NASA Biodiversity and Ecological Forecasting Science Team Meeting

Silver Spring, MD May 06, 2016

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- Encore Performance

ROFFER'S OCEAN FISHING FORECASTING SERVICE, INC.

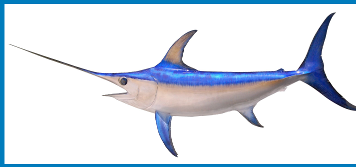
NASA PROJECT HIGHLIGHTS

Management And Conservation Of Atlantic Bluefin Tuna (*Thunnus Thynnus*) And Other Highly Migratory Fish In The Gulf Of Mexico Under IPCC Climate Change Scenarios: A Study Using Regional Climate And Habitat Models.

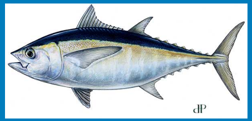
- PI: M. A. Roffer – ROFFS™
- Co-I: J.T. Lamkin (NOAA), F.E. Muller-Karger (USF), S-K Lee (UM CIMAS), B.A. Muhling (UM CIMAS), G.J. Goni (NOAA)
- Other Investigator: Y. Liu (UM CIMAS), M.A. Upton, (ROFFS™) & G. Gawlikowski (ROFFS™), G.W. Ingram (NOAA)
- Other collaborators added: W. Nero (NOAA), J. Franks (USM), J. Quattro (USC)
  D. Enfield (NOAA), John F. Walter (NOAA), A. Bakun (UM RSMAS), K. Ramirez (INAPESCA), F. Alemany (IEO), A. Garcia (IEO) . . and growing
- Start date September 06, 2011 – New End date September 05, 2016

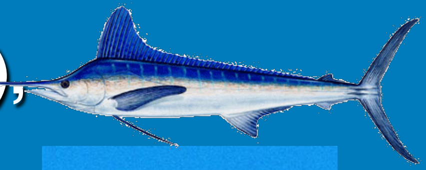
Multi-sector and multi-disciplinary partnership, including government fishery scientists and managers

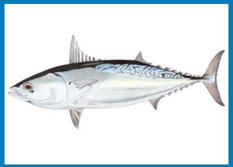
Charismatic Mega Fauna

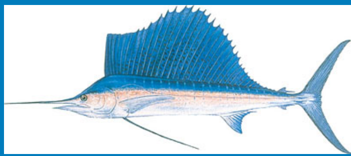


1. Atlantic bluefin tuna (Thunnus thynnus)
2. Atlantic blue marlin (*Makaira nigricans*),
3. Atlantic sailfish (*Istiophorus platypterus*),
4. Atlantic white marlin (*Tetrapturus albidus*),
5. Blackfin tuna (*Thunnus atlanticus*),
6. Bullet mackerel (*Auxis rochei*),
7. Frigate mackerel (*Auxis thazzard*),
8. Longbill spearfish (*Tetrapturus pfluegeri*),
9. Swordfish (*Xiphias gladius*),
10. Yellowfin tuna (*Thunnus albacares*)
11. Skipjack tuna (Katsuwonis pelamis)



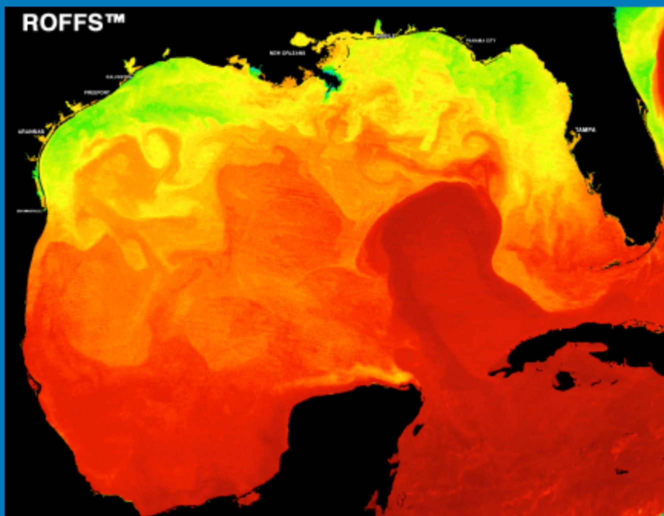






Applications Research: Enhancing Management Gulf of Mexico & North Atlantic Ocean

