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ATLANTIC BLUEFIN TUNA STOCK MIXING WITHIN THE U.S. NORTH CAROLINA RECREATIONAL FISHERY, 2011-2012

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SUMMARY

Membership to natal population, Mediterranean or Gulf of Mexico, was assigned for North Carolina and Virginia (US) Atlantic bluefin collected during winters 2011 and 2012, including members of the abundant 2003 year-class. Maximum likelihood estimates of the sample's mixture were based on otolith stable isotope composition, $\delta^{18}O$ *and* $\delta^{13}C$*. When all ages were included (3-17 years; CFL 117-285 cm; N=218), the contribution of the Gulf of Mexico population was estimated at 28.2% ± 4.6% SD. For the 2003 year-class, the estimated contribution rate of Gulf of Mexico members was 49.2% ± 13.2% SD (N=39). Analysis of archived otoliths(sampled 1996-1998) from US landed fish of similar size range to the NC sample indicated a higher Gulf of Mexico contribution: 56.2% ± 6.5% SD (N=110). Results support the inference that the 2003 year-class, evident in US fisheries during the past 6 years, received strong contributions from the Mediterranean population. Further, results suggest that US fisheries for school and medium size classes (<205 cm CFL) have shown increasing dependence on Mediterranean-origin individuals during the past 15 years.*

KEYWORDS [Age Composition, Otolith Stable Isotopes, Stock Composition, Tuna Fisheries, Thunnus thynnus]

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1. Introduction

Fishing rate and abundance reference points that guide management are controversial for the western stock of Atlantic bluefin tuna, driven by a debate about feasible levels of recruitment. One school posits that recruitment levels were ~10 fold higher in the 1970s and that through conservation measures, we can return to those levels. The other school believes that these historical levels are no longer feasible due to changed states in the environment or population, and that the exploited population is now sustainable at a substantially lower recruitment level. It follows that under the high recruitment scenario, recovery of the depressed population will require a longer rebuilding period and lower threshold fishing rates. Because no strong evidence exists to accept or reject either recruitment reference point, SCRS assessments have historically provided projections for both scenarios (Sissenwine et al. 1998; SCRS 2010). An apparently strong 2003 year-class in US recreational fisheries was observed as the annual progression of juvenile size classes over the recent five year period (SCRS 2010; Figure 11). Similar historical progressions of size modes were observed for the western stock by Mather et al. (1995) and were attributed to strong-year classes, occurring at c. decadal intervals (see also Secor et al. 2012). Still, we do not know with certainty where this 2003 year-class originated. Recent evidence from otolith stable isotope analysis indicates that over the past two decades many school and medium size class bluefin tuna (50-200 cm CFL), captured in US angler fisheries, originated from the Mediterranean population (Rooker et al. 2008; Secor et al. 2012).

Here, we report on the combined analysis from a two-year study to estimate population membership for Atlantic bluefin tuna sampled Jan-April 2011-2012 from the North Carolina (NC) recreational fishery. First year results were reported in Secor et al. (2011). During the past several years, the 2003 year-class has made a dominant contribution to this fishery (**Figure 1**). In 2012, an unusually warm winter caused the "NC" aggregation to first appear off the coast of Virginia and thus our analysis includes fish sampled there as well. Further, past archival tagging studies showed extensive levels of trans-Atlantic migration by the NC aggregation (Walli et al. 2009), with some individuals migrating into the Mediterranean during the spawning season, suggesting that those individuals may have originated there (Block et al. 2005). Population membership within the NC aggregation was estimated using otolith stable isotopes, for which we have a 13-year baseline of age-1 juveniles from natal habitats of the two source populations. Using this baseline, the unknown NC aggregation was classified to source populations using maximum likelihood estimation of the sample's mixture distribution (Millar 1990a). The aggregation's mixing rate was compared to that of a historical sample (year-classes 1986-1992) collected from US mid-Atlantic and New England fisheries.

2. Methods

Fish otoliths (sagittae) were sampled during the NC recreational fishing season (January-April 2011-2012), from fish landed at ports on Cape Hatteras. In 2012, warmer temperatures off Cape Charles, Virginia caused an aggregation to be targeted by charter and sport fishers at Virginia Beach during January and 12 of 218 fish included in this analysis were sampled there. For convenience, we reference the entire sample as the NC sample. We worked with harbor masters and fish cleaners to obtain access to tuna carcasses shortly after fish were landed. For comparison purposes, a subset of the data reported by Rooker et al. (2008) was included. These fish were collected as part of the Large Pelagic Biological Survey for the National Marine Fisheries Service (1996-1998) from US mid-Atlantic and New England waters. The size range, 120-210 cm CFL, was selected to allow comparison to the more recently collected sample.

