ACOUSTIC ASSESSMENT OF JUVENILE BLUEFIN TUNA AGGREGATIONS: A FEASIBILITY STUDY

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Abstract

This project was a feasibility study using multibeam sonar to examine the efficacy of direct assessment methods to determine school biomass of Atlantic bluefin tuna (ABFT). The long term objective is to develop reliable indices of abundance and to improve stock assessments. This was done using high frequency (400 kHz) multibeam sonar mounted on a commercial tuna/lobster boat in Cape Cod Bay, Massachusetts. Tuna purse seine spotter pilots located schools and estimated fish size and school biomass. Aerial imagery of the tuna schools was collected simultaneously with the multibeam data. Together, the sonar and aerial imagery data demonstrate that it is viable to enumerate school size and fish packing density within the school.

Major Accomplishments and Milestones

Our goals were to determine the feasibility of estimating biomass of juvenile Atlantic bluefin (*Thunnus thynnus*) schools in the Gulf of Maine using high frequency (200 kHz) multibeam sonar. This project directly addressed several goals of the NEC, including 1: development and utilization of an ecosystem approach to understanding bluefin tuna fisheries resources, 2. application of new direct assessment methodologies providing fishery-independent information, 3. the pursuit of quantitative information on juvenile ABFT, which represent future production of this fisheries resource, 4. utilization of the unique skills of commercial bluefin fishermen and spotter pilots, who were fully engaged in data collection and interpretation, and also provided user knowledge to help understand a rapidly growing recreational fishery and spatially dynamic assemblage.

Background

In the 1990's and until about 2003, the New England Giant Altantic bluefin tuna (ABFT) fishery comprised a vibrant, highly productive regional industry, supporting up to 40% of some fishermen's annual income. In 1991, landings in New Hampshire alone were worth about $2.1M. Schools of giant size clasess (greater than 73 inches CFL) ABFT documented in aerial surveys numbered in the hundreds, with upwards of 40,0000-50,000 individuals counted annually from 1994-96 (Lutcavage and Kraus, 1995; Lutcavage et al., 1997). Since then, there has been a dramatic decline in commercial landings in the Gulf of Maine, which recent work has linked to bluefin schools shifting further offshore and northward, most likely in response to changes in forage and oceanographic conditions (Golet, 2010; Golet et al., SCRS/#/2010). In contrast, since 2004 there have been unprecedented numbers of juvenile ABFT schools distributed from the southern Gulf of Maine to the Canadian Martimes. These size classes are normally found off the mid-Atlantic states in early summer. An apparent shift in size classes of the New England ABFT assemblage may be taking place, and the increase in juveniles has generated a dramatic increase in recreational effort spanning all coastal states from New England to the mid-Atlantic.

Against the apparent decline and spatial shifts in the New England giant ABFT fishery, there is little information to help predict whether the commercial fishery for "giants" is likely to rebound in the immediate future. A major concern is that in ABFT stock assessments, only two of the current indices cover the juvenile component of the stock. This means that any estimate of recent recruitment is highly dependent upon assumptions or estimates of the selectivity of the five youngest age classes in the most recent year of the stock assessment. Spatial shifts in distribution cannot be readily tracked by CPUE if schools move to areas beyond the reach of the Gulf of Maine fleet. Given these highly limiting gaps in information, new approaches are needed to develop indices of abundance and/or improve the understanding of ABFT population dynamics, and especially for juveniles. The need for fishery independent approaches has been noted as a research priority in the Kobe Report (ANON, 2010) and also called for by ICCAT and NOAA requests for proposals (e.g., NOAA-NMFS-SW-2011-2002651). A direct assessment of juveniles with sonar techniques and aerial reconnaissance has the potential to provide critically needed information for stock assessment. This project also provides a potential new approach for detecting other highly migratory pelagic species.

