Significant Reduction of the Loop Current in the 21st Century & Its Impact on the Bluefin Tuna Spawning Habitat in the Gulf of Mexico

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Introduction

The IPCC-AR4 climate models project that the upper ocean temperature in the Gulf of Mexico (GOM) may increase by ~2°C and the Atlantic Meridional Overturning Circulation (AMOC) may slow down by about 25% during the 21st century (e.g., Schmittner et al. 2005). Both factors can have strong impacts on the Atlantic marine ecosystem, potentially resulting in substantial reduction of productivity in the GOM.

Bluefin tuna (BFT) is one such species that can be greatly affected by future climate change. The spawning of BFT has been recorded predominantly in the northern GOM from April to June (AMJ) with the optimal temperature of 24 - 27°C (Fig. 1). Adult BFTs are adversely affected by warm water and thus avoid warm features such as the Loop Current (LC).

Since the LC in the GOM is a part of the North Atlantic western boundary currents system and is an important pathway of the AMOC, it is expected that the LC be reduced as the AMOC slows down in the 21st century. However, the IPCC-AR4 climate models have typical spatial resolution of ~1°, which is too coarse to resolve and estimate the changes in the strength, position and eddy shedding characteristics of the LC and their effects on the projected warming of the GOM.

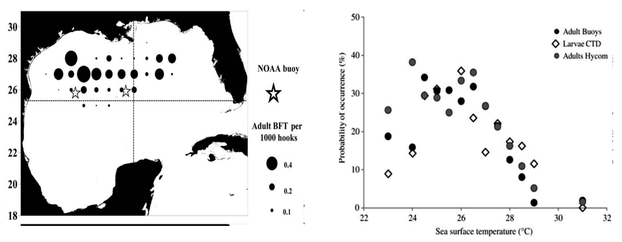


Fig. 1: a) Mean catches of adult BFT per 1000 hooks on long-line fishing vessels, from 1992 to 2009. b) Probability of occurrence of adult and larval BFT in the GOM versus surface water temperatures in the spring.

The main objective of this study is to assess the potential impact of future anthropogenic global warming (AGW) on the GOM using a downscaled high-resolution ocean model constrained with the surface forcing fields, initial and boundary conditions obtained from the IPCC-AR4 model simulations under A1B scenario and predict the effect of climate change on bluefin tuna (BFT) spawning habitat in the GOM.

Models

Ocean model: MICOM coupled to Atmospheric Mixed Layer

Domains: Atlantic Ocean (20° S – 65° N)

Horizontal grid:

- Low resolution (1° for the Atlantic Ocean), run from 1950-2100
- High resolution (0.1° in GOM, 0.25° elsewhere)

Vertical: 16 vertical isopycnic coordinate layers

Surface forcing: Ensemble averaged IPCC atmospheric forcing with bias correction.

IC & BC: IPCC salinity and temperature

Run periods (high resolution):

- Late 20C run: 1981-2000
- Mid 21C run: 2041-2060
- Late 21C run: 2081-2100

BFT habitat model: Based on Muhling et. al (2011).

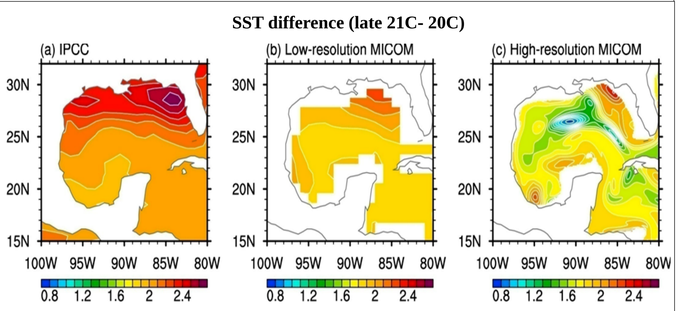


Fig. 2: SST difference in the GOM between the late 21st century and late 20th century during AMJ obtained from (a) the weighted ensemble of 11 IPCC-AR4 models, (b) the low-resolution MICOM experiment (EXP_LR) and (c) the high-resolution MICOM experiment (EXP_HR).

