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Incorporation of habitat information in the development of indices of larval bluefin tuna (*Thunnus thynnus*) in the Western Mediterranean Sea (2001–2005 and 2012–2013)

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ABSTRACT

Fishery independent indices of bluefin tuna larvae in the Western Mediterranean Sea are presented utilizing ichthyoplankton survey data collected from 2001 through 2005 and 2012 through 2013. Indices were developed using larval catch rates collected using two different types of bongo sampling, by first standardizing catch rates by gear/fishing-style and then employing a delta-lognormal modeling approach. The delta-lognormal models were developed three ways: 1) a basic larval index including the following covariates: time of day, a systematic geographic area variable, month and year; 2) a standard environmental larval index including the following covariates: mean water temperature over the mixed layer depth, mean salinity over the mixed layer depth, geostrophic velocity, time of day, a systematic geographic area variable, month and year; and 3) a habitat-adjusted larval index including the following covariates: a potential habitat variable, time of day, a systematic geographic area variable, month and year. Results indicated that all three model-types had similar precision in index values. However, the habitat-adjusted larval index demonstrated a high correlation with estimates of spawning stock biomass from the previous stock assessment model, and, therefore, is recommended as a tuning index in future stock assessment models.

1. Introduction

Managers became concerned about the status of Atlantic bluefin tuna (*Thunnus thynnus*) stocks in the late 1960s. During recent years, stock assessments of Atlantic bluefin tuna (ABT hereafter) have been conducted at least biannually by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Management of ABT is accomplished using two differentiated stocks (the Eastern Stock, spawning in the Mediterranean and the Western Stock, spawning in the Gulf of Mexico), by establishing total allowable catches (TACs) and other complementary measurements, such as temporal closures for specific fishing grounds or minimum size restrictions (Fromentin and Powers, 2005). Virtual Population Analysis (VPA, e.g. Butterworth and Rademeyer, 2008) serves as a technical basis for defining a TAC under different fisheries scenarios (e.g. ICCAT, 2013). Traditionally, results from VPA have been contrasted and calibrated with other complementary abundance indices, primarily based on fisheries-dependent data. For the Eastern Stock, fisheries on juvenile ABT in the Gulf of Vizcaya provided information on recruitment rates; southern Spanish traps, targeting individuals during their reproductive migratory routes into the Mediterranean (Ortiz de Urbina et al., 2007), provided information on adult stock status. During the last decade, the TAC of the Eastern Stock has been reduced and minimum legal sizes for juvenile ABT changed, affecting these two fisheries and associated indices, which may negatively affect the future index availability (ICCAT, 2013) and possibly the quality of the final VPA results. Therefore, there is a need for new approaches that allow tuna abundance estimations for the Eastern Stock using methods that are independent from commercial fisheries.

During recent decades, ichthyoplankton surveys targeting ABT larvae were conducted in several areas of the Mediterranean Sea. However, the surveys employed heterogeneous sampling strategies and methodologies, without any temporal continuity (e.g. Dicenta, 1977; Dicenta and Piccinetti, 1978; Oray and Karakulak, 2005; Piccinetti and

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Piccinetti-Manfrin, 1994; Piccinetti et al., 1996a, 1996b, 1997; Tsuji et al., 1997). In 2001 the Instituto Español de Oceanografía (IEO) started a series of standardized ichthyoplankton surveys around the Balearic Islands (Western Mediterranean Sea), recognized as one of the main spawning areas of the Eastern Stock of ABT (García et al., 2004; Alemany et al., 2010) together with central Mediterranean and the waters around Cyprus (Fromentin and Powers, 2005). The aim of these surveys was characterizing the spawning habitat of this species, deepening the knowledge of its larval ecology, and assessing the influence of environmental factors on larval distribution and abundance. These surveys followed an adaptive sampling strategy, combining intensive sampling of high density larval patches with quantitative sampling over a systematic grid of stations. The abundance of ABT larvae collected during these dedicated ichthyoplankton surveys could provide an alternative to current indices of ABT stock status from fishery-independent data. This approach was already proposed for the Western Stock in the early 1990s (Scott et al., 1993) and updated using standardization via delta-lognormal models (Ingram et al., 2010).

The results from the ichthyoplankton surveys conducted in the Balearic Sea have shown that spatial location of larval habitats of ABT are strongly influenced by mesoscale oceanographic processes (Alemany et al., 2010; Reglero et al., 2012; Muhling et al., 2013; Alvarez-Berastegui et al., 2014), as has also been demonstrated in the Gulf of Mexico (Muhling et al., 2013; Lindo-Atichati et al., 2012). Therefore, larval index values may be influenced by the type of habitat sampled among years. In addition, ongoing climate change could impact the oceanography and ecosystems in the Western Mediterranean (Calvo et al., 2011; Macias et al., 2015), thus inducing changes in the larval habitats of ABT. Within this context, improving the knowledge of how habitat information can increase the performance of larvae index models is important to the advancement of fishery-independent stock evaluation methodologies. Previous larval index calculations (Ingram et al., 2013) have included salinity and temperature as environmental linear covariates, but other recent studies (Reglero et al., 2012) have demonstrated that their effect on the larval habitat characterization may not be linear.

