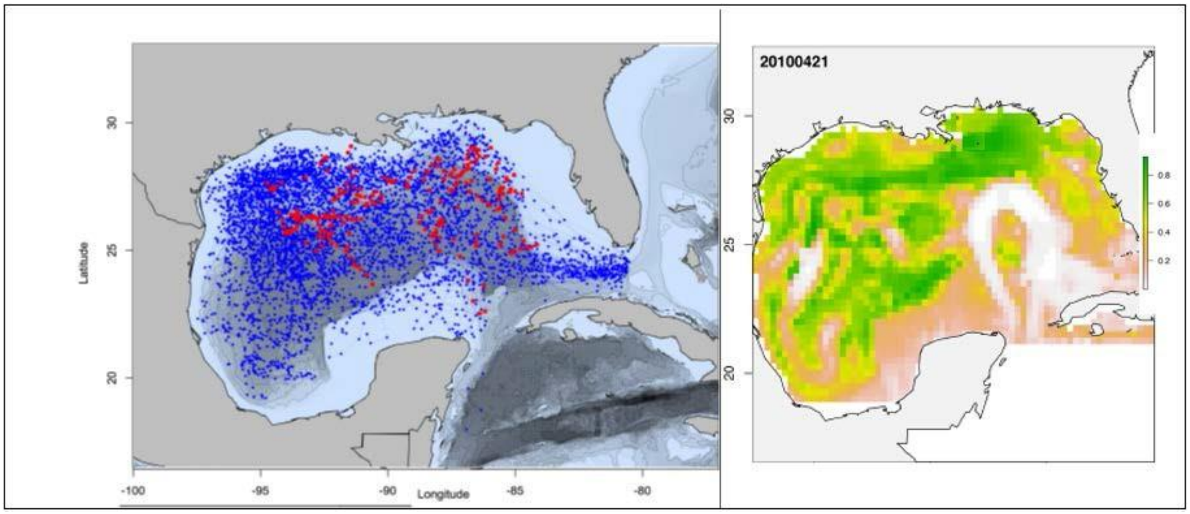

Figure 5. Tagging provides a unique data set of information on how bluefin tuna use habitat in the waters of the Gulf of Mexico. All geolocations (blue) of Atlantic bluefin tuna that visit the Gulf of Mexico from satellite archival and implantable archival tags, and red squares (areas where spawning is predicted to occur based on robust analyses of time series from archival records and coding of unique diving and thermal behaviors that only show up in consecutive days in the Gulf). Shown on the right is environmental correlates predicting spawning habitat with high suitable spawning probability habitat (in green) present in the month of April 2010, based on mapping positions, and associated error, with environmental correlates of these regions (from Hazen et al. (2016)and discussed in objective 3 below).

Identifying Spawning Habitat for Bluefin in the Gulf of Mexico

Electronic tags provide detailed movements of bluefin tuna into the western spawning grounds and evidence for reproductive philopatry of GOM fish to specific areas (Block *et al.*, 2001, Block *et al.*, 2005, Teo *et al.*, 2007a). We have developed dynamic habitat utilization models that provide information on environmental preferences of bluefin during the spawning season (Teo *et al.*, 2007a, b, Teo *et al*, 2010, Hazen et al. *2016*). These data have the potential to allow us to hind-cast, now-cast and forecast areas in the GOM areas being used by mature Atlantic bluefin tuna in relation to oceanographic conditions and newly developed closed areas (Figure 6 and 7). Mature bluefin tuna have been shown to use the western and eastern GOM slope waters for breeding along frontal zones of the Loop Current and within cyclonic features (Teo *et al.*, 2007a, b, 2010). Their habitat preferences appear to be slightly wider in environmental tolerances then the models generated for larvae (Muhling *et al.*, 2010, 2012). Bathymetry, sea surface temperature, eddy kinetic energy, sea surface height anomaly and surface chlorophyll concentration all have had significant effects on pelagic longline “Catch Per Unit Effort” and habitat use patterns of tagged breeding bluefin tuna (Teo *et al.*, 2010). We hypothesize that the optimal environmental conditions at GOM spawning sites represent a balance between the physiological requirements of tuna larvae (Muhling *et al.*, 2010, 2012) and habitat preferences of adult bluefin tuna. The giants, who are up to 600 kg in size, appear from some behaviors we’re observing on tags to have thermoregulatory challenges in the GOM. Growth and development of larval bluefin tunas requires warm temperatures, but large breeding adults (such as the GSL fish) may be thermally stressed in the mixed layer and warm surface waters (required for spawning) in the GOM. Thus far in our models the bluefin choose anticyclonic areas- potentially the coolest region in the GOM for these 1000 lb plus fish. The newest data (Hazen et al. 2016*),* supports the prior environmental preferences identification of spawning bluefin by (Teo *et al.*, 2007b).

