(Towards) Spatial management of bluefin tuna in the Gulf of Mexico

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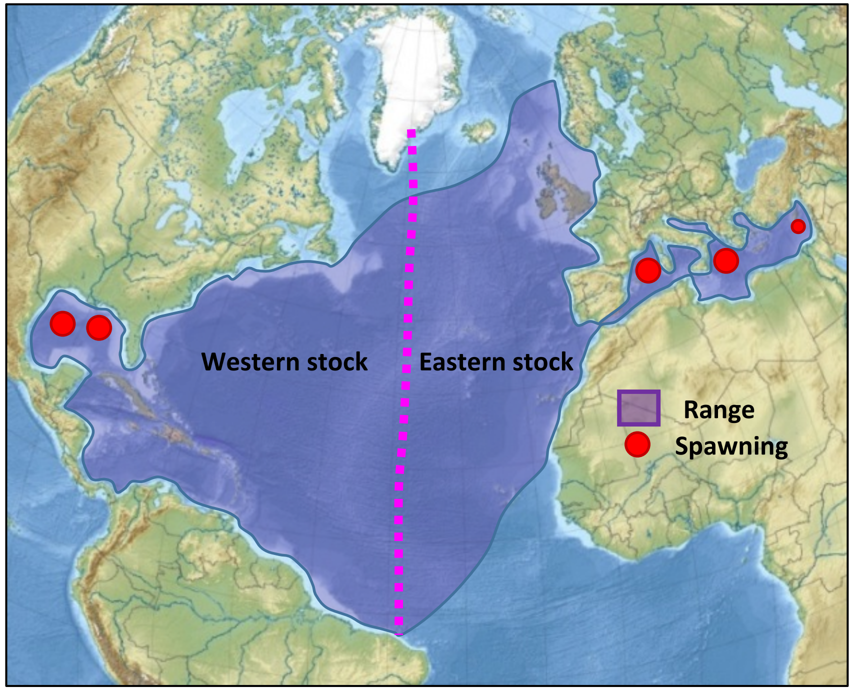
Outline

- Atlantic bluefin tuna: biology and management
- Gulf of Mexico oceanography
- Gulf of Mexico surface temperature prediction
- Surface temperature and bluefin tuna biology
- Links between temperature, biology and management
- Some potential uses for seasonal temperature forecasts
- Future directions

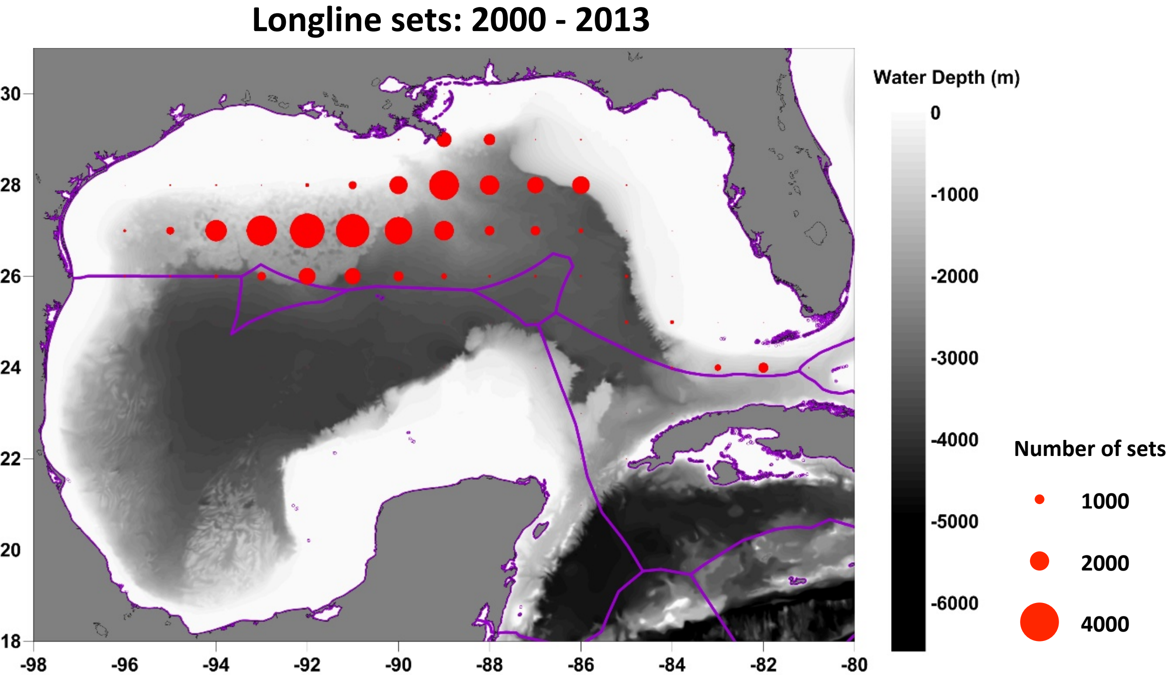
Atlantic bluefin tuna (*Thunnus thynnus*)

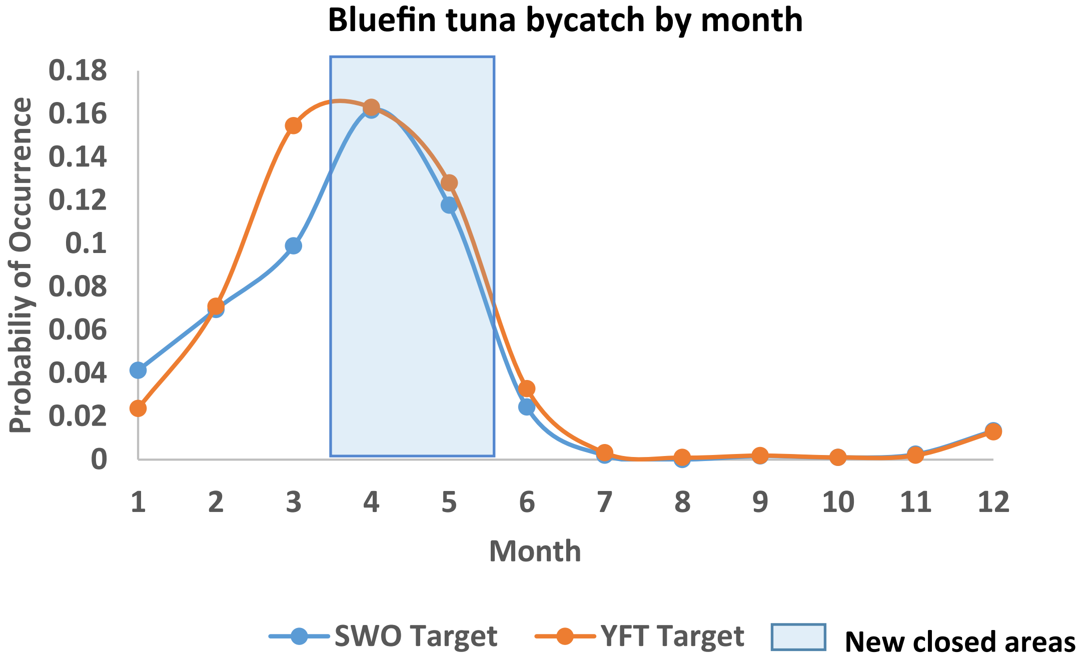
- World's largest tuna: can grow to > 400cm and 500kg
- Highly migratory, capable of trans-Atlantic crossings
- Unique physiology allows them to feed in waters as cold as 3°C
- However, they have only been reported to spawn in two spatially restricted areas:
  - The western stock spawns in the Gulf of Mexico region, during spring
  - The eastern stock spawns in the Mediterranean Sea, during summer



Gulf of Mexico longline fishery

- The primary target species for the Gulf of Mexico pelagic longline fishery are yellowfin tuna and swordfish
  - Directed fishing for bluefin tuna has been prohibited since 1982
- The fishery interacts with bluefin tuna from winter to early summer
- A number of management measures have been introduced to curb bycatch of bluefin, including retention limits, and gear configurations
  - E.g. 2011 introduction of weak hooks
- However, avoiding interactions entirely is preferable
  - High (40-60%) mortality rate of bluefin on longline gear