Larvae and Adults

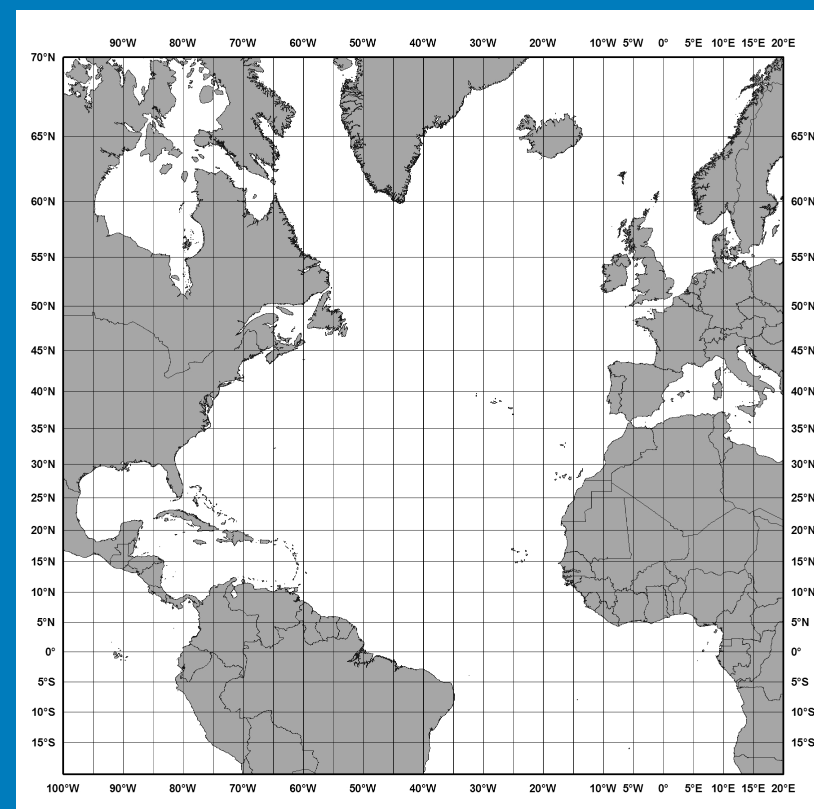


30+ years of NMFS larvae cruise data (larvae, in situ, satellite)

Climate model domain
1000's km

2 m

6 mm



23 years commercial longline data (NOAA + ICCAT)

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Fish Habitat Models + Ocean Circulation Models + Climate change models -> -> ->

-> Ecological Forecasts for Decision Makers

1. To provide reliable tools & forecasts that allow decision makers (NMFS & ICCAT) to evaluate the impacts of climate on ecosystems.
2. To improve skills, share data and applications, and broaden the range of users who apply satellite data and Earth science in ecological forecasting decisions.

Always Thinking Satellite Applications: Fisheries Managers & Effects of Climate Variation on Stock Assessment, Distribution, Recruitment, Catchability, etc.

Everything we do probably has political ramifications due to International management of rebuilding quotas!

