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The first larval age and growth curve for bluefin tuna (*Thunnus thynnus*) from the Gulf of Mexico: Comparisons to the Straits of Florida, and the Balearic Sea (Mediterranean)

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ABSTRACT

Atlantic bluefin tuna (*Thunnus thynnus*) undertake extensive migrations throughout the North Atlantic Ocean, but spawn primarily in the Gulf of Mexico (GOM) and the Mediterranean Sea. Little is known about larval bluefin tuna (BFT) dynamics and growth despite numerous surveys conducted in the GOM. In this study, we describe age-length relationships for larval BFT using otolith increment analysis and compare somatic daily growth as revealed by individual increment widths from the GOM. Otoliths (sagittae) were aged from pre and post flexion larvae collected during multiple spring spawning seasons in 2000–2012 (259 larvae, 2.1–10.9 mm body length, 0–15 daily increments). For the first time, larval growth from the GOM is compared to historical larval collections in the neighboring Straits of Florida and in the Balearic Sea. Our results indicate that growth for GOM larvae is significantly faster than reported from previous studies, indicating different growth strategies during the larval stages for the two spawning grounds. This new growth curve will be incorporated into the calculations of the annual larval index used in the management of this overfished species. Growth and its variability, are important drivers, integral in studies of larval ecology dynamics for BFT.

1. Introduction

Atlantic bluefin tuna, *Thunnus thynnus* (BFT) are the largest and among the most valuable overfished scombrids in the North Atlantic Ocean (Rooker et al., 2007; Restrepo et al., 2010; Anonymous, 2014). Numerous BFT studies have been conducted to inform management decisions and has advanced our understanding of various aspects of their ecology (Fromentin and Powers, 2005; Secor et al., 2008; Rooker et al., 2008). Larval studies have focused on distribution and habitat associations (Alemany et al., 2010; Muhling et al., 2010, 2011, 2013), feeding ecology (Reglero et al., 2014; Yúfera et al., 2014; Tilley et al., 2016), larval condition in the Balearic Sea (García et al., 2006), and most recently, comparative trophic ecology between spawning grounds (Laiz-Carrión et al., 2015). Faster larval growth is generally a good indicator of larval survival, but hatchery and field experiments indicate this relationship is species-specific (Hare and Cowen, 1997; Tanaka et al., 2006; Fiksen et al., 2007; García et al., 2013). However, the contribution of larval BFT growth dynamics remains largely unexplored, despite the need to improve our understanding of early life history and its unidentified links to recruitment.

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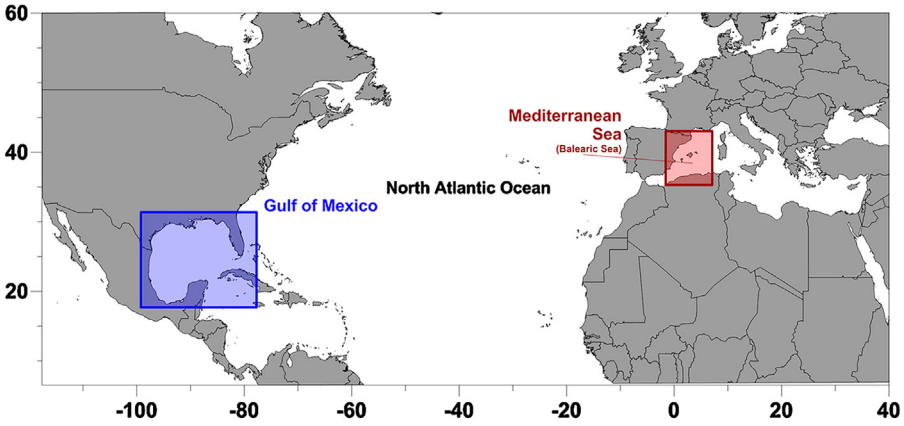

Fig. 1. Overview of the two larval bluefin tuna (*Thunnus thynnus*) study areas (colored boxes) in the North Atlantic Ocean: Gulf of Mexico (blue) and western Mediterranean Sea (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Spawning of BFT is regionally distinct, with nearly all of the western stock spawning in the GOM (Richards, 1976) and the eastern stock spawning principally in the Mediterranean Sea (Fromentin and Powers, 2005) (Fig. 1). Strong repeat homing behavior drives separation of the stocks (Block et al., 2005; Rooker et al., 2008; Wilson et al., 2015). Spawning occurs in the GOM between April and June (Richards, 1976; Scott et al., 1993; Block et al., 2005; Muhling et al., 2013) and takes place mostly in offshore nutrient-poor waters, rather than productive habitats found along the continental shelf (Muhling et al., 2010). Minor spawning events also been recorded along the Gulf Stream, near the Slope Sea, in the Bahamas and in the Mexican Caribbean (McGowan and Richards, 1989; Muhling et al., 2011; Lamkin et al., 2014; Richardson et al., 2016). Larvae hatched in the US Exclusive Economic Zone (EEZ) of the GOM have been sampled annually since 1977 during fisheries-independent plankton surveys carried out by the National Marine Fisheries Service's Southeast Area Monitoring and Assessment Program (SEAMAP) (Lyczkowski-Shutlz et al., 2013). Larval abundances from SEAMAP surveys provide yearly estimates of adult spawning biomass by using modeled abundances of day-one larvae derived from larval length distributions (Scott et al., 1993; Ingram et al., 2010).