Project objectives and scientific hypotheses

The objective of this project was to determine the feasibility of estimating biomass of juvenile ABFT schools in the Gulf of Maine using high frequency sonar and concurrent aerial reconnaissance. The initial hypothesis that we were testing were whether high frequency sonar can be used to detect, image, and ultimately assess school biomass of a pelagic schooling species, juvenile ABFT. During the course of the experiment, this initial hypothesis was developed to include the combined use of sonar and aerial imagery. Several key questions were outlined at the start of this project:

1. Is it possible to collect synoptic, quantifiable multibeam acoustic backscatter from a school of juvenile ABFT, i.e., can we survey the entire school and determine the school volume or number of individuals in the school?
2. Will it be possible to properly (quantifiably) account for, or avoid, surface reflections that may contaminate the acoustic measurements?
3. Is it possible to determine that the school is comprised exclusively of ABFT? If not, will it be possible to determine from school morphology which portions are dominated by the bluefin tuna and which are dominated by a second species (assumed to be a food source, such as herring or sand lance). Based on spotter and purse seine experience and our own observations (e.g., Lutcavage et al., 2000), we expect that schools are likely to be mono-specific.
4. Is the level of effort and quantity of data collected of reasonable size so that this methodology could be extended to a large scale (multiple school) annual survey of juvenile ABFT in the Gulf of Maine and elsewhere, such as off the Eastern Shore and Long Island, where they also aggregate in summer months?

Participants

Project participants included PIs Dr. Molly Lutcavage (LPRC, UMass Amherst, formerly UNH LPRC) and Dr. Tom Weber (UNH CCOM), with Michelle Heller (UNH undergraduate student), Ben Galuardi (UNH LPRC), Dr. Larry Mayer (UNH CCOM), Dr. Gary Melvin, DFO St. Andrews Lab, NB, Sam Holdsworth (UNH grad student and NOAA Corp Officer), Capt. Bill Muniz (F/V Lilly), Louis Catalina (mate), George Purmont (spotter pilot), Mark Brochu (spotter pilot), and Mark Avila (spotter pilot), Dr. Yuri Rzhanov, (UNH CCOM), and Dr. Shachak Pe'eri (UNH CCOM).

Methods

This work was focused on field trials during which a multibeam sonar was mounted on a small commercial fishing vessel (tuna/lobster boat, FV Lily). The sonar was mounted so that it's swath of beams was oriented in a plane perpendicular to the vessels heading, with the idea being that this orientation would allow a high-resolution image of the fish school to be constructed from multiple pings as the vessel traveled around the fish school. In actual practice, we found that it was only possible to keep pace with the bluefin schools, and were not usually successful trying to encircle them. Two multibeam sonars,200 kHz SM2000 sonar in 2008 (loaned by Dr. Melvin and DFO), and a 400 kHz Reson 7125 in 2009. were used during this project. The 2008 data collection was severely limited due to the late awarding of the grant in relation to timing of the tuna field season, and we faced poor weather and sighting conditions. Consequently, this report focuses mainly on results from 2009 trials, although we did record useful sonar information and gained technical insights.

The vessel was guided to ABFT tuna schools by spotter planes – an essential component of this work that provided the flexibility and speed required to survey highly mobile bluefin schools. The general approach each day was as follows: the spotter plane(s), usually George Purmont (sometimes assisted by Brochu) would scout a likely area while the vessel transited to the same area. When the pilot located a school, the plane would guide the vessel in close to the school. At this point, the vessel would stop, we would then deploy the sonar (Fig. 1), and then we'd acoustically target the school with the aid of the spotter pilot. The acoustic data was geo-referenced using the ship's position collected using a standard GPS unit. At the same time, Purmont provided his estimate of school size (tonnage) and size ranges of individuals in the school, along with a description of their behavior or school shape via radio, which we logged.

In addition to the sonar data, we added an aerial photography component to the experiment after the first year. Although this was not originally proposed in the NEC study, funding from the LPRC's NOAA grant provided an additional resource for 2 weeks time and effort for two CCOM digital mosaic mapping experts, Drs. Yuri Rzhanov and Shachak Pe'eri, assisted by Ben

Galuardi from LPRC. The aerial photography provided a separate view of the school that - if the school was shallow enough – provided both the horizontal shape of the school as well as data that could be used to enumerate specific individuals in the upper few meters of the water column. The camera used for this – a Canon EOS REBEL T1j - was owned by one of the commercial spotter pilots (Mark Brochu). In order to georeference the aerial imagery with the sonar data, a GPS and a pitch/roll/heading sensor was attached to the camera. Data collected (multibeam and aerial photography) were processed using custom MATLAB software.