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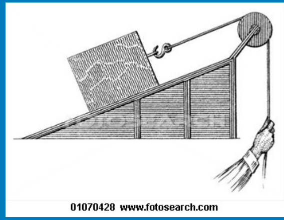
Summary of Methods

1. Developed habitat models of larvae and adults using boosted classification tree and neural network models
   a. Multivariate, non-parametric methods
2. Downscaling climate models for 100 year forecasts
   a. CMIP5 simulations using MOM4 (GFDL Modular Ocean Model) – Grid: 0.1° in GOM, 0.25° outside
   b. Now MOM4/5-TOPAZ biogeochemical model.
      a. 1° x 1° North Atlantic -> 0.08° in GOM, 0.25°
3. Satellite IR, ocean color, (NASA-MODIS, NOAA, JPSS-VIIRS), altimetry
   a. In habitat model development
   b. Provide strategic and tactical cruise work
   c. Climatology of GMex & North Atlantic
   d. Validation of climate models



Newly Published or Found

1. Domingues, R., G. Goni, F. Bringas*, B. Muhling, D. Lindo-Atichati, and J. Walter, 2016: Variability of preferred environmental conditions for Atlantic bluefin tuna (Thunnus thynnus) larvae in the Gulf of Mexico during 1993-2011. Fish. Oceanogr., *25(3):320-336 (doi:10.1111/fog.12152).
2. Muller-Karger F, Smith J, Werner S, Chen R, Roffer M, Liu Y, Muhling B, Lindo-Atichati D, Lamkin J, and Enfield D. 2015. Natural Variability of Surface Oceanographic Conditions in the Offshore Gulf of Mexico. Progress in Oceanography, 134, 54-76.
3. Karnauskas M, Schirripa MJ, Craig JK, Cook GS, Kelble C, Agar J, Black B, Enfield D, Lindo-Atichati D, Muhling BA, Purcell K, Richards P, and Wang C. 2015. Evidence of climate-driven ecosystem reorganization in the Gulf of Mexico. Global Change Biology, 21,2554–2568.
4. Muhling, B.A., Liu, Y., Lee, S-K., Lamkin, J.T., Roffer, M.A., Muller-Karger, F. (2015) Potential impact of global warming on the Intra-Americas Seas: Part 2: Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. Journal of Marine Systems 148: 1-13.
5. Muhling, B.A., Liu, Y., Lee, S-K., Lamkin, J.T., Ingram, W. (2014) Climate change impacts on spawning grounds of Atlantic tunas in the northern Gulf of Mexico. Bulletin of the Japanese Fisheries Research Agency 38: 101-103.
6. Lindo-Atichati D, Bringas F, and Goni G. 2013. Loop Current excursions and ring detachments during 1993-2010. International Journal of Remote Sensing 34(14), 5042-5053.
7. Lindo-Atichati D, Bringas F, Goni G, Muhling B, Muller-Karger FE, and Habtes S. 2012. Variability of mesoscale structures with effects on larval fish distribution in the northern Gulf of Mexico during spring month.Marine Ecology Progress Series 463, 245-257.

Now 20 Peer Reviewed Pubs

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Publish or Perish

1. Liu, Y., S.-K., Lee, D.B. Enfield, B.A. Muhling, J.T. Lamkin, F.E. Muller-Karger, and M.A. Roffer. 2015. Impact of global warming on the Intra-Americas Sea: part-1. A dynamic downscaling of the CMIP5 model projections. J. Mar. Syst. 148:56-69.
2. Muhling, B.A., Y. Liu, S.-K. Lee, J.T. Lamkin, M.A. Roffer, F.E Muller-Karger, and J.F. Walter III. 2015. Potential impact of climate change on the Intra-Americas Sea: Part-2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. J. Mar. Syst. 148: 1-13.
3. Muhling, B.A., P. Reglero, L. Ciannelli, D. Alvarez-Berastegui, F. Alemany, J.T. Lamkin, and M. A. Roffer. 2013. A comparison between environmental characteristics of larval bluefin tuna (Thunnus thynnus) habitat in the Gulf of Mexico and western Mediterranean Sea. Marine Prog. Ser. 486:257-276.
4. Muhling, B.A., M.A. Roffer, J.T. Lamkin, G.W. Ingram, Jr., M.A. Upton, G. Gawlikowski, F.E. Muller-Karger, S. Habtes, and W.J. Richards. 2012. Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bull. 64(4):697-687.
5. Habtes, S., F.E. Muller-Karger, M. A. Roffer, J.T. Lamkin, and B. A. Muhling. 2014 A comparison of sampling methods for larvae of medium and large epipelagic fish species during SEAMAP ichthyoplankton surveys in the Gulf of Mexico. Limnol. Oceanogr.: Methods 12: 86-101.
6. Muhling, B.A., J.T. Lamkin, J.M. Quatro, R.H. Smith, M.A. Roberts, M.A. Roffer, and K. Ramirez. 2011. Collection of Larval Bluefin Tuna (Thunnus thynnus) Outside Documented Western Atlantic Spawning Grounds. Bull. Mar. Sci. Bull. *Mar. Sci.* 87(3):687-694.).
7. Muhling, B.A., J.T. Lamkin, and M.A. Roffer. 2010. Predicting the Occurrence of Bluefin Tuna (*Thunnus thynnus*) Larvae in the Northern Gulf of Mexico: Building a Classification Model from Archival ta. Fish. Oceanogr. 19:6, 526-539.

