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DIRECT ASSESSMENT OF JUVENILE ATLANTIC BLUEFIN TUNA: INTEGRATING SONAR AND AERIAL RESULTS IN SUPPORT OF FISHERY-INDEPENDENT SURVEYS

Angelia S.M. Vanderlaan[1], J. Michael Jech[2],
Thomas C. Weber[3], Yuri Rzhanov[3], and Molly E. Lutcavage[1]

SUMMARY

*There is a clear need for direct assessment for Atlantic bluefin tuna (*Thunnus thynnus, *ABFT), including formulation of experimental designs and pilot surveys for abundance estimation. In the western Atlantic, aerial surveys are highly feasible for juvenile ABFT because of their surface availability. Our goals are to design, implement, and analyze a fisheries-independent survey of juvenile ABFT. We used aerial imagery to determine the school's surface shape and to enumerate bluefin tuna visible in the upper few meters of the water column and sonar data provided information on school height. By integrating acoustic and aerial data we can estimate school biomass and aggregation behavior. In 2015 we plan to use a marine hexacopter to obtain more highly resolved aerial images of schools, with improved geo-rectification required for automated target recognition and objective counts of individuals. Although not without challenges, the analytical techniques we're developing will provide more objective, multi-dimensional information on ABFT schools. Direct assessment also offers a means of tracking shifts in coastal distribution of highly mobile ABFT, especially as traditional indices of abundance may no longer be appropriate.*

RÉSUMÉ

*Il est clairement nécessaire de procéder à une évaluation directe du thon rouge de l'Atlantique (*Thunnus thynnus, *ABFT), dont la formulation de modèles expérimentaux et d'études pilotes afin d'estimer l'abondance. Dans l'Atlantique Ouest, des prospections aériennes sont parfaitement faisables pour les juvéniles de thon rouge de l'Atlantique en raison de leur disponibilité à la surface. Nos objectifs consistent à concevoir, mettre en place et analyser une étude indépendante des pêcheries concernant les juvéniles de thon rouge de l'Atlantique. Nous avons utilisé des images aériennes afin de déterminer la forme de la surface du banc et de compter les thons rouges visibles dans les quelques mètres supérieurs de la colonne d'eau, et les données des sonars ont fourni des informations sur la hauteur du banc. L'intégration de données acoustiques et aériennes nous permet d'estimer la biomasse du banc et le comportement d'agrégation. En 2015, nous avons l'intention d'utiliser un hexacoptère marin afin d'obtenir davantage d'images aériennes de haute résolution des bancs, avec une meilleure géo-rectification nécessaire aux fins de la reconnaissance automatisée de l'objectif et d'un comptage effectif des spécimens. Les techniques analytiques que nous élaborons, non sans difficulté, fourniront des informations plus objectives et multidimensionnelles sur les bancs de thons rouges de l'Atlantique. L'évaluation directe permet également de suivre les changements de la distribution côtière du thon rouge de l'Atlantique extrêmement mobile, plus particulièrement car les indices d'abondance traditionnels peuvent ne plus convenir.*

[1] Large Pelagics Research Center, University of Massachusetts Amherst, P.O. Box 3188, Gloucester, MA 01931, USA. Email address of lead author: avanderl@eco.umass.edu
[2] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA.
[3] Center for Coastal and Ocean Mapping, University of New Hampshire, 24 Colovos Road, Durham, NH 03824, USA.
[3] University of New Hampshire, Center for Coastal and Ocean Mapping, Durham, NH, USA.

RESUMEN

Es claramente necesaria una evaluación directa del atún rojo del Atlántico (Thunnus thynnus, ABFT), *lo que incluye la formulación de diseños experimentales y prospecciones piloto para la estimación de la abundancia. En el Atlántico occidental, las prospecciones aéreas son muy viables para los juveniles de atún rojo del Atlántico a causa de su disponibilidad en la superficie. Nuestros objetivos son diseñar, implementar y analizar una prospección independiente de la pesquería de juveniles de atún rojo del Atlántico. Se utilizaron imágenes aéreas para determinar la forma en superficie del banco y para contar a los atunes rojos visibles en metros superiores de la columna de agua y los datos del sonar proporcionaron información sobre la altura del banco. Integrando los datos acústicos y aéreos se pudo estimar la biomasa del banco y el comportamiento de agregación. En 2015 está previsto utilizar un hexacóptero marino para obtener imágenes aéreas de los bancos de mayor resolución, con una mejor geo-rectificación para el reconocimiento automatizado del objetivo y el recuento eficaz de ejemplares. Aunque no sin dificultades, las técnicas analíticas que estamos desarrollando proporcionarán información más objetiva y multidimensional sobre los bancos de atún rojo del Atlántico. La evaluación directa ofrece también un medio de hacer un seguimiento de los cambios en la distribución costera del atún rojo del Atlántico, muy móvil, especialmente dado que los índices de abundancia tradicionales podrían no ser ya adecuados.*