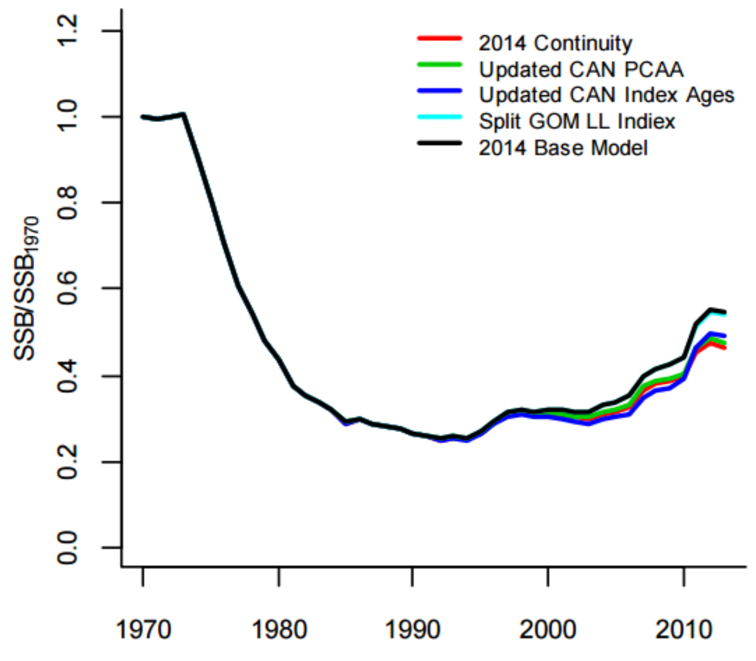




Management measures

- Managed under dual authority of Magnuson-Stevens Act (NMFS) and Atlantic Tunas Convention Act (ICCAT)
- Stocks at historically low levels, despite strong regulation. Some evidence of recent recovery
- Western stock currently at year 16 of a 20 year rebuilding plan
- Recent Amendment 7 to management plan introduced several new management measures, including two new closed areas in the Gulf of Mexico during spring
- Notes that protection of spawning fish could "enhance spawning potential and stock growth"

Spawning stock biomass relative to 1970 (VPA)



ICCAT

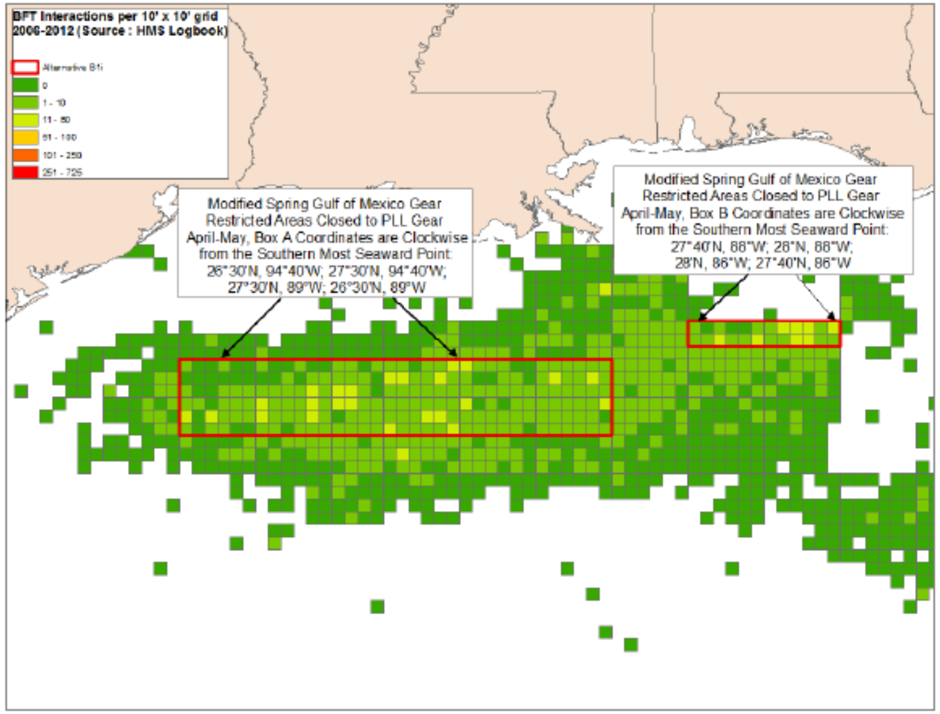
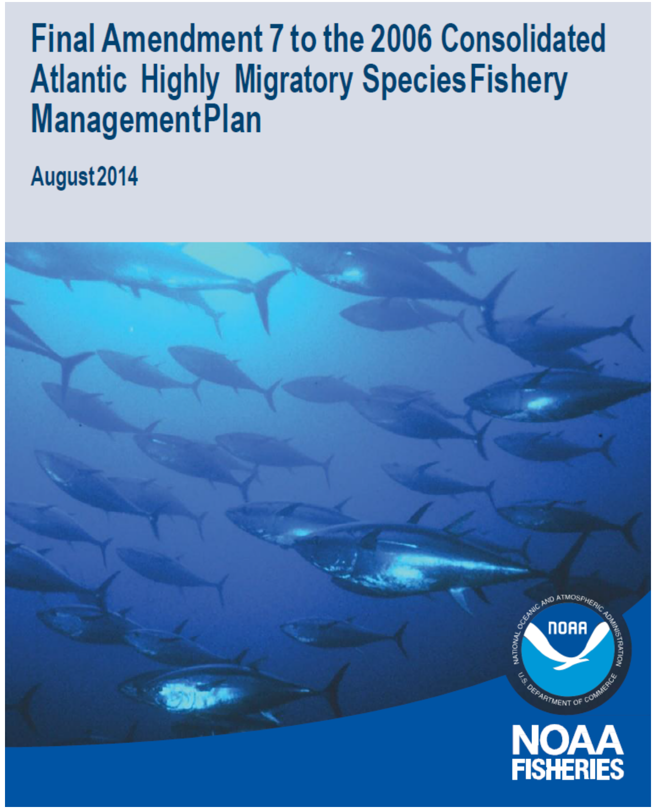
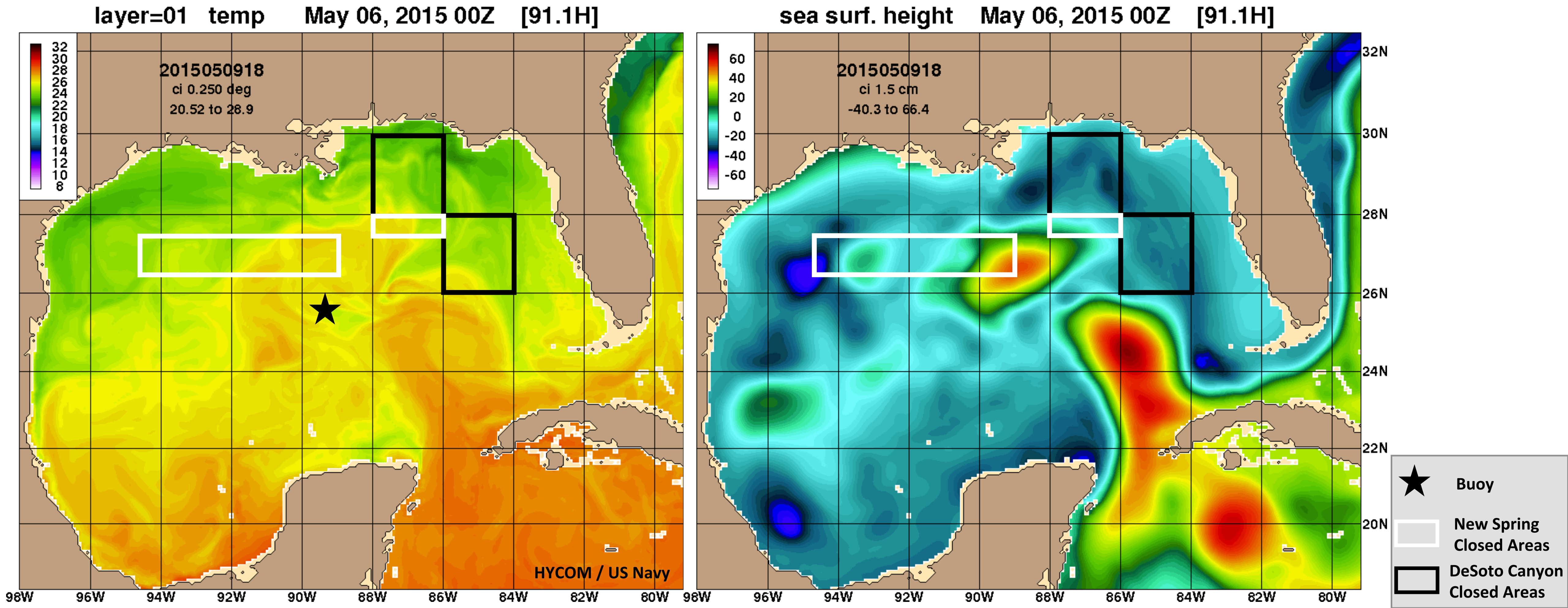