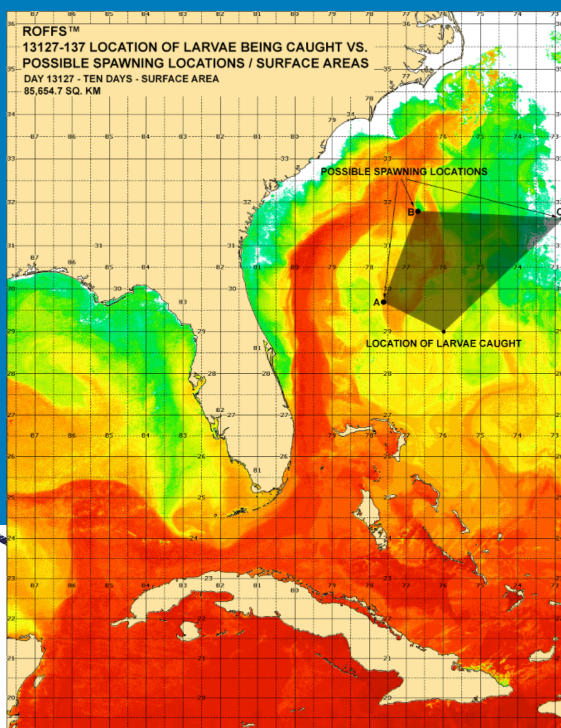
Publish or Perish

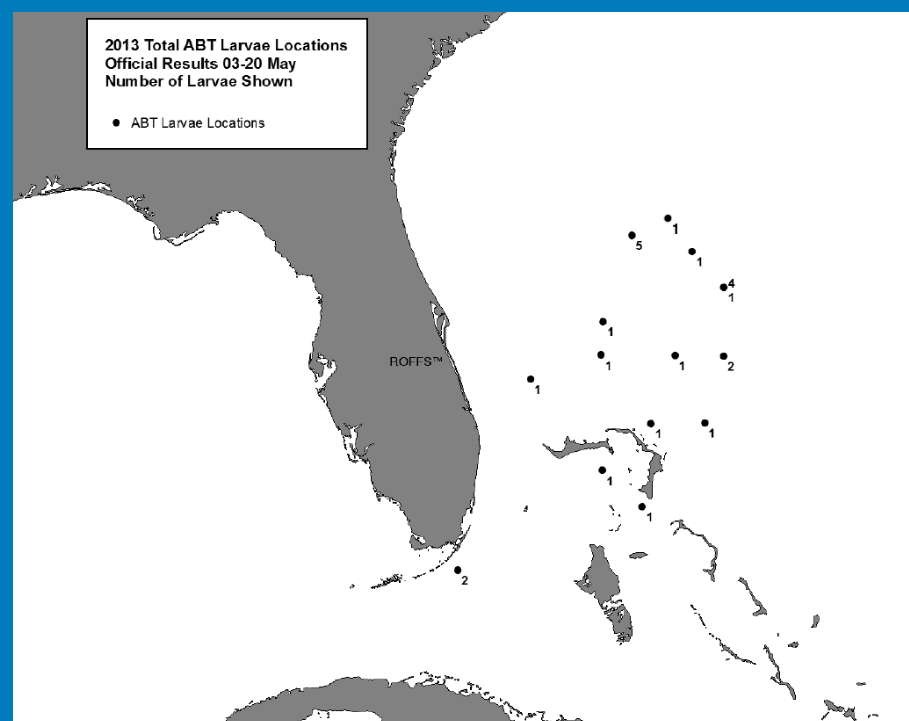
1. Muhling, B.A., Lee, S-K, Lamkin, J.T. (2011) Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. *ICES Journal of Marine Science* 68: 1051-1062.
2. Muhling, B.A., Roffer, M.A., Lamkin, J.T., Ingram, G.W. Jr., Upton, M.A., Gawlikowski, G., Muller-Karger, F., Habtes, S., Richards, W.J. (2012) Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bulletin, doi:10.1016/j.marpolbul. 2012.01.034.
3. Liu Y., S.-K. Lee, B. A. Muhling, J. T. Lamkin and D.B. Enfield, 2012: Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. J. Geophys. Res., 117, C05039, doi:10.1029/2011JC007555
4. Muhling, B.A., P. Reglero, L. Ciannelli, D. Alvarez-Berastegui, F. Alemany, J.T. Lamkin, and M. A. Roffer. 2013. A comparison between environmental characteristics of larval bluefin tuna (Thunnus thynnus) habitat in the Gulf of Mexico and western Mediterranean Sea. Marine Prog. Ser. 486:257-276.
5. Muller-Karger, F.; Roffer, M.; Walker, N.; Oliver, M.; Schofield, O.; Abbott, M.; Graber, H.; Leben, R.; Goni, G., 2013. "Satellite Remote Sensing in Support of an Integrated Ocean Observing System," Geoscience and Remote Sensing Magazine, IEEE , 1 (4): 8-18, 2013 doi: 10.1109/MGRS.2013.2289656
6. Hooidonk, R.V., J.A. Maynard, Y. Liu, and S.K. Lee. 2015. Downscaled projections of Caribbean coral bleaching than can inform conservation planning. Global Change Biol. Doi: 10.1111/gcb.12901

Still Working on: Are Bluefin Spawning Outside the Gulf of Mexico

YES bluefin tuna ARE spawning in Bahamas and north (east of northern South Carolina) and south of the Yucatan. But we do not see good habitat conditions every year derived from our habitat models