KEYWORDS

Stock assessment, Bluefin tuna, Aerial survey, Echosounders

1. Introduction

Many fisheries management agencies concentrate on the formulation of indices on past, present, and future states of the population (Hutchings *et al.* 1994) and are often based on catch-per-unit effort (CPUE). CPUE indices can be misleading as catches over time can occur because of factors other than changes in abundance (Maunder and Punt, 2004). Accumulated evidence indicates that interpreting CPUE data from commercial fisheries is difficult, particularly for pelagic species (Lo *et al.* 1992), such as ABFT. Misinterpretations of elevated CPUE in the northern cod (*Gadus morhua*) fishery contributed to overestimations of stock size, inflated quotas (Rose & Kulka 1999), and collapse of the fishery. These misinterpretations, and failure to manage a fishery appropriately, can have disastrous effects on social and economic conditions (Maunder *et al.* 2006). Consequently, direct assessment and fisheries-independent estimation of fish abundance are especially important in the management of a valuable fish species.

The need for, and potential benefits of direct assessment of ABFT is well considered, and fishery scientists have called for the development of experimental designs and pilot surveys for juvenile abundance estimation (Fromentin and Powers 2005). ICCAT reiterated its importance and prioritized development of fisheries independent indices of abundance, through aerial surveys, at the last ABFT stock assessment (Anon. 2012). Fisheries-independent data used to develop an index of abundance for juvenile ABFT is also useful to follow short-term dynamics or to detect the effects on recruitment of variation in environmental conditions, climate change, managerial changes, or pollution events such as oil spills (Anon. 2012).

Aerial surveys have been widely used since the 1940's to estimate the size and density of wildlife populations, including birds, marine and terrestrial mammals (Pollock *et al.* 2006). Spotter pilot based aerial surveys of bluefin tuna were initially conducted on a trial basis in the Gulf of Maine by the US Bureau of Commercial Fisheries. Scientific surveys were later organized and conducted there from 1993-1997 (e.g., Lutcavage and Kraus 1995, Lutcavage *et al.* 1997a), as well off the Bahamas (Lutcavage *et al.* 1997b) and Virginia, USA (unpublished report to NMFS). Although results were promising, and a conceptual framework for future work was advanced (Lutcavage and Newlands 1999), political opposition to use of spotter planes in the US commercial bluefin fishery thwarted continuation of the surveys. At the time, the fishery-dependent (i.e., non transect-based) SPUE (sightings per unit effort by 100 km, counts of surface individuals) results were deemed not useable in ICCAT bluefin stock assessments (Polacheck *et al.* 1998), although the spatially- and temporally resolved information on schools was mined for behavioral information as well as biophysical interactions and predator prey associations (Humston *et al.* 2000, Schick *et al.* 2004, Schick and Lutcavage 2009. New analytical approaches to use spotter-based SPUE are being considered by CSIRO for Southern bluefin tuna assessments (J. Farley, personal communication), and might prove useful for ABFT.

Bluefin assessment aerial surveys are now conducted in the Mediterranean (Cañadas *et al.* 2011, Di Natale and Idrissi 2013) and in Australia (Eveson *et al.* 2011). These surveys rely on observers or spotter pilots for estimates of abundance and sizes of tuna within a school. Relying on observers in aerial surveys introduces perception bias where the observers fail to see tuna at the surface (Marsh and Sinclair 1989). Different observers can also vary in their sighting prowess (Eveson *et al.* 2011). Perception bias can be reduced by rotating observers to reduce observer fatigue to ensure high quality data. However, it's important that observers use a consistent searching strategy, and there's a constant need for improved training of observers (Anon. 2011). There is also availability bias, where the animals are not available to the observers when concealed by other animals, turbid waters, or sun glint (Marsh and Sinclair 1989). In addition to the uncertainties identified in aerial surveys of spawning aggregations (Cañadas *et al.* 2011), tonnage and sizes of individuals in the school are estimated by the spotters/observers (Cañadas *et al.* 2011) and not independently verified. Generalized linear mixed models are used to estimate abundance of southern bluefin tuna (*T. maccoyii*) based on aerial surveys (Eveson *et al.* 2011). These models incorporate an observer effect that estimates the relative sighting ability of each observer pair, but don't account for difference among observers, nor are they independently verified.