Figure 2.12 Modified Spring Gulf of Mexico Gear Restricted Areas (Alternative B 1i) Number of Bluefin Interactions with Pelagic Longline Gear (2006 – 2012)



Gulf of Mexico oceanography

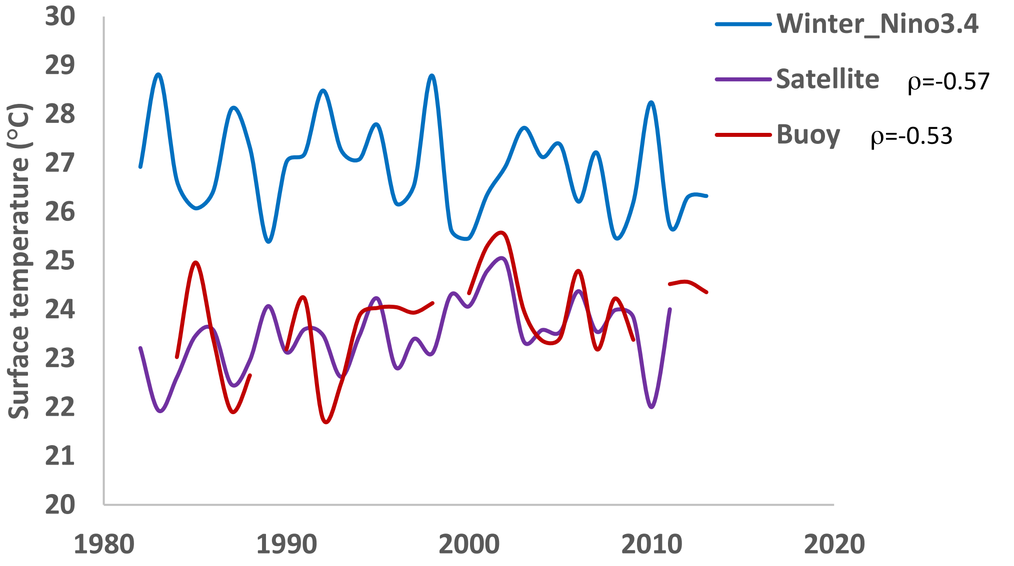
- 30 day loop from early May to early June shown
- The eastern Gulf of Mexico is strongly influenced by the Loop Current
- Surface temperatures warm rapidly during April and May as air temperatures increase



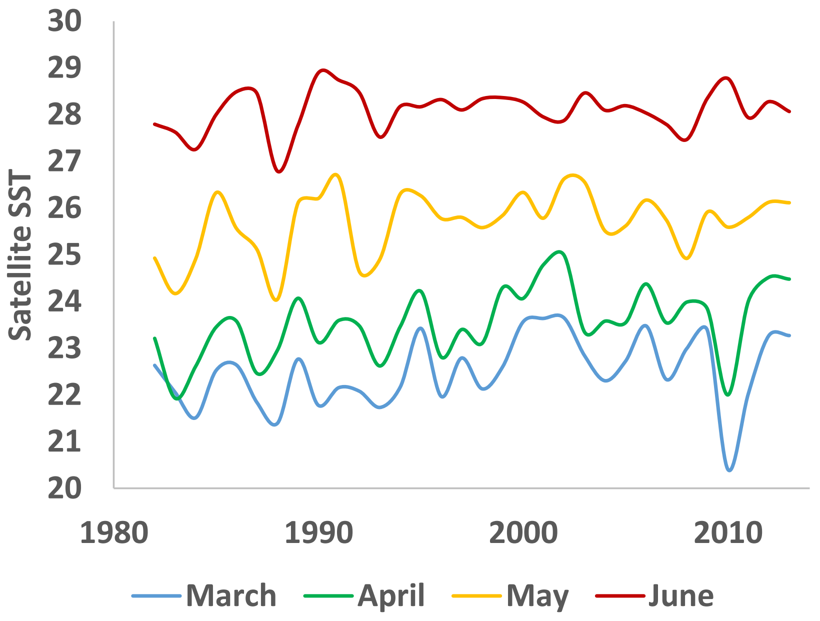
Spring warming

- 30 years of buoy and satellite data show high interannual variability in spring surface temperatures
- March and April temperatures are strongly correlated, greater variability among other months
- Negative correlation with Nino 3.4 index: warm Pacific in previous winter associated with cool Gulf during spring (e.g. Alexander & Scott, 2002)
- Conditions on bluefin tuna spawning grounds in the Gulf of Mexico are therefore variable, but potentially predictable

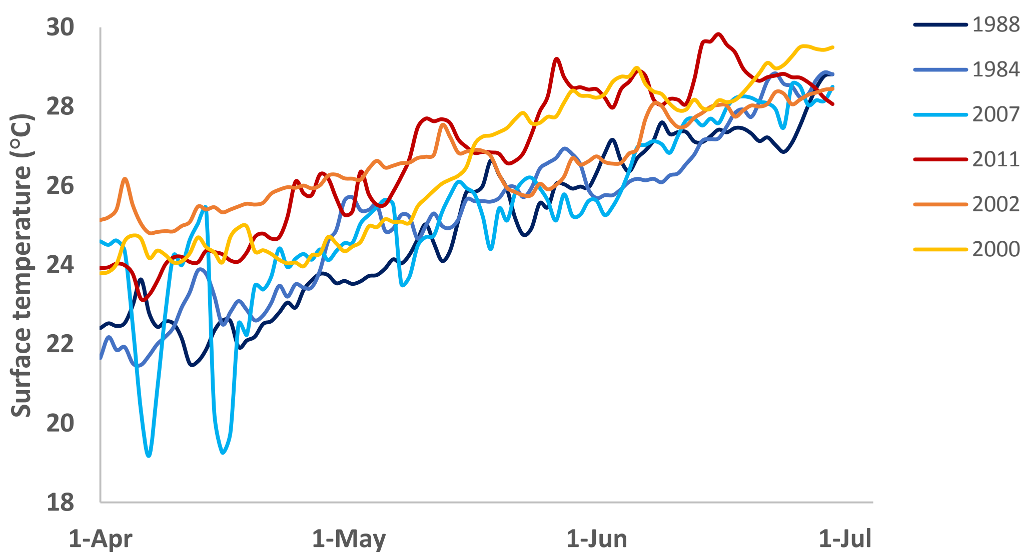
April surface temperatures vs. previous winter Nino 3.4 index



Monthly spring surface temperatures (satellite observations)