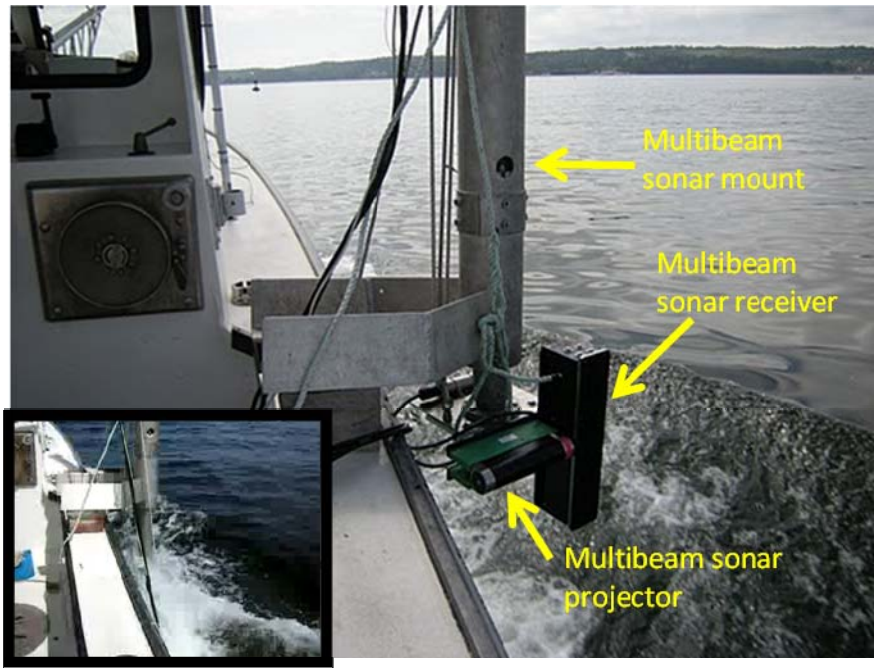

Figure 1. *Multibeam sonar mounted on F/V Lilly during 2009 field season. This image shows the sonar in its retracted position during transit. The inset shows the mount when the sonar is deployed.*

Data

Due to a late start in year one, this project extended over two field seasons: a late start and shortened 2008 field season and a very productive 2009 field season.

2008: Data were collected for two days at sea (4 and 11 September). Weather conditions were marginal, and there was difficulty finding fish. An example of the data collected using the 200 kHz SM2000 is shown in Figure 2. No aerial imagery was collected in 2008.

2009: Data were collected from 14-20 August, during which time we collected 750 GBytes of Reson 7125 multibeam data. Our spotter plane equipped with a digital camera collected an additional 7 Gbytes of aerial photography (over 1000 images).

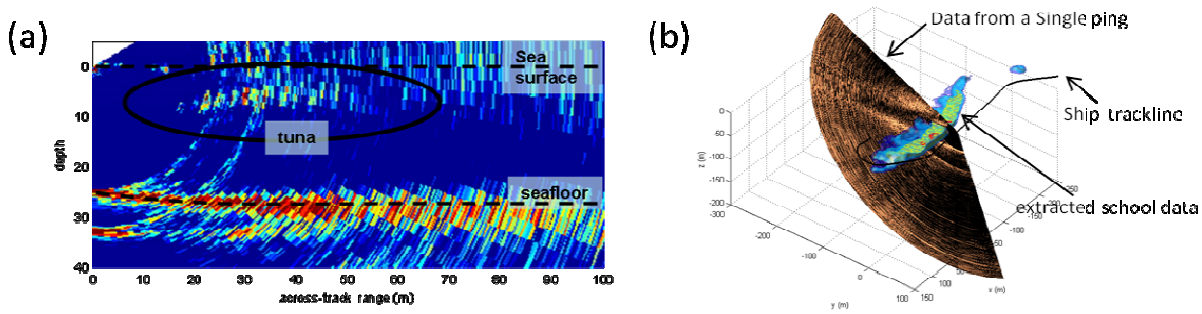

Figure 2. *Example of data collected with the SM2000 multibeam sonar during the 2008 field season.*