The acoustic sampling of ABFT schools completed in conjunction with aerial surveys will provide essential information on the perception of juvenile ABFT including information on the packing density and volume of individuals within an entire school, as well as their size distribution. By using photographs of the schools we seek to eliminate the subjectivity of observer estimates of abundance and sizes of individuals within a school. We are developing integrative analytical techniques leading to capability of formal surveys of juvenile ABFT across their spatio-temporal range on the US shelf (Galuardi and Lutcavage, 2012).

Our overall goal of our ongoing research is to provide an index of abundance (absolute or relative) that is fisheries independent, reliable, robust, and quantitatively objective. To achieve this goal, we must develop analytical techniques for enumeration and size determination that remove the inherent biases and subjectivity of aerial surveys that are currently being used to count juvenile bluefin tuna. If proven successful, and previously pilot studies demonstrate encouraging results, our integrated aerial and acoustic sampling has the potential to reduce perception bias as well as availability biases associated with tuna at depth obscured by surface individuals.

2. Data Collection

This project and future work relies of cooperative research with members of the fishing industry, and requires chartering a bluefin tuna fishing vessel and a spotter plane. In our field studies, a Simrad EK60 scientific echosounder was mounted on the vessel's bow so that its beam was parallel with the vessel's heading. This vastly improves our ability to keep ABFT schools within range of the transducer compared to mounting the sonar on the starboard side of the vessel as in previous studies.

In our initial field studies with a split-beam echosounder, the fishing vessel was guided to tuna schools via spotter pilots. For each survey day, the spotter plane would scout a likely area while the vessel transited to the study area. When a school was spotted, the spotter pilot would guide the vessel to within several boat lengths (30 to 50 m) of the school. At this point, the vessel would stop, deploy the echosounder, and then acoustically acquire the school, optimizing orientation of the transducer head via sight lines of the captain (in the tuna tower) and spotter pilot. The acoustic data is georeferenced using ship's position collected with a standard GPS unit.

A photographer in the spotter plane took aerial images using a Canon EOS 60D with an 18-135mm lens. To georeference the aerial imagery with the echosounder data, a GPS and an attitude (pitch/roll/heading) sensor is attached to the camera. Photographers were instructed to include the fishing vessel in the photographs with the tuna schools and this allowed us to continue our analyses when the attitude sensor on the camera failed. There are many advantages to having an aerial view of the school: aerial imagery provided both the horizontal shape of the school as well as data that could be used to enumerate specific animals in the upper few meters of the water column (e.g., Weber *et al.* 2013).

3. Data Analyses

3.1 Aerial Imaging Processing

Imaging processing is completed within Matlab and there are several measurements we estimated for the school from the georectified aerial images (**Figure 1**). A convex hull was fitted around the school by joining points that have been manually outlined. From the convex hull we obtain an estimate of school area and parameter. An ellipse is also fitted to the school based on the convex hull and from the ellipse we obtain measurements of orientation, the major axis length, the minor axis length, location where the beam crossed the major axis, the centroid mass and the center of mass, and the school beam distance (**Figure 1**).

3.2 ABFT School Morphology and Profiles of Aggregation Behavior

Aerial and acoustic images were processed using classification schemes developed in MATLAB. By combining aerial and acoustic data, we can construct the three-dimensional morphology – including the internal structure of schools.

Currently, we're integrating aerial photographs with acoustic data to determine the height, width, and length of the school (**Figure 2**, bottom right panel) and to estimate abundance and biomass within a school. The split-beam echosounder captures narrow (two degree) vertical slices (ten degrees) of the tuna schools. We focused on acoustically imaging ABFT schools, but not the location within the school that we were capturing. Under certain conditions, possibly related to the ensonification angle, it was difficult to acoustically image the school. We're now determining the best ensonification angle between the transducer and fish to capture a strong acoustic signature of the juvenile ABFT. This analysis will inform 2015 field procedures and survey design.