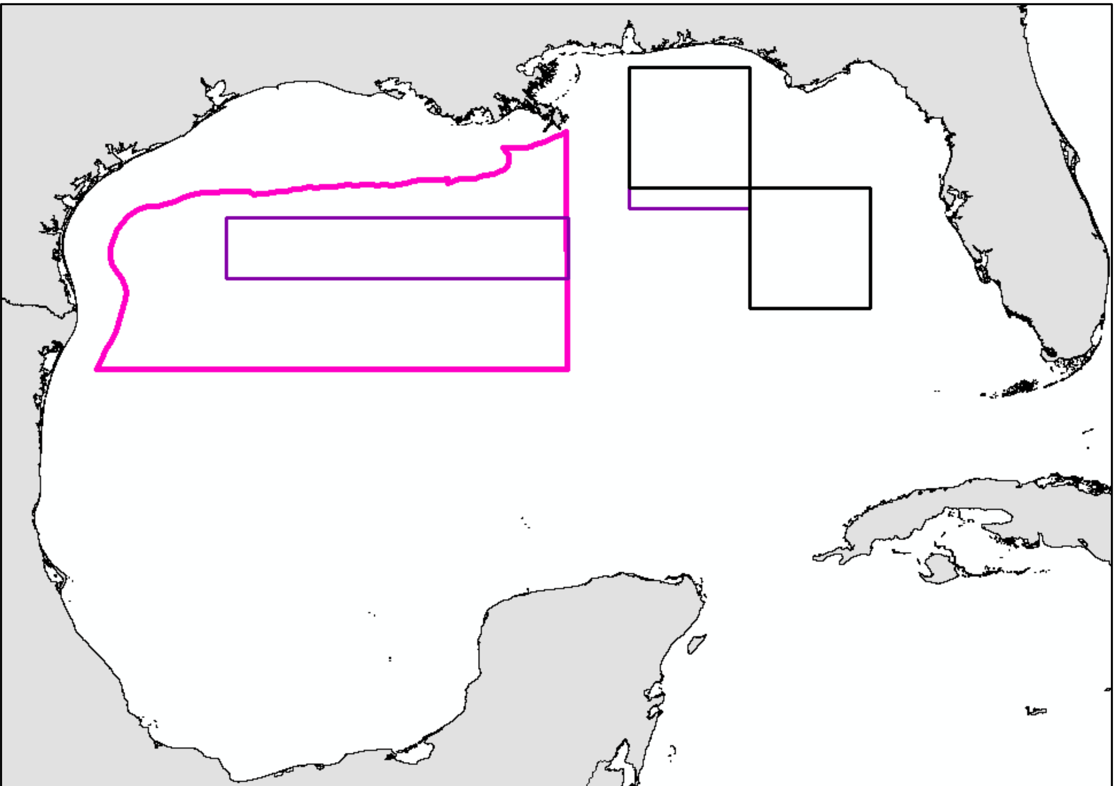


Spring warming at buoy 42001: 3 warmest vs. 3 coldest years

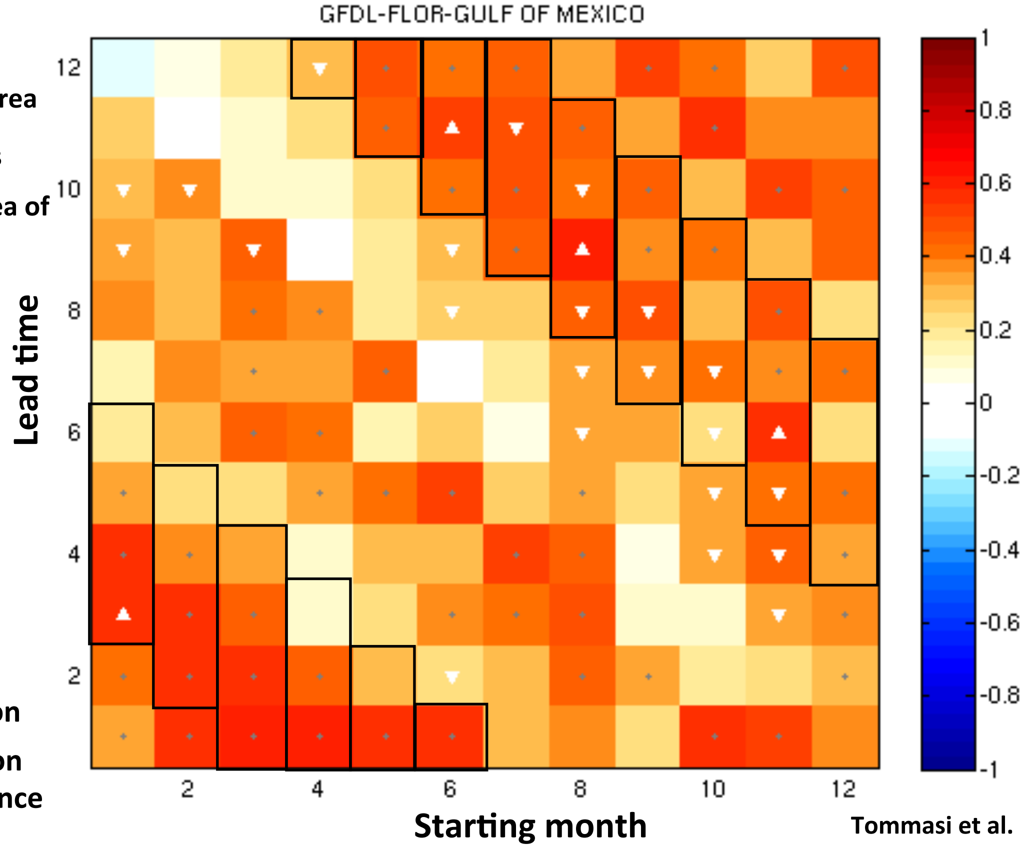


Predictability of Gulf of Mexico surface temperature

- We selected an initial area of interest where bluefin tuna interactions and spawning are high, but away from the area of influence of the Loop Current
- GFDL FLOR model shows promise:
  - Spring temperature anomalies well predicted in previous summer – fall for north western Gulf of Mexico
  - March and April were usually better predicted than May and June



DeSoto Canyon Closed Area
New Spring Closed Areas
Seasonal Forecasting Area of Interest



Significant correlation
Significant correlation higher than persistence

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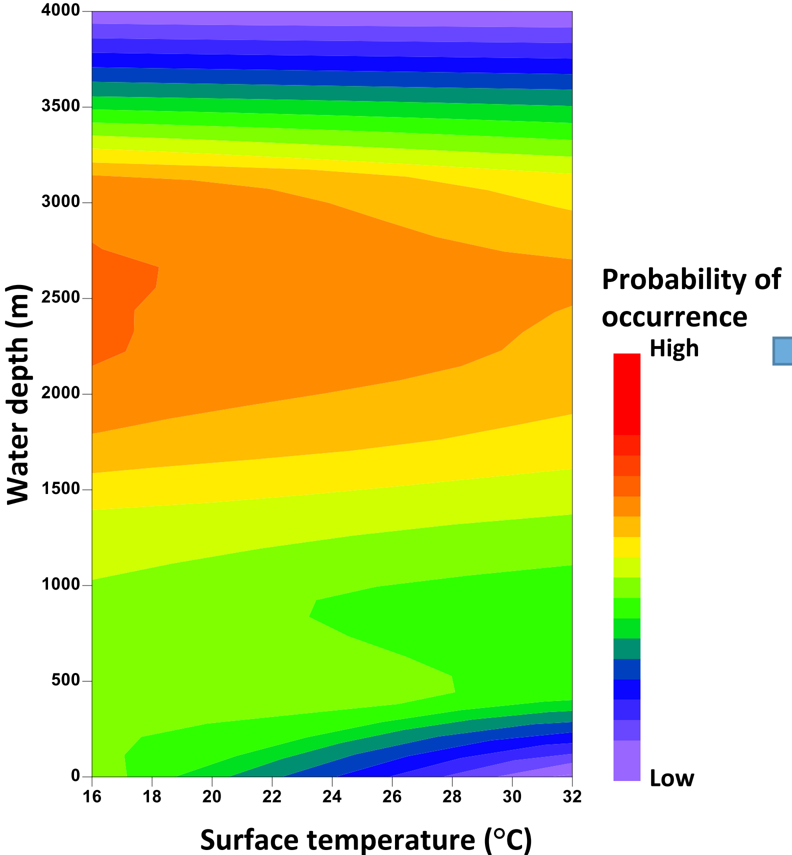
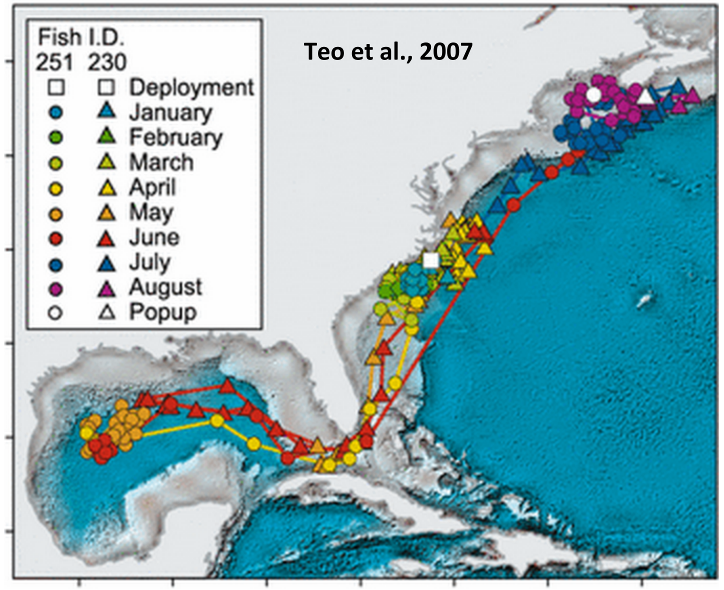
Bluefin tuna and temperature: adults