Cooling effect due to the reduced LC

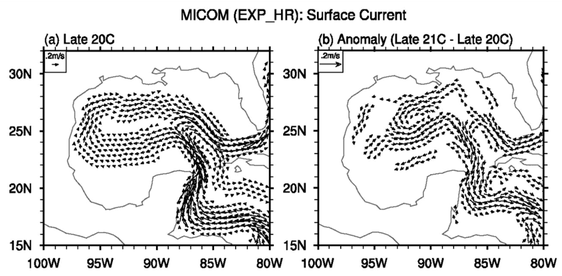


Fig. 3: (a) Long-term mean surface current in the late 20th century during AMJ obtained from EXP_HR. (b) Anomalous (i.e., late 21st century – late 20th century) surface current in the GOM during AMJ obtained from EXP_HR.

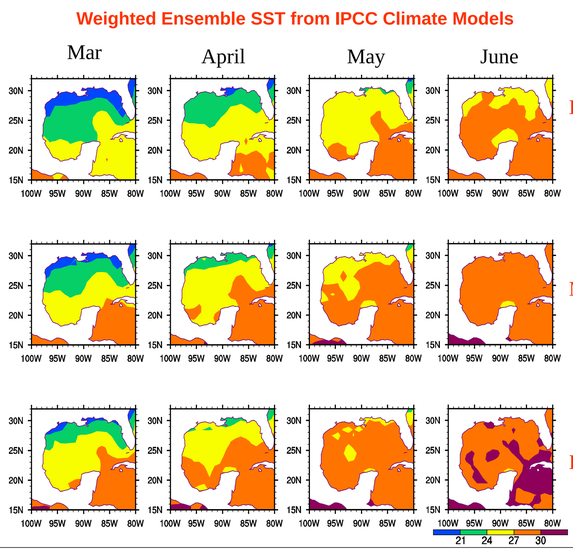


Fig. 4: Predicted suitability of habitat in the GOM for adult BFT, based on SSTs from the IPCC-AR4 models during the late 20th century, and the mid 21st century and late 21st century. These categories are estimated based on the published associations between SST and BFT spawning and physiology.

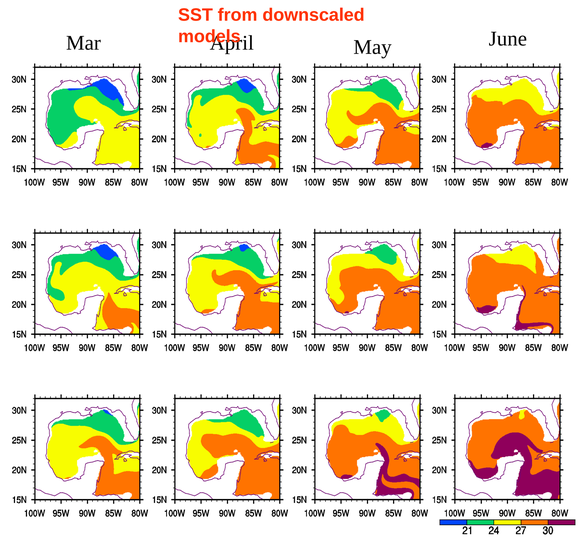
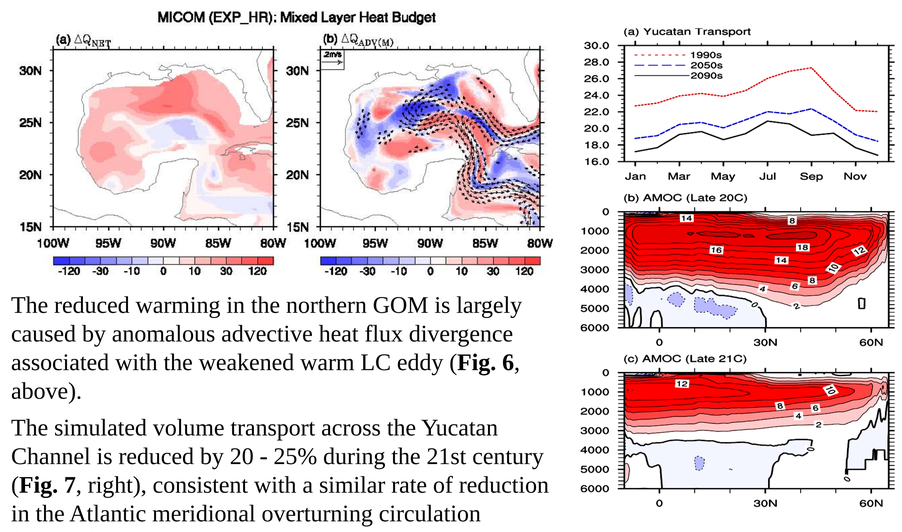