We are extracting school dimensions from both the split-beam echosounder data as well as the georectified aerial images. During our field trials in 2012, we generally stayed with a school for approximately 10-30 minutes, and can use the aerial photographs and acoustic data to observe the morphological evolution of the tuna school. An example of changing school dynamics is demonstrated in **Figure 3**. Not only is the school morphing through time, but the school dimensions extracted is partially a function of the location within the school the transducer is sampling. The split-beam echosounder has a very narrow beam (~2° horizontally) and does not sample the entire school, but rather a slice of it. For this reason we also measure the distance across the school where the beam intersects the school in the aerial images (school beam length, **Figure 1**).

The school height and width estimates from the acoustic data change through time, as the school changes in shape, but also due to the sampling location within a school, so a wide range of estimates on dimensions of the school is obtained. For example, the tuna school observed in **Figure 2** had estimates of school width that ranged from 2 m to a maximum of 19 m, with an average of 9±3m (mean ± standard deviation). Similarly, school height for the same school ranged from 1 to 29 m with an average of 15±5 m. This will have to be considered during survey design as it has the potential to bias the estimates of fish density. By combining the aerial images with acoustic data we have to potential to determine the 3-dimensional shape of tuna schools.

4. Future Work

Image quality and processing has become an issue in our previous fieldwork. The attitude sensors mounted on the camera malfunctioned and did not provide reliable data. The manufacturer confirmed afterwards that the sensor is apparently not suitable over 1 G or unstable flight. Furthermore, the images taken during previous studies were not of sufficient quality for automatic detection of ABFT during image analyses. To overcome these obstacles we were funded by NOAA to purchase WASABI (Water imaging, Aerial Surveying, Automated Biological Instrument), an Unmanned Aerial vehicle (UAV) or hexacopter, to obtain high-resolution aerial images.

UAVs are readily becoming at alternative to wildlife surveys conducted by airplanes and vessels, and have been evaluated to monitor marine mammals (Koski *et al.* 2009, Hunt *et al.* 2013), terrestrial biodiversity (Koh and Wich 2012, Jones *et al.* 2006) and sea birds (W. Perryman, personal communication, NOAA SW Fisheries Science Center, La Jolla, CA, USA). UAVs provide a statistically robust option for a variety of wildlife survey applications and provide visual imagery at more localized and biologically distinguishable level by flying at lower elevations than aircraft and satellites (Jones *et al.* 2006). UAVs also reduce the risk to human life that is associated with using observers aboard aircraft during aerial monitoring (Kaski *et al.* 2009).

To optimize value, cost, and risk associated with conducting joint aerial and acoustic surveys, we propose to launch WASABI from our survey vessel to capture aerial imagery, thus removing the need for an airplane and spotter pilot. WASABI allows us to record photographic images at slower speeds, lower altitudes, and with greater control than via spotter aircraft. Furthermore, the difficulties associated with geo-rectification of aerial photographs taken from a spotter plane, due to plane’s own magnetic field interfering with the attitude sensor on the camera, will be eliminated by using WASABI. The improved low altitude/high resolution images taken from WASABI will help us develop automated target recognition of ABFT. Our work so far demonstrates feasibility for shark and leatherback turtles, but we have not obtained the image quality required for smaller juvenile ABFT from photographs taken via spotter plane.

Aerial surveys are highly feasible for juvenile ABFT because of their high surface availability on the mid-Atlantic shelf (Galuardi and Lutcavage 2012), and studies have previously confirmed suitability for larger size classes in some locations. Our proposed research will develop quantifiable estimates of ABFT and could correct biases associated with aerial surveys. Our initial field trials using acoustic and aerial mapping approaches demonstrated the feasibility of determining size, area, and total biomass of schools (Weber *et al.* 2013), as well as the sizes of individuals within schools. An additional benefit is that abundance estimation derived from our surveys would be fisheries independent and not confounded by changes to management and changes fleet.