Otoliths are routinely used to age fishes and generate growth curves that contribute to fisheries stock assessments (Ingram et al., 2010), ecological studies (Hare and Cowen 1997) and to approximate spawning times (Richardson et al., 2016). Daily increments are bipartite structures composed of a transparent layer (L-zone) and a darker but often-wider layer (D-zone) when viewed with transmitted light (Campana and Jones, 1992; Secor et al., 1995). Previously, otoliths of larval BFT were aged from specimens collected in the Straits of Florida (SOF) (Brothers et al., 1983) and the Balearic Sea in the Western Mediterranean (García et al., 2006, 2013). Age validation studies have not been conducted for larval BFT; however, Itoh et al. (2000) confirmed daily periodicity of increment formation for Pacific bluefin tuna (*Thunnus orientalis*) from 4 to 71 days. The larval growth curve used in the current management plan for this species is based upon samples collected by Brothers et al. (1983) in the SOF at the edge of the Gulf Stream from 19 May to 2 June 1981 and has not been updated since. To date, larval BFT collected from the primary spawning grounds in the GOM have not been aged.

Complementary to generating growth curves, comparing otolith biometrics can disentangle daily variability within and among larval cohorts as it relates to larval ecosystem dynamics (Sponaugle, 2010). Otolith radius (OR) measurements have been utilized to compare cohorts (Quintanilla et al., 2015), while the variability of daily increment widths (IW) has been used as an indicator of somatic growth (Brothers and McFarland, 1981; Shulzitski et al., 2012; Zenteno et al., 2014). Recruitment of BFT exhibits large interannual variability, the drivers of which remain unresolved. Otolith biometrics can facilitate a better understanding of biotic and abiotic drivers that play a key role in the development of credible predictive recruitment models for BFT that ultimately contribute to stock assessment models.

This study replaces the existing BFT larval growth curve by ageing otoliths from larvae collected from the GOM and compares their age at length estimates with those reported for BFT larvae from the SOF (Brothers et al., 1983) and the Balearic Sea (García et al., 2013).

2. Material and methods

2.1. Sample collections

Collections of BFT larvae for this study comprise two separate sampling efforts conducted in the GOM from 2000 to 2012 during the adult spawning seasons. In the first effort, larvae were collected from 2000 to 2010 by the University of Southern Mississippi Gulf Coast Research Laboratory (GCRL dataset henceforth) in a sampling area bounded by longitudes 85.7926° to 89.7498° W and latitudes 24.2703° to 29.1503° N (Fig. 2). Larvae were collected using multiple sampling gears. A Tucker trawl (1 × 1.4 m) was towed at three discrete depths (1, 10, and 20 m), and a rectangular net (1 × 2 m) was towed horizontally through the water column. Additionally, a ring net (0.6 m diameter) was towed at the surface, and a bongo net (60 cm OD) was towed obliquely from 0 to 30 m depth. All nets were fitted with 333 μm mesh netting. Net tow duration was approximately 10 min at a target vessel speed of two knots.

The second study area was larger but contained within the US EEZ and bounded by longitudes 81.4645° to 96° W and latitudes 24.3917° to 29.5° N. Sampling was carried out during 24-h operations from 30 April through 29 May 2012 beyond the 200 m depth contour. The survey was part of the SEAMAP spring plankton survey with some additional stations sampled (Millet, 2012) (SEAMAP dataset henceforth). Two rectangular nets (1 × 2 m) were used, one outfitted with 947 μm mesh netting that targeted the neuston layer and a second net outfitted with 505 μm mesh netting that undulated between 0 and 10 m for 10 min intervals (Habtes et al., 2014). The latter net was fitted with a mechanical flowmeter (2030R, General Oceanics, Inc) attached at the center of the net to record volume filtered. For additional sampling methodology in the GOM, see Laiz-Carrión et al. (2015). All samples (GCRL and SEAMAP datasets) were fixed in 95% ethanol and transferred to 95% or 70% ethanol respectively.