Fig. 5: Same as Fig. 4, except that the SSTs are from the downscaled model results. The GOM is warmed everywhere, but the spatial pattern of the warming is quite different from that of the IPCC-AR4 models (Figure 2a). In particular, the SST increase in the high-resolution model (Figure 2c) is much less especially in the northern GOM. A potential cause for this difference may be the weakening of the LC and the associated reduction in the warm water transport through the Yucatan Channel, which are not well simulated in the IPCC-AR4 models.



The reduced warming in the northern GOM is largely caused by anomalous advective heat flux divergence associated with the weakened warm LC eddy (**Fig. 6**, above).

The simulated volume transport across the Yucatan Channel is reduced by 20 - 25% during the 21st century (**Fig. 7**, right), consistent with a similar rate of reduction in the Atlantic meridional overturning circulation (AMOC).

Impact on the BFT habitat

Fig. 8 Applications of IPCC climate model results to the BFT habitat model

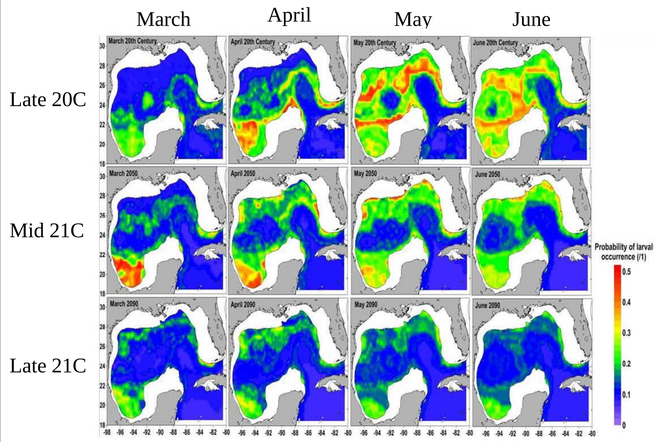


Fig. 9 Applications of downscaled model results to the BFT habitat model

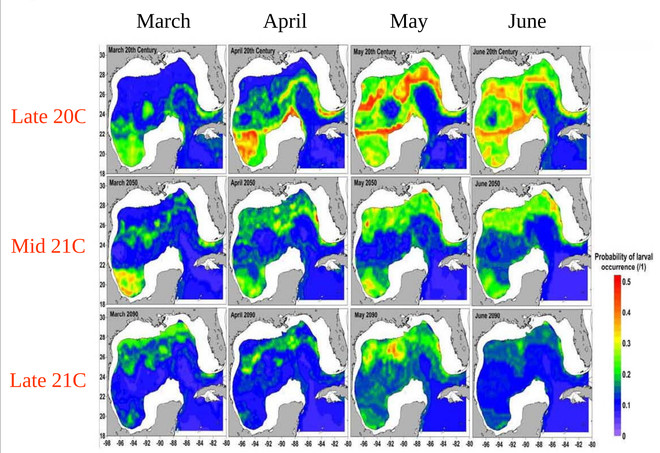


Fig 8 & 9: Prediction of the extent of habitat suitable for the occurrence of larval bluefin tuna in the Gulf of Mexico under late 20th century conditions, and projected conditions in mid and late 21st century for the months of March, April, May and June. The probability of occurrence (%) is shown, based on output from the boosted classification tree model using the mean temperature values from the IPCC climate models (Fig. 8) and downscaling models (Fig 9).

Conclusions

The simulated volume transport by the Loop Current (LC) is reduced considerably by 20 - 25% during the 21st century, consistent with a similar rate of reduction in the AMOC.

The effect of the LC in the present climate is to warm the GOM, therefore the reduced LC and the associated weakening of the warm LC eddy have a cooling impact in the GOM, particularly in the northern basin.

The northern GOM is characterized as the region of minimal warming. Low-resolution models, such as the IPCC-AR4 models, underestimate the reduction of the LC and its cooling effect, thus fail to simulate the reduced warming feature in the northern GOM.

Reduced warming in the northern GOM mitigates the reduction of BFT spawning ground. Nevertheless, downscaling model results show that the bluefin tuna habitat ground will be reduced drastically by late 21st century.