We have already identified “spawning proxies” (Hazen et al., 2016), these mathematical codes highlight the unique behaviors we have identified that are characteristic in the time series records in the GOM. To date, we have identified a cluster of these “spawning proxies” that include shallow oscillating diving above the thermocline, presence in warmer SSTs, and when body temperature is available, higher then median internal body temperatures. In addition, tags provide more information on environmental data sets (increased opacity, decreased light extintion of the water masses coincident with presence in cyclonic eddies). From location data, oceanographic conditions (extracted from environmental grids) that are correlated with these time series changes in behaviors to discern what environmental habitat shifts correlate with the behavioral shifts in archival data (see also Teo *et al.*, 2007a). To incorporate environmental conditions from satellite oceanographic inputs, we used general additive mixed models (GAMMs; Block *et al.*, 2011, Hazen *et al.*, 2012) to examine the track and behavioral switching in the context of the oceanographic environment (SST, SSH, chlorophyll, geostrophic flow, thermocline depth, eddy kinetic energy, and gradients). Together this will provide predictions for putative spawning site areas based on real track data, and actual behaviors from high resolution time series, that can be observed in relationship to the currently proposed April and May closed areas.

TAG continues to put tags out in 2016 (20 PAT tags, 22 acoustics in Canada, 18 scheduled for Ireland). We will make tag data available with continued resources from ICCAT.

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Appendix 1.

Read Me File for Files In Deliverables 2 and 3

README for Deliverable 2 and 3 datasets

Each etag is in a folder listed by eventid.

Eventid information within the code breaks down as follows:

Atlantic bluefin species code = 51
2 digit deployment year
3 digit sequential integer per year per species
2 digit sequential integer per individual tagged animal

e.g., 519900100 is the first tag deployed on the first Atlantic bluefin in 1999.
The eventid approximates tagging date order but is not a perfect match.

We have gathered a basic set of files for each etag we use to process tags. We are not a company we are a small laboratory so some variation will exist from CLS processing. The naming conventions vary within each file type due to the age of the data and when it was processed.

These files are:

archival binary -- xxx.wch from Wildlife Computers, or xxx.bin from Lotek/NMT tags
transmitted binary -- xxx.prv, xxx.log, or xxx.txt file from Wildlife Computers popup tag
raw archival time series -- xxxTS.csv, xxxTS.txt or
xxx-Archive file name
archival time series weekly plot -- xxxWP.pdf, xxx_weekly.pdf
light level longitude -- xxx_longitude.csv, xxx_longitude.txt, xxx_long.csv, xxx-Locations.csv, xxxDL.txt
profile of depth temperature (pdt) -- xxx_pdt.csv, xxx-PDTs.csv, generally only present for transmitted popup data
pdt plot -- xxxBT.jpg, xxx_TBT.jpg, xxxBT.jpg
geolocation -- xxx_findlats.csv, xxx_geodata.csv, xxxSSM.txt
geolocation plot -- xxxVW.jpg, xxx_findlatsxxx.jpg, xxxgeolocations.jpg, xxxSSMxxx.jpg

see ssm_README.txt for more details on the SSM geolocation files.