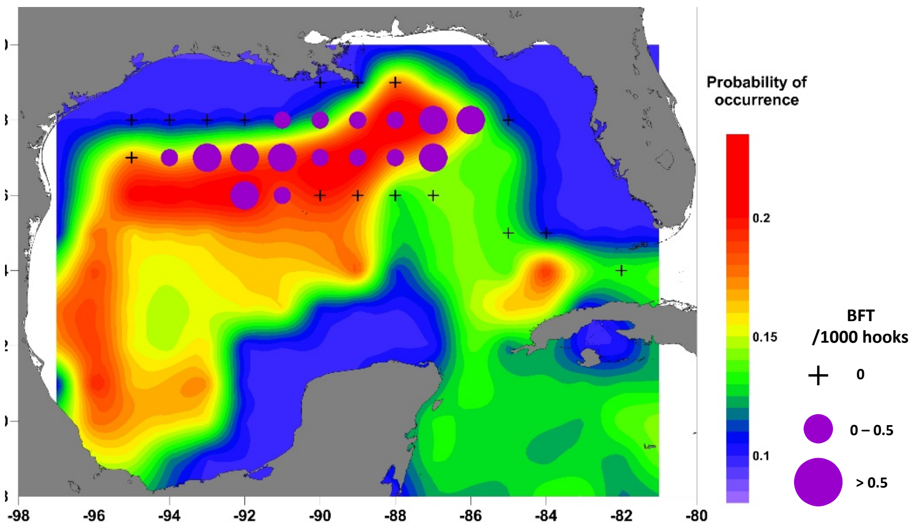
- Adult bluefin have very broad temperature tolerances (~3 – 30°C)
- From ~January – June, they are widely distributed throughout the offshore Gulf of Mexico
- Simple habitat models using temperature and water depth show higher catches over shelf break, and temperature-driven seasonal cycle
- Catches sometimes slightly higher in cooler years, but signal obscured by changes in fishing practices, gears and regulations

Simple habitat model



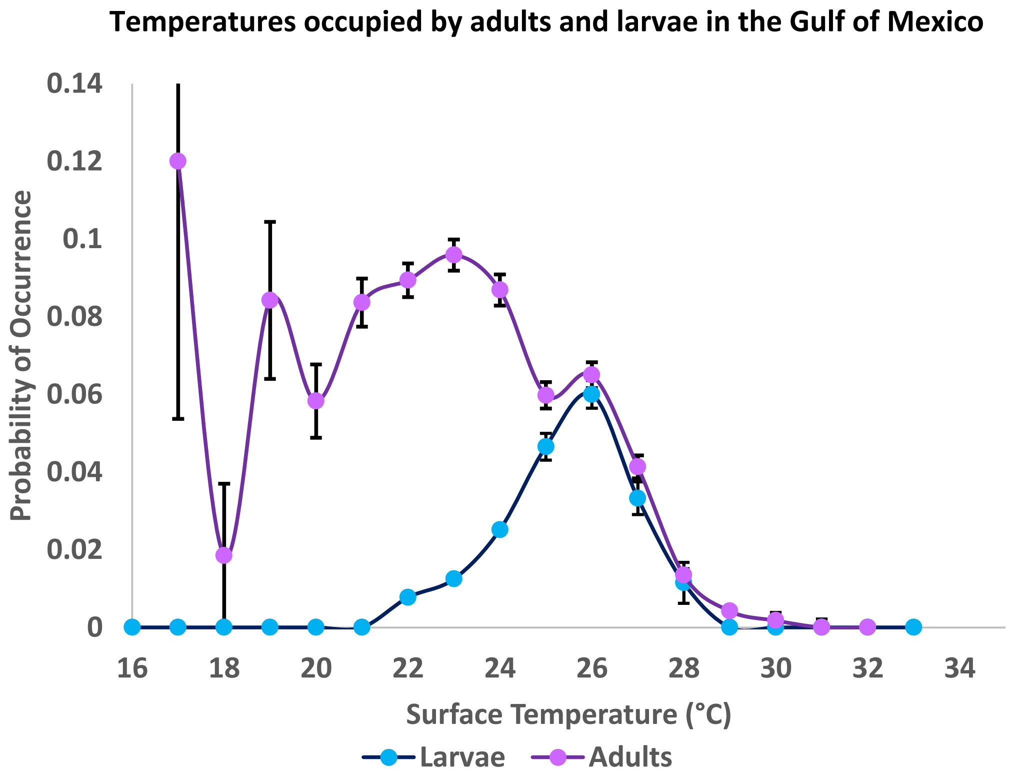


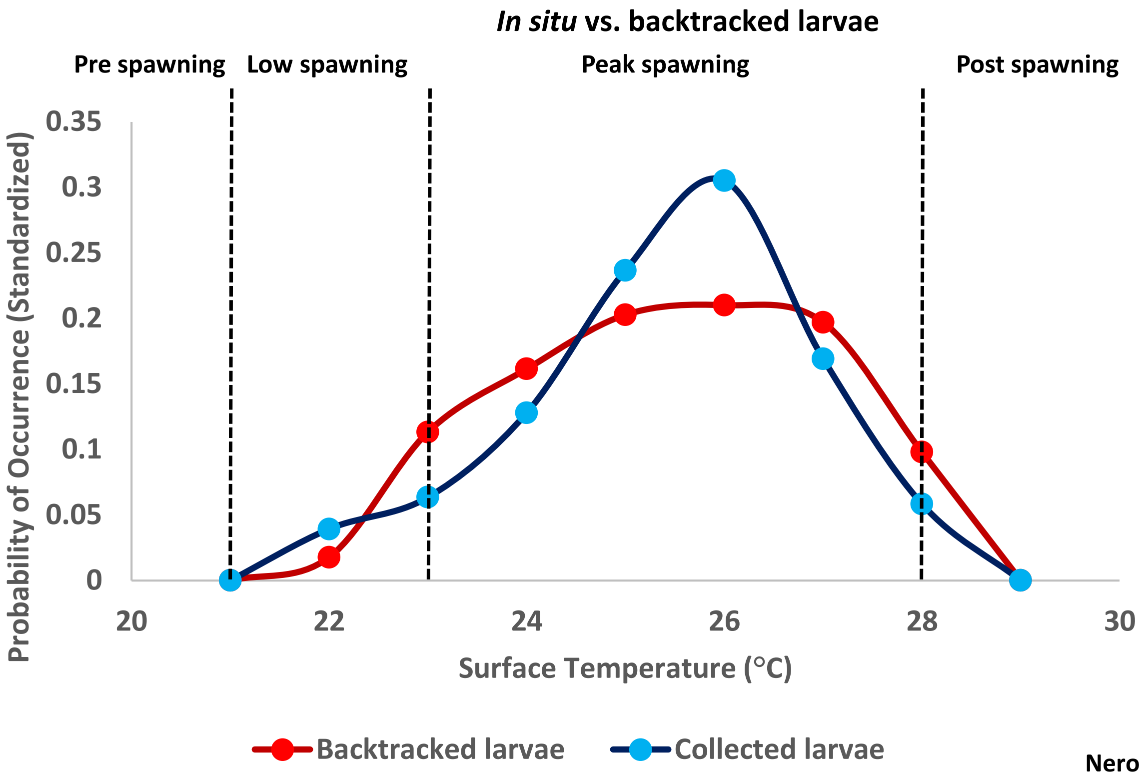
April 2010



Bluefin tuna and temperature: larvae

- Adults are present in the Gulf from winter, and start spawning in spring
- Larvae are most abundant where temperatures are 24 – 28°C, from April – June
  - Relationships better known than for adults: advantages of fishery-independent surveys!
- Backtracking suggests that spawning commences at ~22-23°C, and stops at ~28 – 29°C