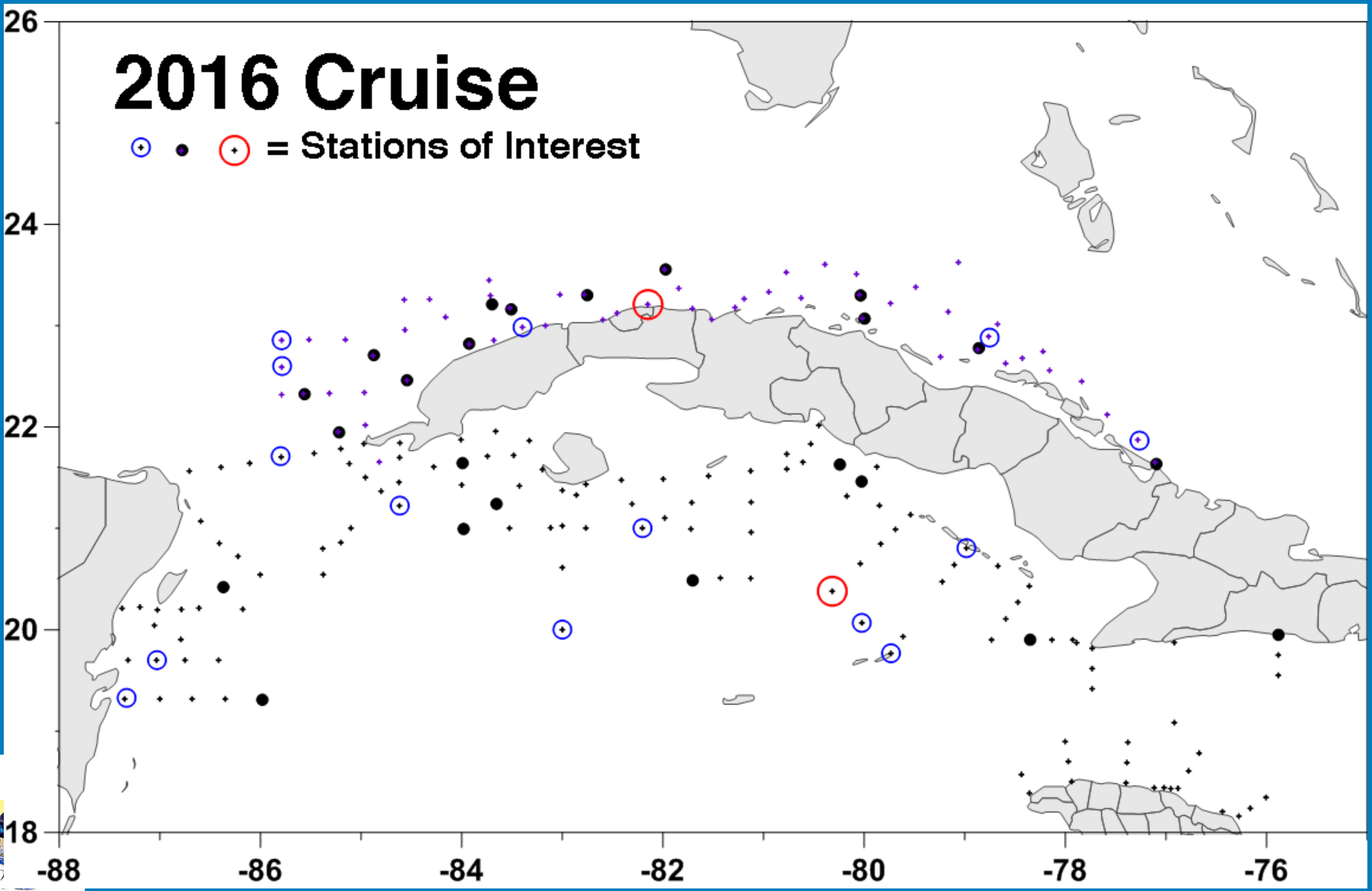
Need for repeat and routine sampling due to 2013 results.





May 2015 Cruise

First U.S. involved research since 1950's
Researchers from U.S., Cuba, Mexico, Spain, Jamaica



