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Potential impact of climate change on the Intra-Americas Sea: Part 2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats

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ABSTRACT

Increasing water temperatures due to climate change will likely have significant impacts on distributions and life histories of Atlantic tunas. In this study, we combined predictive habitat models with a downscaled climate model to examine potential impacts on adults and larvae of Atlantic bluefin tuna (*Thunnus thynnus*) and skipjack tuna (*Katsuwonus pelamis*) in the Intra-Americas Sea (IAS). An additional downscaled model covering the 20th century was used to compare habitat fluctuations from natural variability to predicted future changes under two climate change scenarios: Representative Concentration Pathway (RCP) 4.5 (medium–low) and RCP 8.5 (high). Results showed marked temperature-induced habitat losses for both adult and larval bluefin tuna on their northern Gulf of Mexico spawning grounds. In contrast, habitat suitability for skipjack tuna increased as temperatures warmed. Model error was highest for the two skipjack tuna models, particularly at higher temperatures. This work suggests that influences of climate change on highly migratory Atlantic tuna species are likely to be substantial, but strongly species-specific. While impacts on fish populations remain uncertain, these changes in habitat suitability will likely alter the spatial and temporal availability of species to fishing fleets, and challenge equilibrium assumptions of environmental stability, upon which fisheries management benchmarks are based.

1. Introduction

Average upper ocean temperatures have increased markedly in many regions of the world in recent decades (Hansen et al., 2006; Rhein et al., 2013), and evidence of associated shifts in the distributions of marine populations continues to accumulate (Last et al., 2011; Nye et al., 2009; Pinsky and Fogarty, 2012). Temperature-sensitive organisms may respond by moving poleward, to deeper waters, or they may become locally extinct from key habitats altogether in response to warming conditions (Dulvy et al., 2008; Fodrie et al., 2010; Perry et al., 2005). The life history requirements, migratory behavior and motility of each species will affect its ability to adapt to a changing environment, or to relocate to more favorable habitats (Koehn et al., 2011; Sharp, 1978). While organisms with broad physical tolerances may be able to withstand warming temperatures with a minimum of adaptive behavior, those already existing close to their physical limits are more likely to be significantly affected (Dulvy et al., 2008; Rijnsdrop et al., 2009).

In addition to changes in spatial distributions, climate change may influence marine species through loss or degradation of habitat, altered rates of larval survival and recruitment potential, and subsequent impacts on stock resilience, as a result of physiological and behavioral responses to environmental gradients (Ciannelli et al., 2005; Perry et al., 2005; Scavia et al., 2002). Where species are exploited and/or managed, climate change will introduce additional complexities. Although the potential role of environmental variability in stock dynamics is being increasingly recognized, and capacity to incorporate climatic changes is improving (Daskalov, 1999; Jacobson and MacCall, 1995; Punt and Hilborn, 1997; Wayte, 2013), most fisheries are still largely managed and assessed under the assumption that ocean climate characteristics are stationary. Robust fisheries management in a changing climate that may alter abundance, distribution or productivity of fish stocks will require incorporating predicted climatic impacts (Hobday et al., 2013).

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The Intra-Americas Sea (IAS) comprises the semi-enclosed Caribbean Sea (CBN) and Gulf of Mexico (GoM) in the western Atlantic Ocean. In recent years (2005–2010), climatological summer surface temperatures in the region, particularly the GoM, have been among the warmest recorded globally. Continued warming in this geographical area may therefore test thermal tolerances of resident species beyond currently observed limits worldwide. In addition, the position of the northern GoM coast limits poleward expansion, and may restrict the ability of species to avoid unfavorably warm water temperatures through northern displacement.

The IAS is essential habitat for a number of highly migratory fish species, particularly tunas and billfishes (Schaefer, 2001). Water temperature is of high physiological importance to these animals, as it impacts their cardiac function (Blank et al., 2004), swimming abilities (Dizon et al., 1977), spawning activity (Medina et al., 2002), egg hatching (Gordoa & Carreras, 2014; Miyashita et al., 2000; Wexler et al, 2011) and larval growth (Garcia et al., 2013; Wexler et al., 2011). Indirectly, water temperature may also drive migration patterns (Fromentin et al., 2014), and dynamics of prey species (Trenkel et al., 2014). However, temperature tolerances among species vary widely. Tropical forms such as skipjack tuna (SKJ: *Katsuwonus pelamis*) and yellowfin tuna (YFT: *Thunnus albacares*) are found in waters of up to 30–32 °C, and prefer ambient temperatures of >16 °C (Boyce et al., 2008). Conversely, the temperate Atlantic bluefin tuna (BFT: *Thunnus thynnus*) feed extensively in waters of <10 °C, and are likely to be physiologically stressed by temperatures > 28–29 °C (Blank et al., 2004; Block et al., 2005; Boyce et al., 2008).

Despite these differences, spawning activity has been reported for all Atlantic tunas within at least some portion of the IAS (Espinosa-Fuentes & Flores-Coto, 2004; Lindo-Atichati et al., 2012; Muhling et al., 2010; Richards et al., 1993; Ueyanagi, 1971). While some species such as SKJ spawn over large areas throughout much of the year (Nishikawa, 1978), others show much more spatiotemporally restricted spawning. BFT is the most extreme example, with the western population spawning only in the GoM and immediate surrounds from April to June (Knapp et al., 2014; Muhling et al., 2013).