Otoliths were cleaned of adhering tissue, briefly rinsed and stored dry. A single otolith (right or left) was embedded in plastic resin and a 2.0 mm thick section cut from the center containing the juvenile and surrounding portions of the otolith (see Schloesser et al. 2010 for additional details on otolith processing). The juvenile portion of the otolith, specifically the area circumscribed by the first annulus, was identified with the aid of a template from measured juvenile otolith sections, which served to increase the consistency with which the first year of life was sampled. Carbonate material was rastered from that region using a New Wave Micromill ©. Powdered carbonate samples were analyzed for $\delta^{18}O$ and $\delta^{13}C$ at the University of Arizona Environmental Isotope Laboratory. Analytical precision was estimated at ± 0.1‰ and ±0.06‰ respectively for $\delta^{18}O$ and $\delta^{13}C$ (Schloesser et al. 2010). Following the micromilling procedure, otolith section thickness was reduced further to permit visualization of annuli for age determination. Images were taken with a digital camera paired with a dissecting microscope. Annuli were interpreted without reference to information on the specimen by a single experienced reader using Adobe Photoshop CS2 Version 9.0 to record images and annuli counts. Interpretation of age through direct counts of otolith annuli has been verified through bomb radiocarbon dating analysis (Nielson and Campana 2008). Precision was tested between two independent readers for the entire sample and was within two annuli.

Classification of the unknown mixture to source populations in the overall NC sample and year-class specific subsets was performed using a maximum likelihood estimation (MLE) method (aka finite mixture distribution; Prager and Shertzer 2005). The sample subset attributable to the 2003 year-class was tested and compared to the entire NC sample. To bracket ageing error, individuals assigned to immediately adjacent year-classes (2002-2004) were also included in population assignment tests. A fourth sample was derived from previously analyzed otoliths (Rooker et al. 2008) comprising individuals of similar size as the NC sample, but sampled from angler category fisheries for the period 1996-1998.

The MLE approach requires a baseline sample that represents all source populations. Here two are assumed: Mediterranean (MED) and Gulf of Mexico (GOMEX). The current baseline is relatively large (N=279), covers many year-classes (MED: 1998-2010; GOMEX: 1998-2004, 2006-2007), and shows consistent separation between the two population regardless of year-class (Schloesser et al. 2010). A common approach is the conditional maximum likelihood estimate procedure termed HISEA (Millar 1990b). This procedure fits the mixture distribution based on (1) the source population distributions and (2) possible mixing proportions in the unknown sample.

3. Results

The entire sample ranged from age 3 to 17 and exhibited modes attributable to the 2003 and 2005 year-classes (**Figure 1**). According to age estimates, the 2003 year-class was well represented in the NC sample (N=39: 18% of total sample).

Maximum likelihood estimates of population contribution rates were similar between the 2003 and the combined 2002-2004 year-classes subsamples: 49.2±13.2 SD% and 45.0±8.8% were classified to the GOMEX population, respectively (**Table 1**). Standard deviations for the mixture estimates indicated that the rates were not significantly different than a 50% mixing proportion. The entire NC sample showed a substantially lower contribution from the GOMEX population, 28.2±4.6%, the likely influence of younger individuals in the overall sample (**Figure 1**). The historical sample of fish, sampled 1996-2000, exhibited a higher GOMEX population contribution rate: 56.2 ±6.5%.

There was a slight but significant difference in stable isotopes between sampling years (ANCOVA, covariate=CFL; δ^{18}O: $F = 6.47$, $p = 0.01$; δ^{13}C: $F = 20.2$, $p = <0.001$). In 2012 mean δ^{13}C (-9.01) was depleted in comparison to 2011 (-8.76), whereas mean δ^{18}O was enriched (-1.10) in 2012 in comparison to 2011 (-1.21). The source of this difference may have been due to processing or analytical error and is currently under investigation. To evaluate the influence of this error on results, stable isotope data in 2012 was adjusted for levels of mean enrichment from the 2011 data, and mixture rates were estimated from these adjusted values. The mixture rate for the 2003 year-class was similar to the unadjusted rate (Table 1) with 44.8% GOMEX contribution. The contribution of the Gulf of Mexico population for the entire NC sample increased slightly from 28.2% to 36.9%. Adjusting 2011 rather than 2012 stable isotope values caused increased skew towards Mediterranean population assignment in comparison to those values shown in Table 1.

4. Discussion

Otolith stable isotope stock composition analysis indicates the NC winter fishery, and the aggregation that supports it, is comprised of both western and eastern stocks. The 2003 year-class, apparent in this and other US fisheries during the recent period shows nearly equal proportions of eastern and western stock fish. Alternatively, inclusion of all sampled age-classes indicates that the NC fishery now receives dominant contributions (>60%) from the eastern stock, a substantially higher rate than observed for similar sized US landed fish sampled 12-16 years earlier (45%). Interestingly, there is evidence for a strong 2003 year-class produced in the Mediterranean Sea, based on annual changes in modal lengths and estimated ages (SCRS 2010; Figure 12).