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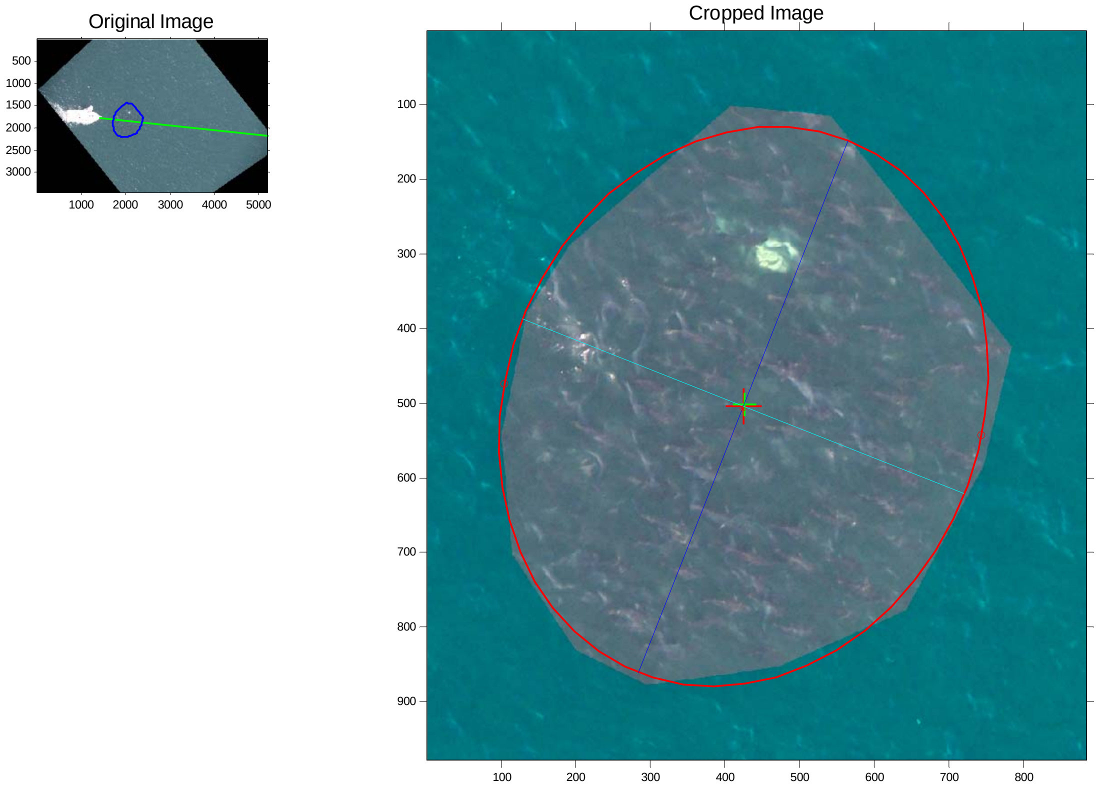

Figure 1. Processing of georectified aerial images. A convex hull (blue polygon) is fitted to points that have been manually imputed to outline the school (left panel). An ellipse (red polygon right panel) is also fitted to the convex hull (original colour right panel) where we measure the centroid (green cross), the center of mass (red cross) the major and minor axis (faint blue lines). This distance across the school that is intersected by echosounder beam (green line left panel) is also measured.