Increasing water temperatures are therefore highly likely to impact migration, spawning, larval survival and recruitment of tuna populations in the IAS. Different species may show different responses and vulnerabilities, depending on their physiology and life history. When a simple habitat model for occurrence of larval BFT was previously applied to an IPCC-AR4 climate model projection, results suggested almost complete loss of spring spawning habitat in the late 21st century (Muhling et al., 2011a). However, a subsequent study in which downscaled global climate models to a regional scale indicated that temperature projections for the northern GoM may be over-estimated by global models (Liu et al., 2012). This was due to the inability of these low resolution models to resolve the characteristics of the Loop Current. Liu et al. (2012) instead predicted that the major circulation features of the GoM will weaken substantially by the late 21st century, slowing the rate of warming in the northern GoM. These results imply a need to consider the dynamics of regional current systems when predicting the biological and ecological impacts of climate change.

Here, we aimed to extend current knowledge of climate change impacts on tunas in several ways. First, we obtained projections of future conditions using a high-resolution ocean model. This model was constrained with new versions of surface forcing fields, and initial and boundary conditions obtained from the Coupled Model Intercomparison Project phase-5 (CMIP5) model simulations, under 20th century, Representative Concentration Pathway 4.5 (RCP 4.5) and 8.5 (RCP 8.5) scenarios (Liu et al., this issue). In addition, to explore the usually-neglected impact of natural climate variability on the region, we used outputs from a high-resolution dynamically downscaled ocean model, for the period 1871–2008 (Liu et al., this issue). These experiments provided simulations of ocean temperature conditions for more than a century before the present day, and projections for nearly one century into the future. We applied temperature fields from these models to habitat suitability models constructed for two life stages (adults and larvae) of two tuna species within the broader IAS region: one tropical (SKJ) and one temperate (BFT). Habitat models were parameterized using present day data, and then applied to both past and future projections of ocean conditions. Variability in adult and larval habitats, and potential losses and gains into the future were then quantified.

2 . Methods

2.1 . Adult data

Catch rate data for adult BFT and SKJ were obtained from the International Commission for the Conservation of Atlantic Tunas (ICCAT) Task II database, downloaded from www.iccat.es. All gear types were

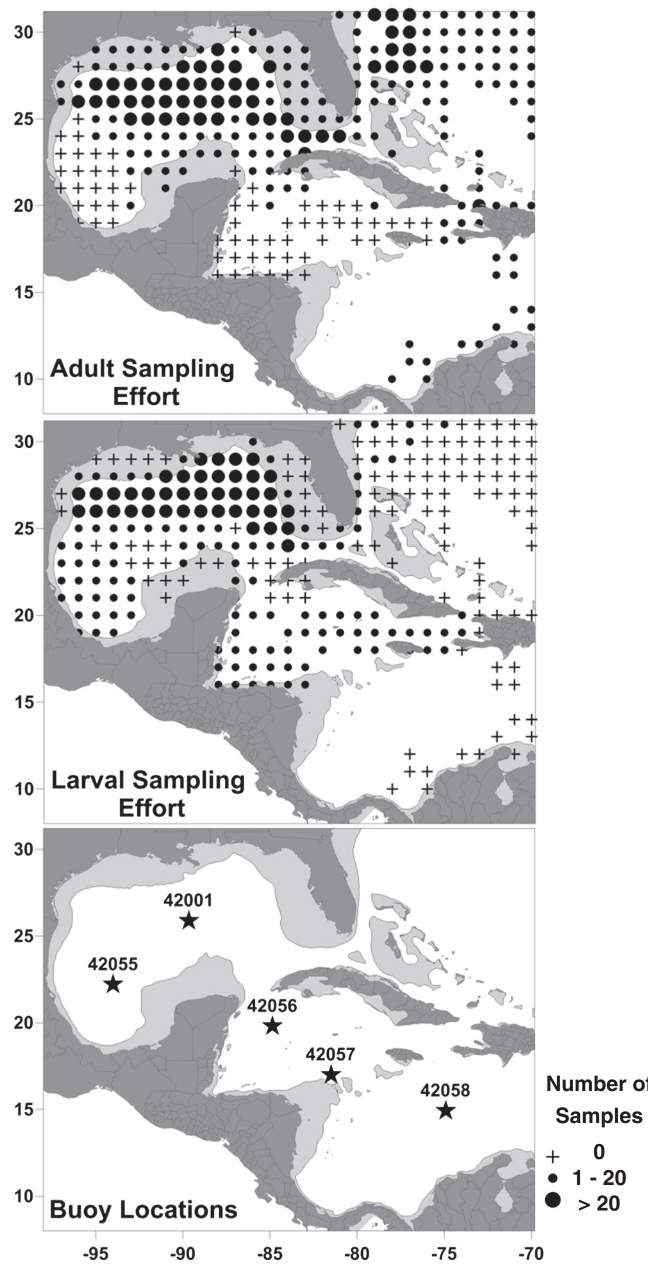

Fig. 1. Total number of data points available for adult (top), and larval catch locations (middle). Locations of five buoys used to calculate surface temperature trend by month are also shown, with NOAA identification numbers (bottom). The shaded region in each map represents the 200 m depth contour.