Accuracy and precision in the estimated mixing rates are related to sample size, error in year-class assignment, measurement error for the stable isotopes, and the representativeness of the baseline and unknown samples (Fabrizio 2005). Ageing errors will influence accurate year-class assignment. Ageing precision was typically within 2 years, which led us to bracket year-classes to ensure inclusion of the 2003 year-class. Similar mixing proportions between the 2003 and 2002-2004 subsets were observed (**Table 1**) indicating that these estimates were robust to ageing imprecision. The baseline is a moderately large sample representing many year-classes (including the 2003 year-class). Similarly the representativeness of the sample should increase with sample size, sampling events and number of years in the sample. An important error detected in this study was slight inter-annual changes in stable isotope levels unrelated to fish size. These may be attributable to analytical error. Fortunately, we can test this by re-running milled otolith powders. Based on its amplitude of bias, this error did not likely affect the inferences of (1) equivalent contributions of western and eastern stocks to the 2003 year-classes or (2) dominant MED population contributions to the overall NC aggregation.

The mixing rate observed in US fisheries is influenced by underlying size- and population-specific migration behaviors (Walli et al. 2009). Evidence from conventional tagging, otolith stable isotopes, and tracer contaminant analysis all indicated that smaller Mediterranean juveniles show an increased propensity to undertake trans-Atlantic migrations than do larger juveniles (Rooker et al. 2007; 2008; Dickhut et al. 2010; Secor et al. 2012). This trend was supported by the higher MED contribution rate for the entire NC sample, which was composed of a high proportion (>50%) of fish ≤6 years old. Previous otolith stable isotope analysis indicated that adults from US and Canadian fishery samples (principally the Gulf of Maine and Canadian Maritimes) were almost exclusively classified as originating from the Gulf of Mexico population (Rooker et al. 2008b; Schloesser et al. 2010). On the other hand, the largest (285 cm CFL) and oldest (17 years) individual in the NC sample, certainly an adult, was classified by quadratic discriminant function analysis (see Secor et al. 2011) as a MED individual at a probability of >99%. This could indicate that the NC aggregate, which is composed of juveniles and adults (Walli et al 2009), could represent a different contingent (group of fish with a similar migration pathway*: sensu* Secor 1999 and Fromentin and Powers 2005; see term use also by Mather et al. 1995) than aggregations fished in New England or Canada. Archival tagging research supports strong connectivity between large juveniles and adults of the NC aggregation with the MED population (Block et al. 2005; Walli et al. 2009).

Results presented here support earlier studies that showed substantial contributions of the eastern stock population to US fisheries and associated aggregations (Block et al. 2005; Rooker et al. 2008a,b; Dickhut et al. 2010). In judging how population mixing influences the impact of strong year-classes on future population states, a pertinent issue is historical trends in population contribution rates. In a companion SCRS paper, otolith stable isotope stock composition analysis indicates that Gulf of Mexico contributions to school fisheries may have been substantially higher in the 1970s than in the recent period (Secor et al. 2012). Higher contributions by the eastern stock during the past two decades to US fisheries could be the result of stronger relative recruitment and/or high trans-Atlantic migration rates by the Mediterranean population. Evaluating how stock-specific recruitment and movement patterns influence stock mixing among principal bluefin tuna fisheries and aggregations will require integration of empirical estimates of these parameters into spatially explicit stock assessment models (Taylor et al. 2011; Kerr et al. 2012).

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Table 1. Natal population mixture rates for Atlantic bluefin tuna sampled in North Carolina and Virginia Beach during January-April, 2011-2012. Also included are population classifications for historical samples (year-classes 1986-1992) for fish of similar size to those for the recent NC sample (Rooker et al. 2008). MED=Mediterranean population; GOMEX=Gulf of Mexico population; MLE=maximum likelihood estimate of population composition; SD=standard deviation.

Year-classes	Year(s) sampled	Location/Study	N	Population	MLE %	MLE SD
2003	2011-2012	Virginia and North Carolina/ This study	39	MED GOMEX	50.8 49.2	13.2
2002-2004	2011-2012	Virginia and North Carolina/ This study	76	MED GOMEX	55.0 45.0	8.8
2002 and 2004	2011-2012	Virginia and North Carolina/ This study	37	MED GOMEX	59.4 40.6	12.3
1994-2009	2011-2012	Virginia and North Carolina/ This study	218	MED GOMEX	71.8 28.2	4.6
1986-1992	1996-1998	Mid-Atlantic, New England/ Rooker et al. 2008a, b	54	MED GOMEX	22.5 77.5	10.3

Figure 1. Age (top panel) and curved fork lengths (bottom panel) for North Carolina and Virginia Beach (US) Atlantic bluefin tuna sampled during January-April 2011 and 2012. Ages were estimated through enumeration of otoliths. Ages are presented by sampling year. The 2003 year-class is shown as age 8 and age 9 fish respectively for 2011 and 2012 samples.