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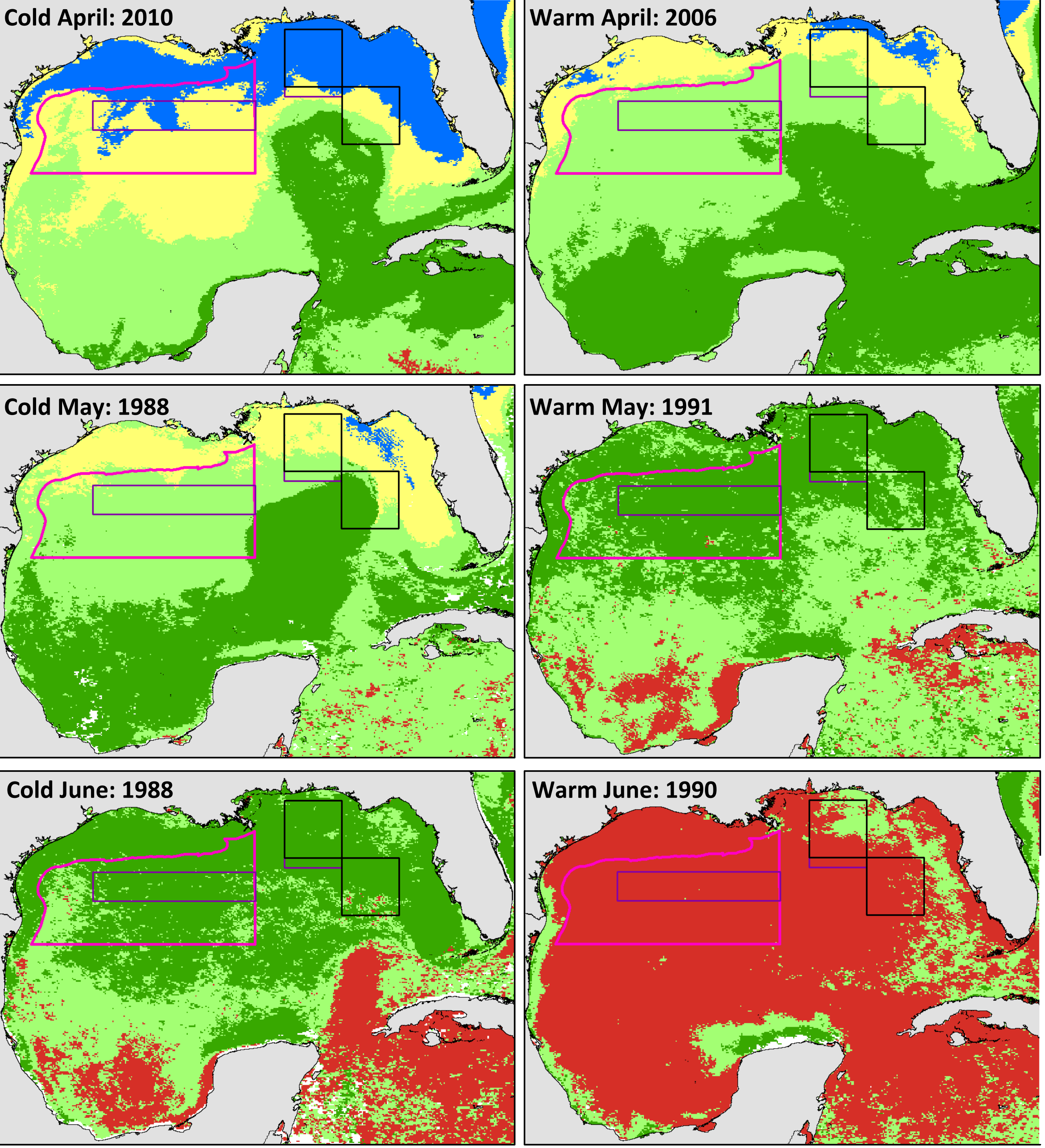
Variability in temperature and spawning activity



- Interannual variability in temperature could drive variability in spawning activity, and thus the effectiveness of closed areas in protecting spawning fish
- The low correlation between early (March – April) and late (May, June) spring temperatures affects spawning season length:
  - Spawning begins later in cool Aprils, and finishes sooner in warm Junes

Temperature and likely spawning activity

- <21°: Pre-spawning
- 21 - 23°: Low spawning
- 23 - 25°: Spawning
- 25 - 27°: Peak spawning
- 27 - 28°: Spawning
- >28°: Post spawning

Management Areas

- Seasonal forecasting area of interest
- New Spring Closed Areas
- DeSoto Canyon Closed Areas

	March	April	May	June	Optimal Closure
1982					April - June
1983					May - June
1984					May - June
1985					**April - May**
1986					**April - May**
1987					May
1988					May - June
1989					April - June
1990					**April - May**
1991					**April - May**
1992					**April - May**
1993					May - June
1994					**April - May**
1995					March - May
1996					May
1997					**April - May**
1998					**April - May**
1999					**April - May**
2000					March - May
2001					March - June
2002					March - June
2003					**April - May**
2004					**April - May**
2005					**April - May**
2006					March - May
2007					April - June
2008					April - June
2009					March - May
2010					May
2011					April - June
2012					March - May
2013					March - May

Implications: Retrospective analysis of closed area effectiveness

- In 12 out of the past 32 years, and April – May closure would have been most effective at protecting spawning bluefin tuna
- Peak spawning (25 – 27°C) usually occurred during May
- In cooler years, a May – June closure would often have been more effective
- The effective length of the spawning season varied:
  - e.g. long season 2001, 2002
  - e.g. short season 1987, 1996, 2010

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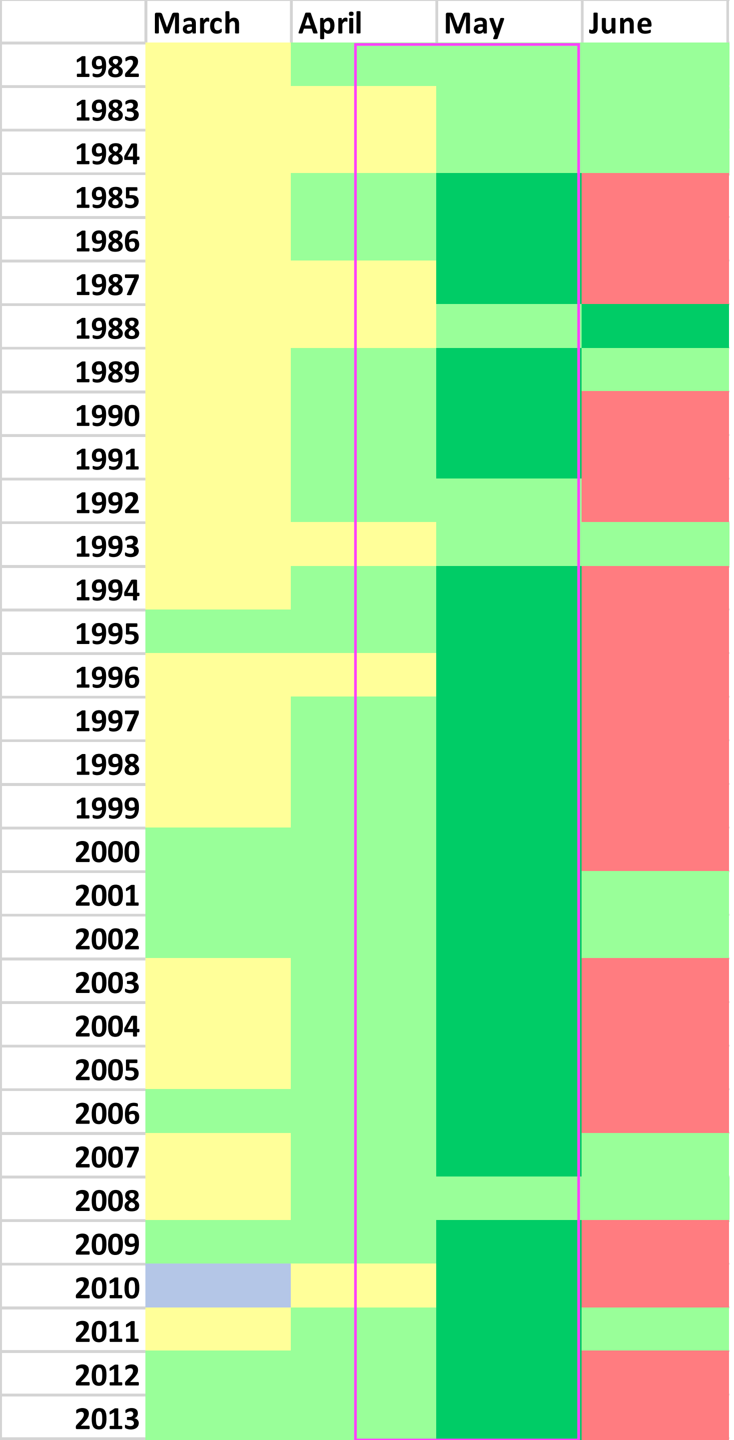