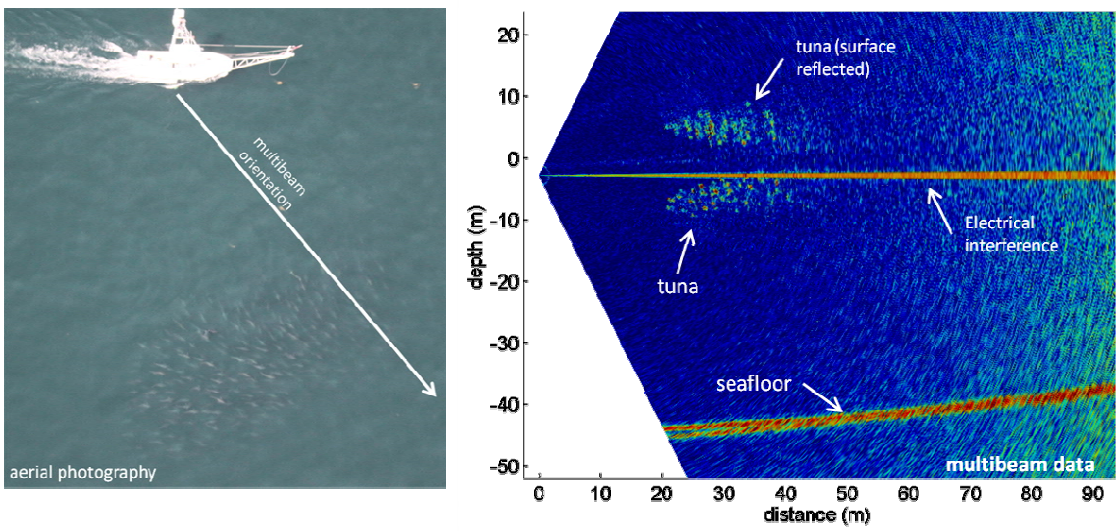

Figure 3. *Example of data collected during the 2009 field season: simultaneous aerial photograph and multibeam data showing a school of juvenile bluefin tuna. As seen from the aerial photograph, the multibeam sonar was located on a starboard mount on the vessel, and oriented in the direction shown.*

Results and conclusions

The key questions that we hoped to address with this project are as follows:

Is it possible to collect synoptic, quantifiable multibeam acoustic backscatter from a school of juvenile ABFT (i.e., can we survey the entire school and determine the school volume or number of individuals in the school)?

Two images from a school of juvenile ABFT are shown in Figure 4. The school is initially at the surface (left panel) when initially observed, occupying only the surface water (< 10 m) in a water depth of approximately 85 m. As these measurements continue, the vessel becomes closer to the

school and the fish sign begins to deepen (Figure 4, right panel), likely as a response to the vessel, while maintaining a similar morphology (thin layer). The morphology of the school (a thin layer) is readily apparent in Figure 4, and profile across the fish school (providing estimates of school width and depth) can be quantitatively estimated from each sonar 'ping'. Note that the fish in these images are close to the sea surface, and so we often get a somewhat irregular 'image' school (mirror reflection) that appears to be above the surface.

Figure 5 shows a closer look at the same two school images in Figure 4. The school height (approximately 2 m thick) and school length (25 m and 40 m) are readily apparent, giving an aspect ratio of less than 10:1 (i.e., length to width). Note that with the multibeam sonar we are only able to image a vertical slice through the school on any one ping, which can distort the true aspect ratio depending on the horizontal morphology of the school. Individual tuna are visible in Figure 4, which makes it possible to estimate the number of fish using echo counting techniques. This process is prone to bias however, and is not trivial: a threshold would have to be set in order to determine where a detection has occurred, and the proper selection of this threshold must account for the beampattern of the system. We have shown here, however, that it is possible.

Based on data similar to what we are shown here, as well as the experience gained during this field experiment, one of our findings is that it would be extremely challenging to image an entire school in four dimensions (3 spatial dimensions plus time) using a multibeam echo sounder. The fish were too mobile to make it possible to circle them with the lobster vessel (at survey speeds up to 8 kts). However, what we were able to do was to get vertical slices of the school in order to establish school height, and where individuals were resolvable it's likely that we would be able to estimate fish packing density.