The ABT larval abundance data gathered during scientific surveys are useful for developing an index of abundance, which would represent the second fishery-independent index of abundance of ABT in the world, and currently the only fishery-independent index concerning the eastern Atlantic stock. Therefore, the objective of this study is to present abundance indices of ABT larvae collected around the Balearic Islands based on delta-lognormal models and evaluate their adequacy as indicators of the temporal trend of spawning stock biomass (SSB). We also evaluated whether including environmental spatial variability into the larvae indices, thus accounting for differences in the percentage of larval habitat sampled each year, improves the quality of the larval indices. To reach these objectives, different larval index models are compared and related to SSB obtained from the ABT stock assessment of ICCAT (ICCAT, 2013).

2. Methods

2.1. Field sampling methodology

During the period 2001–2005 ABT larvae were collected by oblique tows performed down to 70 m in the open sea or down to 5 m above the sea floor in stations shallower than 70 m, using a 333 μm mesh fitted to 60 cm mouth opening Bongo nets (Bongo 60) (see details in Alemany et al., 2010). In addition, subsurface tows between 5 m and surface were carried out at the same stations in 2004 and 2005 by means of a Bongo net with a 90-cm mouth opening equipped with a 500 μm mesh (Bongo 90). In 2012 and 2013, ABT larvae were collected by oblique tows from the thermocline (~30 m) to the surface, using a 500 μm mesh fitted to a Bongo 90. In each of those years, around 200 stations, located over the nodes of a regular grid of 10×10 nautical miles, covering most of the known ABT spawning areas in this region (from 37.85° to 40.35°N and from 0.77° to 4.91°E), were sampled during the spawning peak of the species in the Western Mediterranean (Fig. 1). Additional sampling stations during the surveys that were focused on other research and not strictly part of the standard survey grid were not included in the dataset for analysis (Fig. 2), and the number of sampled stations and the dates of the surveys are shown in Table 1. In all haul-types, flowmeters were fitted to the net mouths for determination of the volume of water filtered. Plankton samples were fixed on board with 4% formaldehyde in seawater. In the laboratory, all fish larvae were sorted under a stereoscopic microscope. Tuna larvae were then identified to species level and ABT larvae standard length was measured by means of an Image Analysis System. For stations with large catches, a subsample of larvae was measured, and those counts were extrapolated to the total number of larvae at that station. In addition, at each station, a vertical profile of temperature, salinity, oxygen, turbidity, fluorescence and pressure was obtained using a CTD probe SBE911. Dynamic height was calculated from the CTD data by vertical integration of the specific volume, using 600 m as the level of no motion. (At shallow stations, or when data was recorded only down to 350 m, the density anomaly of the closest station (closer than 15 nm) was assigned at the lower recorded level). Geostrophic velocities were obtained at each sampling location by the first-derivative of the dynamic height profiles objectively analyzed onto a 3 nm×3 nm regular grid, see Balbín et al. (2014) for more details.

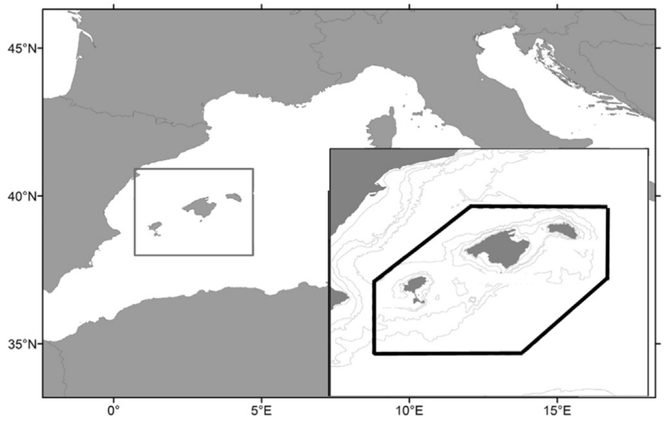

Fig. 1. The area around the Balearic Islands in the Western Mediterranean where ichthyoplankton surveys were conducted for this study.

Following the methods of Ingram et al. (2015), the numbers of specimens collected at a station, with corresponding gear-type, were adjusted to the number of 2-mm larvae, using the decay in numbers at size, derived from a length-based catch curve for each gear-type (Fig. 3). Due to the decreased selectivity in both gears for 2-mm larvae, a coefficient was also used for adjustment: 1.022 for Bongo 60 and 2.199 for Bongo 90. For years 2004 and 2005, the Bongo 90 larval catches were not measured. Therefore, to adjust these numbers, the length distribution of the 2004–2005, Bongo 90 was assumed to be that summarized from 2012 and 2013 surveys Bongo 90 length data. Finally, larval density was calculated by dividing the adjusted catch numbers by the volume filtered by the gear; abundance was calculated by multiplying the density by the tow depth.

2.2. Statistical methodology

Three larval indices were computed to assess the effect of improving the habitat information on index development. The first model, denoted as “basic larval index” (BLI), included no environmental variables in its formation. The second model, denoted as “standard larval index” (SLI), included salinity and sea surface temperature to evaluate if there were any linear effects of these environmental