Implications: Effectiveness of the annual larval survey

- Larval abundances from annual shipboard surveys are formulated into an index of spawning stock biomass
  - The only current fishery-independent index for the western stock
- The timing of the survey is largely fixed: mid-April to the end of May
- Temperature variability likely affects the ability of the survey to properly index the stock
  - Good temporal match: 1985, 1986, 1994, 2005
  - Poor temporal match: 1988, 1993, 2008

Temperature and likely spawning activity

- <21°: Pre-spawning
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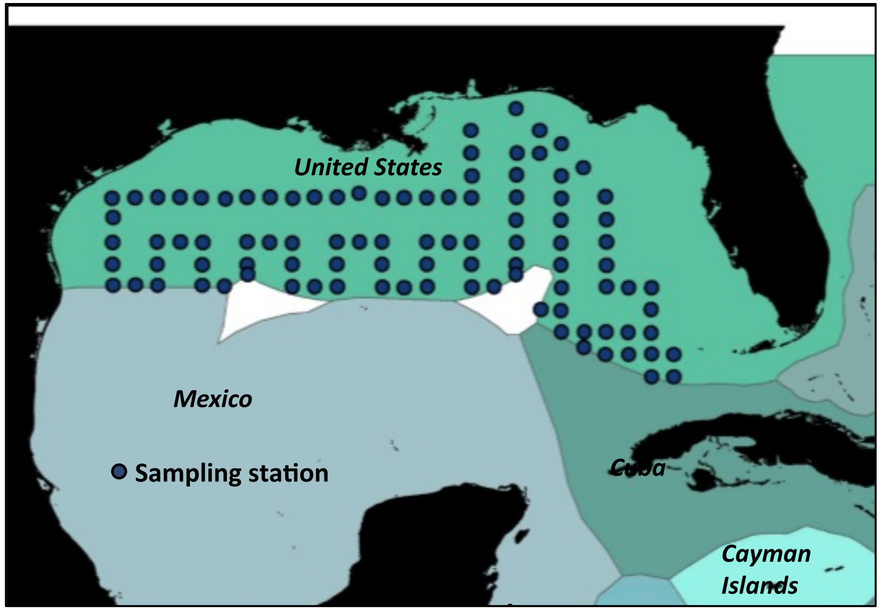
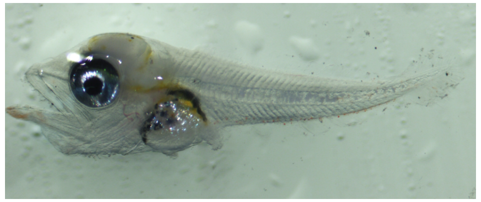
- Larval survey timing

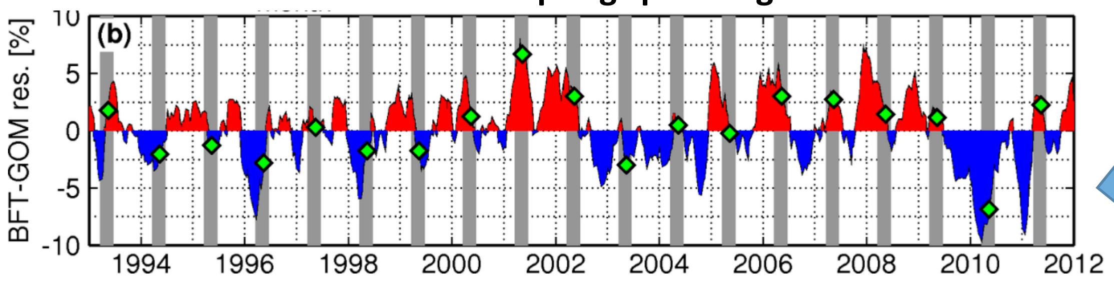




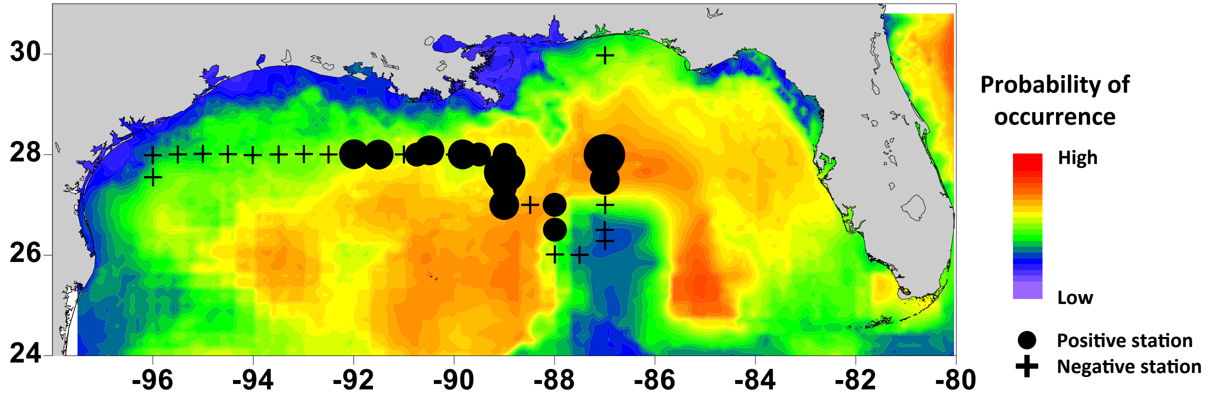
Implications: Spawning season length and recruitment

- A predictive habitat model for larval bluefin tuna distributions has been developed over the past few years (Muhling et al., 2010, 2012)
  - Input variables include temperature, chlorophyll, current magnitude, sea surface height
- Domingues et al. (submitted) extended this approach to look at the spatiotemporal persistence of spawning habitat throughout the spring
- This index was correlated with (model derived) recruitment of age-1 fish
  - i.e. a longer spawning season = more recruits