Although this was not part of our original NEC plan, the horizontal school morphology was captured using aerial photography, as previously described for by manual classification of photos from aerial surveys for adult ABFT (e.g., Lutcavage and Kraus, 1995; Lutcavage et al., 1997). In order to analyze the aerial imagery to obtain school parameters such as the number of fish, packing density, surface area, etc., the images were classified (fish/no-fish) using a manual classification scheme developed for this project using MATLAB. Figure 6 shows a raw image (left panel) and the result of the manual image classification with each ABFT identified with a unique color/id (right panel). Several different school types (soldier, dome, oriented, as described in Lutcavage and Kraus, 1995) were observed during this experiment, and this is readily observable from the aerial imagery (Figure 7).

One of the drawbacks from the aerial photography is that it is not possible to verify that all of the fish are being observed because of the rapid extinction of light with depth. However, combining the multibeam sonar data, which has very good depth discrimination and field of view, and aerial photography, which has very good horizontal discrimination and field of view, it is highly likely that we would be able to quantitatively estimate both school volume and fish number density. We experienced problems achieving a stable mount for the attitude sensor on the pilot's hand held camera, which sometimes resulted in blurry aerial images, but we are working with CCOM experts to improve system mounting and aerial photography.

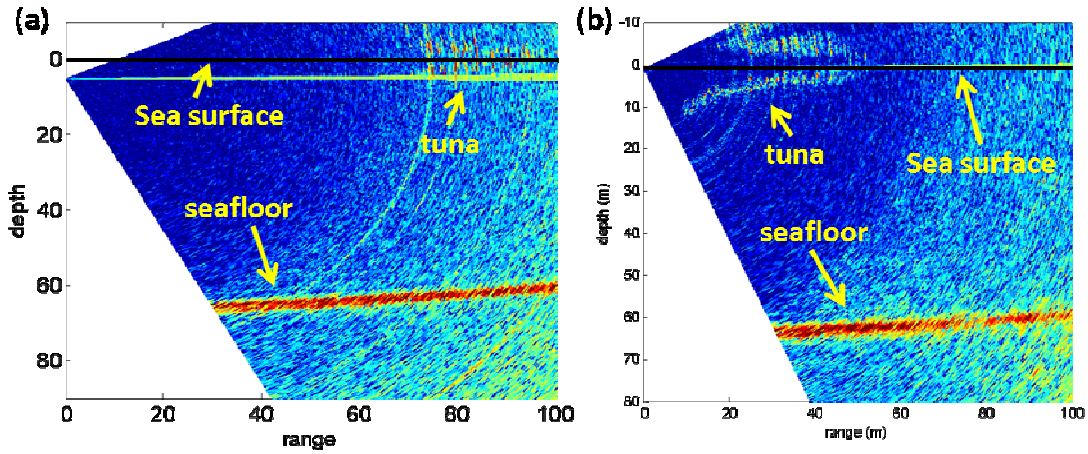

Figure 4. *Reson 7125 400 kHz multibeam echo sounder data showing a 'slice' of the water column.*

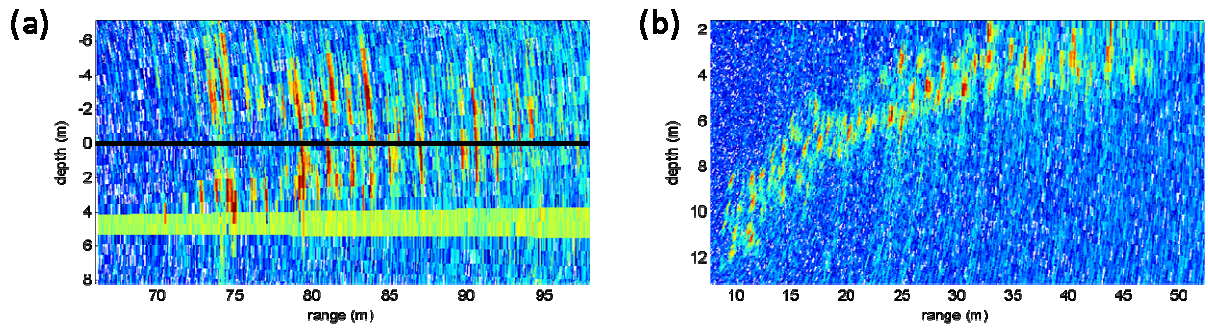

Figure 5. *A close up view of the juvenile ABFT schools from Figure 4. Note that the proximity of the fish to the (smooth) sea surface results in an image school (mirror reflection), apparent in the left panel.*