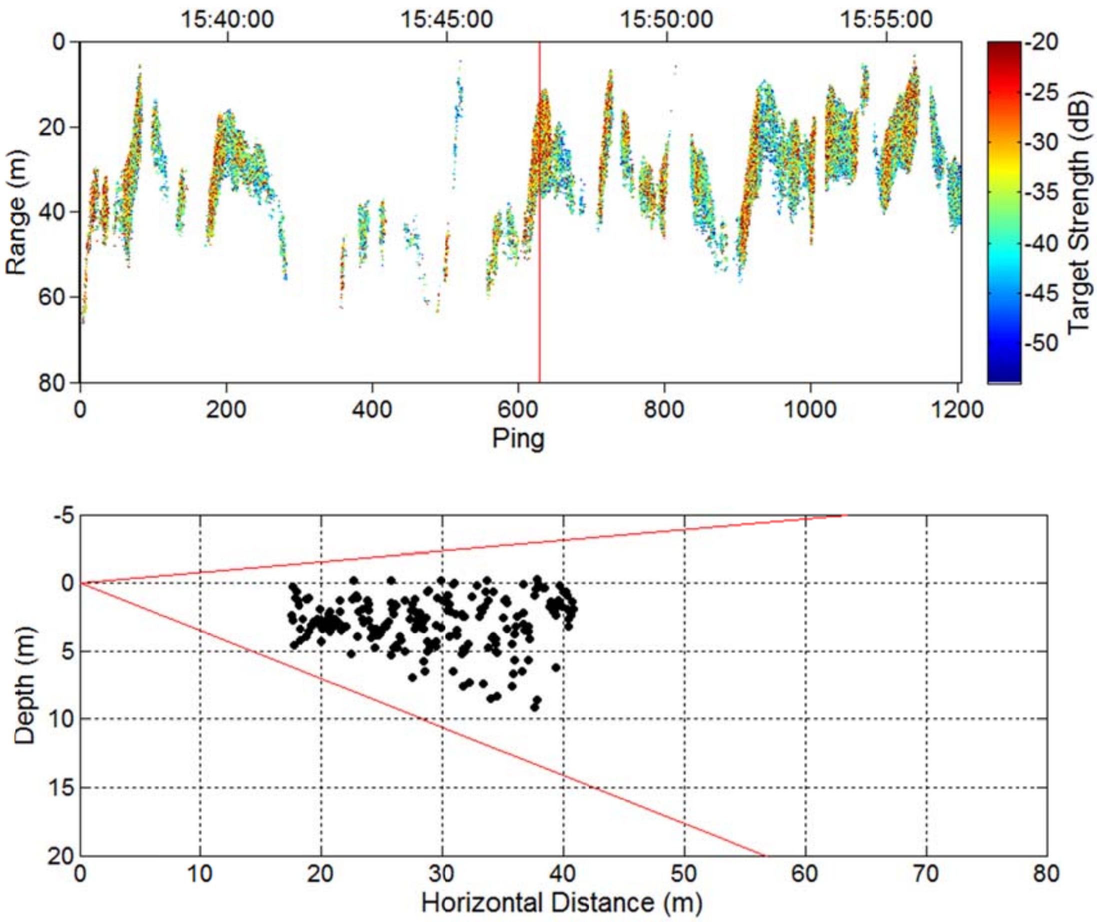

Figure 2. Echogram of a juvenile Atlantic bluefin tuna school (upper panel) that was approximately 250-300 individuals between 30-50 pounds (14-23 kg) after a mask and a threshold has been applied to extract the backscatter attributable to the juvenile tuna. The in-situ targets (lower panel) for one ping (represented in the vertical red line in the upper panel) of the echogram. The school height and width can be estimated from the dimensions of the targets in one pin of the echogram. The diagonal red lines represent the range of the transducer.

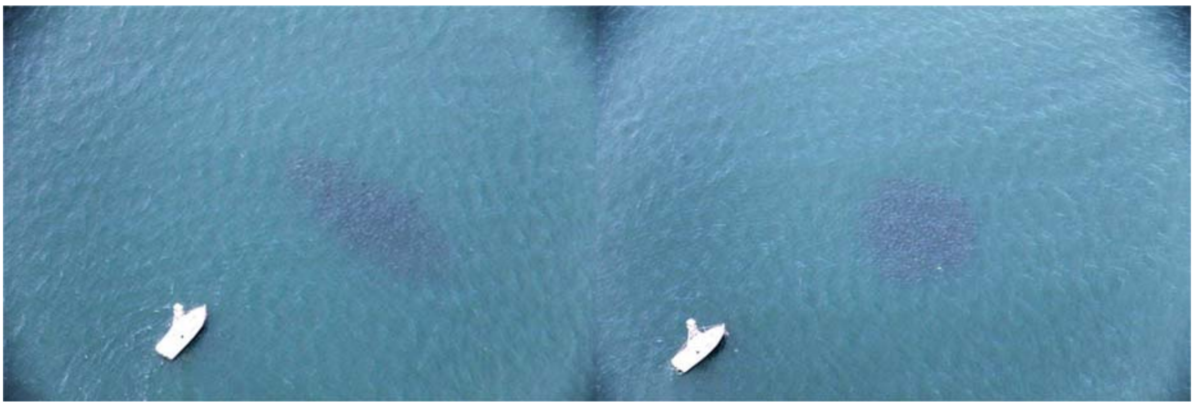

Figure 3. Two examples of aerial photographs of the same juvenile Atlantic bluefin tuna school with approximately 250 to 300 individuals weighting approximately 30-50 pounds (14-23 kg). Contrast in photos has been increase by 50%.