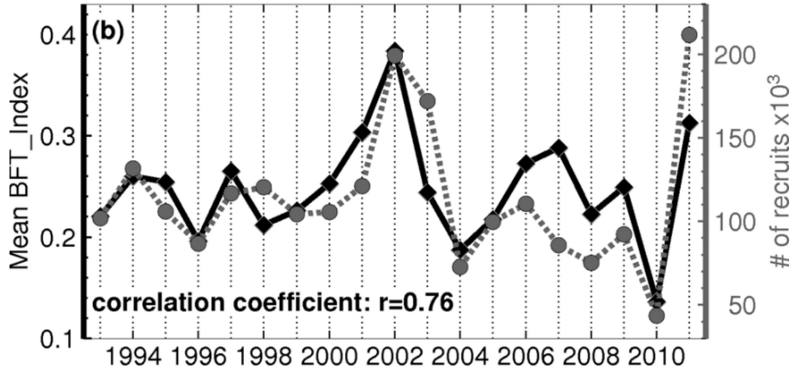
Time series of spring spawning habitat



Larval habitat model: May 2010

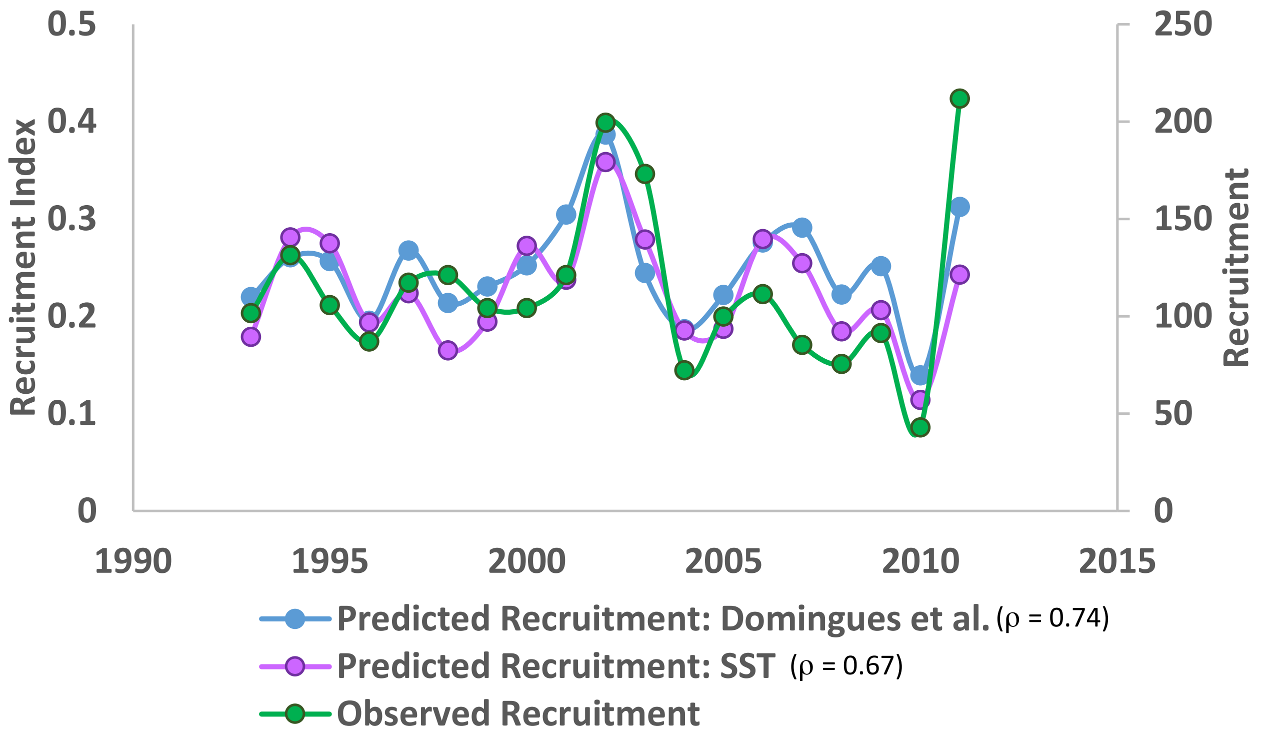


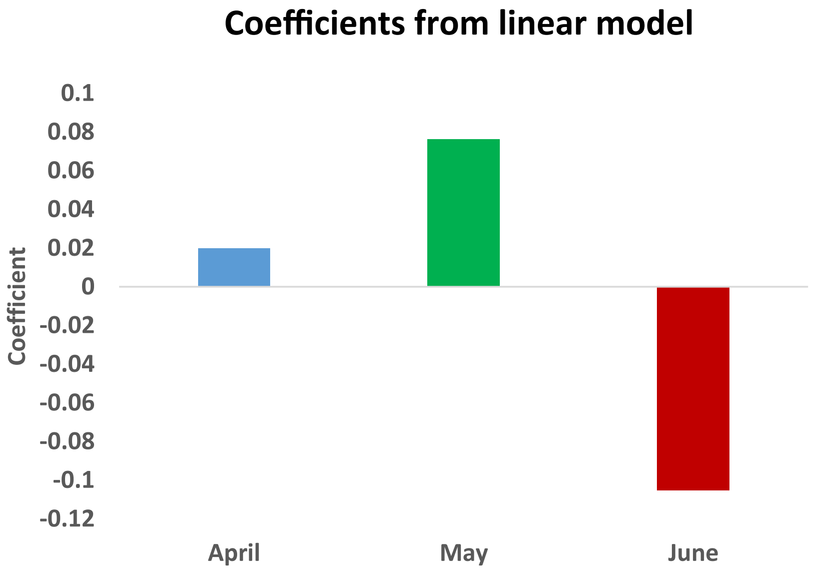
Habitat index vs. recruitment



Spawning season length and recruitment-2

- Interannual variability in spawning season length was largely temperature-driven
- I assessed the ability of monthly temperatures (April – June) to reproduce this time series
- Predictions of recruitment from monthly temperatures only were nearly as good as those from the more complex habitat model ($\rho = 0.74$ vs. $\rho = 0.67$)
- Higher recruitment was associated with warmer April and May, and cooler June
- This raises the possibility of recruitment predictability, and forecasts





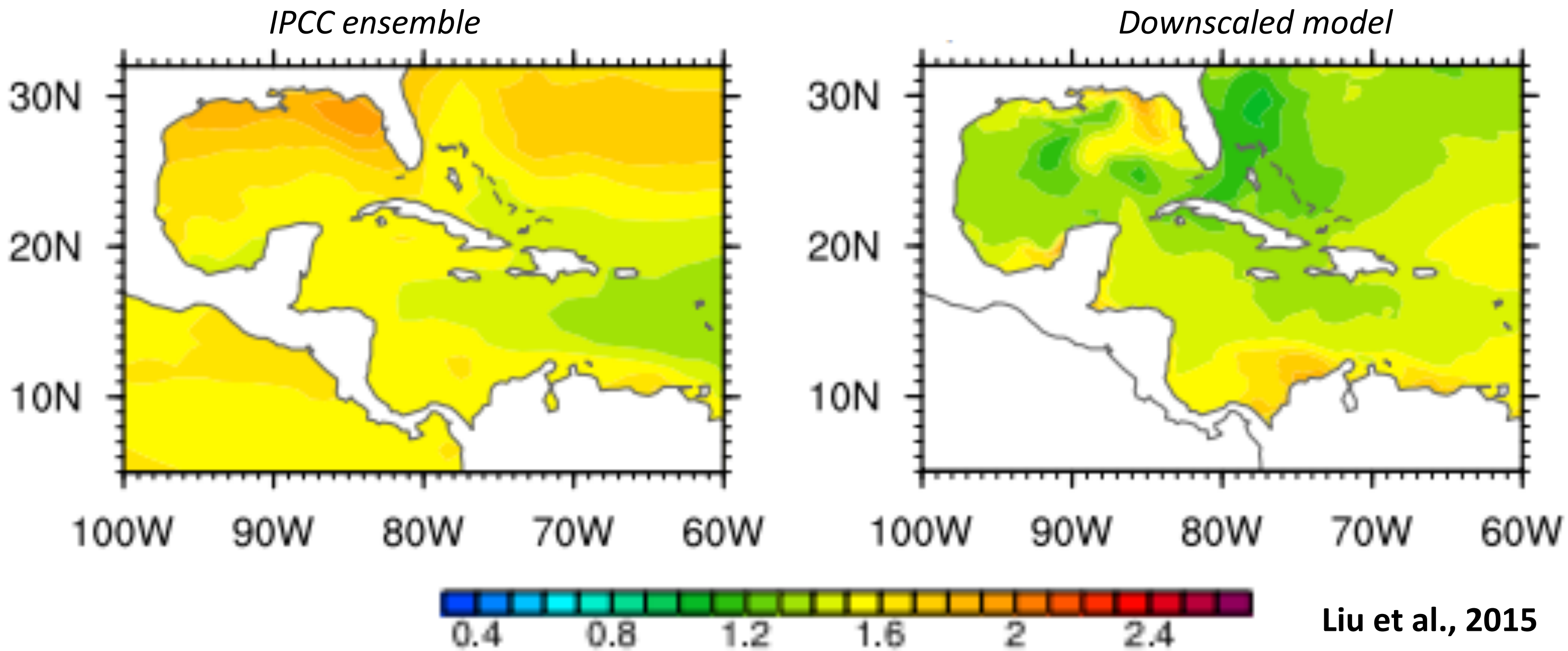
Summary

- Spring surface temperatures in the western Gulf of Mexico are reasonably predictable
- Temperature is primarily important for bluefin tuna in the Gulf through *spawning initiation*
- Interannual variability in temperature drives spawning activity, and thus:
  - Potential effectiveness of closed areas designed to protect spawning fish
  - Potential effectiveness of annual larval surveys in indexing spawning stock biomass
  - Length of the spawning season, and perhaps recruitment

Future directions

- How could seasonal forecasts be useful for management?
  - Closed area effectiveness: is April – May always optimal?
  - Larval surveys: limited ability to change dates, but perhaps spatially. Statistical implications? Links to larval index?
  - Recruitment predictions: if temperature relationships can be verified
- How accurate would forecasts have to be to be useful?
- Temperature and other protected/bycatch species: e.g. marlin
- Is the resolution of the climate model important
  - i.e. would downscaling be helpful?
- Other regions?

Late 21st century spring SST minus late 20th century SST



Liu et al., 2015

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