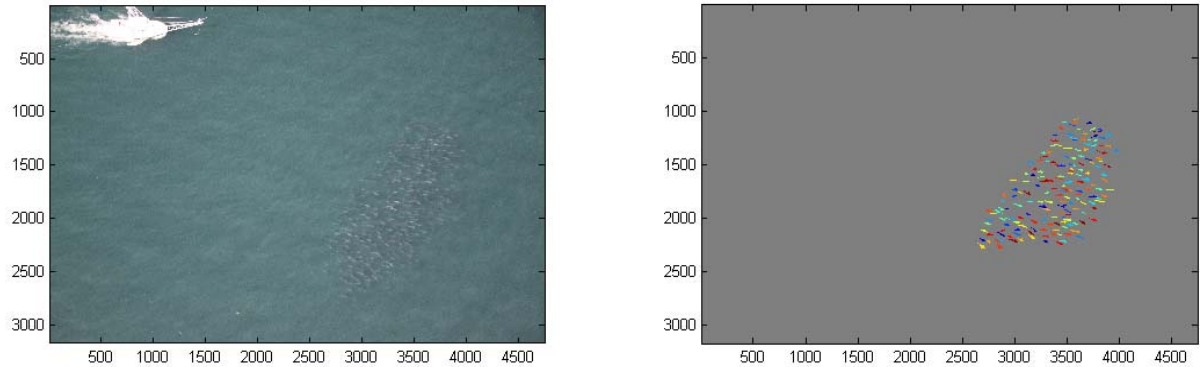

Figure 6. *Raw aerial imagery (left) and manually classified image on the right. Note that each identified bluefin tuna is a unique color.*

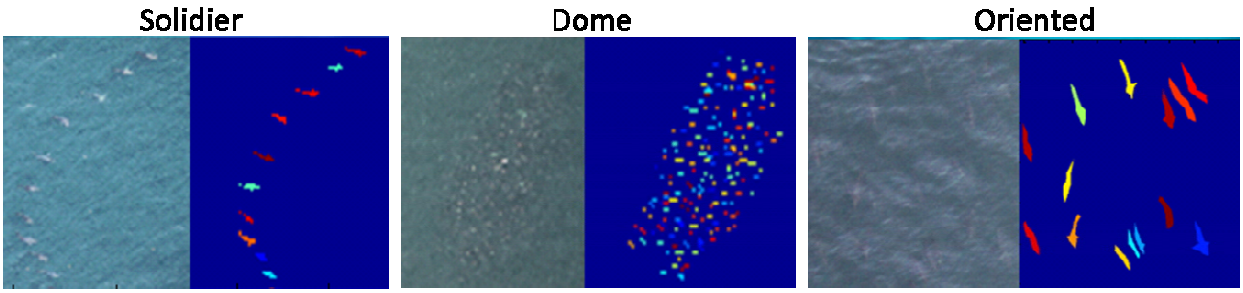

Figure 7*. Previously described ABFT school types observed from the aerial photography.*

1. *Will it be possible to properly (quantifiably) account for, or avoid, surface reflections that may contaminate the acoustic measurements?*

   The methodology used during this field work relied upon a commercial spotter pilot to locate the ABTF schools visually, which resulted in all of the observed schools being very near the surface. For a smooth surface, there are four paths between the multibeam sonar transducer head and each individual fish:

   - Transducer-fish-transducer (direct path)
   - Transducer-surface reflection-fish-transducer (surface reflected path)
   - Transducer-fish-surface reflection-transducer
   - Transducer-surface reflection-fish-surface reflection-transducer

   Paths that are reflect off the surface immediately prior propagating back to the transducers are manifested as image schools (mirror reflections) that appear to be above the surface (Figure 5a), and are easily discriminated from the direct path. However, the direct path and the surface reflected path can potentially confound the result. At close ranges when the fish are diving underneath the vessel, the distance between these two paths can be as much as the transducer depth (~2 m), making it difficult to determine which is a fish and which is a reflection. At far ranges (e.g., > 45 m), the paths begin to converge and ultimately the 'double' sonar return from the fish merges into one. The latter scenario is better for echo counting of individual fish, but would still confound an echo integration analysis

2. *Is it possible to determine that the school is comprised exclusively of tuna? If not, will it be possible to determine from school morphology which portions are dominated by the tuna and which are dominated by a second species (assumed to be a food source). Based our research experience and spotter and purse seine input, we expect that schools are likely to be mono-specific.*

   We found no acoustic or visual evidence that of anything other than the bluefin tuna. Concurrent with our sonar field trials, stomach content analysis conducted on juveniles of the same size classes as fish imaged in our trials primarily contained sand lance (*Ammodytes* sp.), and sometimes small squid or krill (Lutcavage, unpubl. observations). We might expect to eventually target both ABFT and their prey with sonar and aerial photography, since we've directly observed giant bluefin schools amidst

surface schools of sandlance, and on the bottom adjacent to herring schools, via our tracking vessel's fishing sonar (e.g., see Lutcavage et al., 2000), but cannot predict how often this juxtaposition might occur.

3. *Is the level of effort and quantity of data collected small enough that this methodology could be extended to a large scale (multiple school) annual survey of juvenile ABFT in the Gulf of Maine and elsewhere, such as off the VA and MD Eastern Shore, where they also aggregate in summer months?*

   This project demonstrated that an effective methodology for an annual assessment of juvenile AFBT would be a combined sonar and aerial survey. Combining this insight on small scale school dynamics with information determined from sonic tracking, psat tagging, and environmental analyses, we hope to build an understanding of the spatial extent of schools as well as their behavior and availability.

Impacts of the Project and applications

Integrated findings from our combined studies (sonar, aerial observation, electronic and conventional tagging, biological sampling, modeling) will be used to fill in current gaps in knowledge on ABFT, and can help develop fishery independent assessment methods, as well as better operations models for understanding fisheries dynamics in support of assessment and management. This study successful engaged commercial fishermen and spotter pilots as part of a direct assessment team, and laid groundwork to develop cooperative research partnerships for future field trials for ABFT abundance determination. As methodology is developed, we hope that new fishery independent approaches advocated by the Kobe Process and other RFMOs (e.g., see Mesnil et al., 2009) can be used to inform ICCAT's stock assessments and evaluation of regional indices of abundance, availability and catch patterns.

This project is a complementary research project related to NOAA Award: NA04NMF4550391 Small Fish PSAT Tagging and New Initiatives, M. Lutcavage, PI. In that study, we conducted analysis of PSAT tag data returned from adult and juvenile ABFT, and continue to collect ecological information and satellite tag data from PSAT tags on ABFT. Walter Golet completed his PhD on the somatic condition, age and growth, feeding patterns, and historical trends of ABFT in the Gulf of Maine, and John Logan completed a PhD on trophic relationships of juvenile and adult ABFT in the NE and NW Atlantic, with collaborative results submitted for publication.

Future Research

Combining this insight on small scale school dynamics with information determined from sonic tracking, psat tagging, and environmental analyses, we hope to build an understanding of the spatial extent and structural dynamics of schools, as well as their behavior and availability. With

funds budgeted in our current NOAA project on juvenile ABFT PSAT tagging, our plans are to host an expert working group in autumn or winter 2010 to determine best approaches and survey rationale. These experts will include fisheries sonar experts from AZTI, IFREMER, UNH CCOM, and Marine Inst. Bergen, Norway, aerial survey experts from CSIRO, and ABFT population assessment scientists. We also intend to prepare proposals to seek funding for new work via applicable NOAA, NASA, NSF, or ICCAT scientific calls,

Presentations

Lutcavage presented a summary of preliminary findings to the Spring 2010, US ICCAT Scientific Advisory Committee, evening public session on bluefin tuna research, Silver Spring, MD, April, 2010, and also at two bluefin tuna Seminars presented by Coastal Conservation Assoc New Hampshire's "Tuna Mania", Portsmouth, NH, January, 2010, and Big Fish Event, sponsored by The Hook Up, Boston, MA, April, 2010).

Published reports and papers

In preparation

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Signed

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