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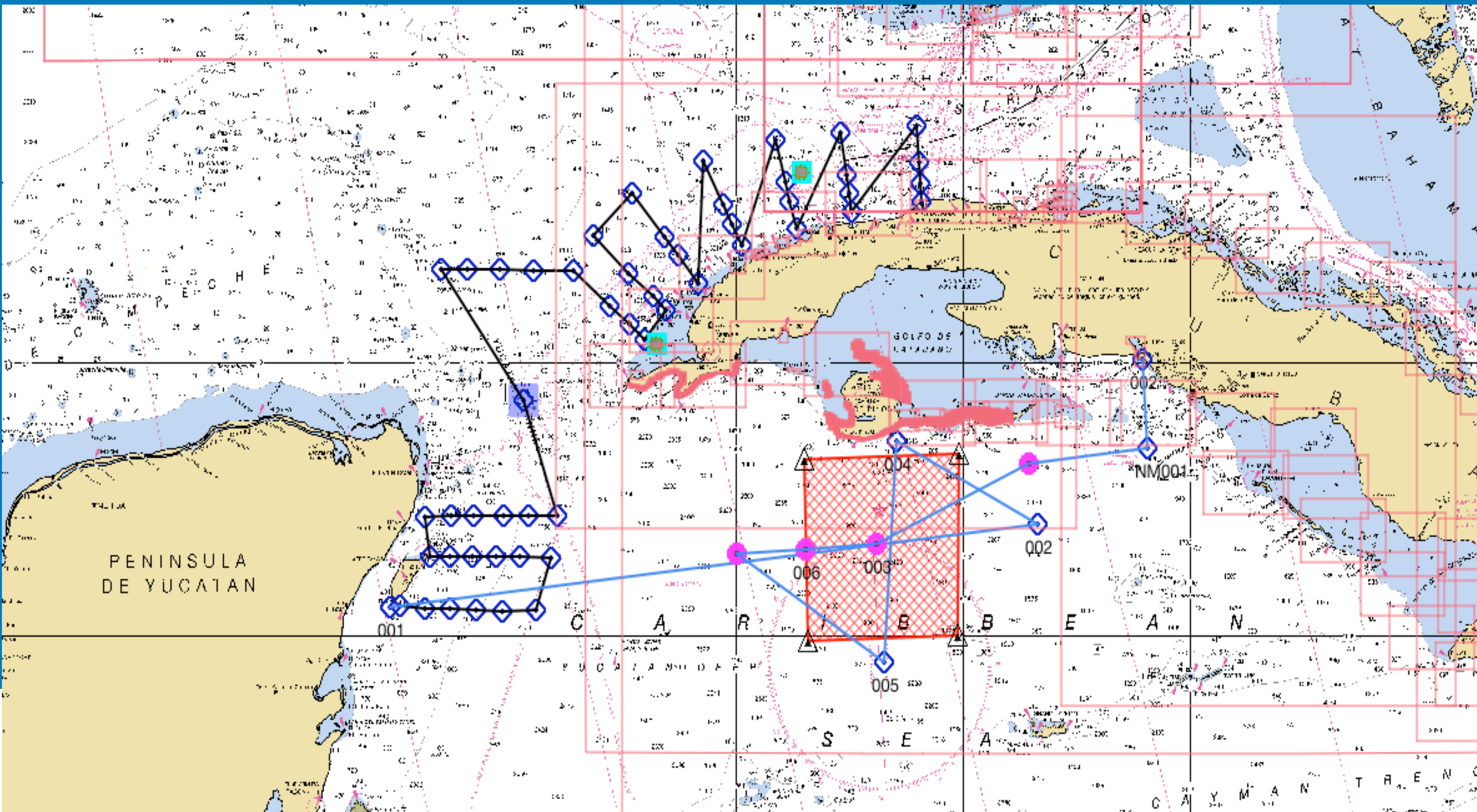
2016 Cruise

Researchers from U.S., Cuba, Mexico, Spain, & Japan



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Biodiversity Relevance

- How do species survive over millennia when habitats change?
- Will the Gulf of Mexico population become extinct due to reproductive failure?
- Will population just move to Bahamas or other new favorable habitat to spawn?
  - Aspects of serial spawning appear important
- How much of the population will be lost?
  - How do you manage this under rapid and "gradual" change?
    - Answer: remote sensing & habitat modeling to evaluate

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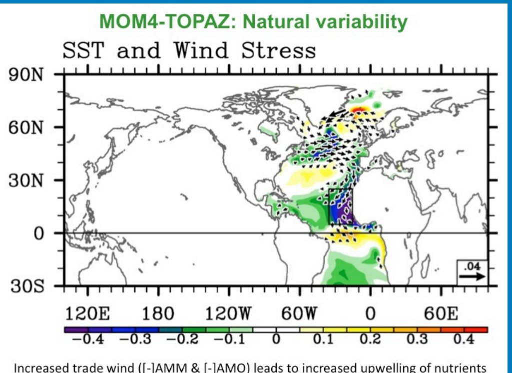
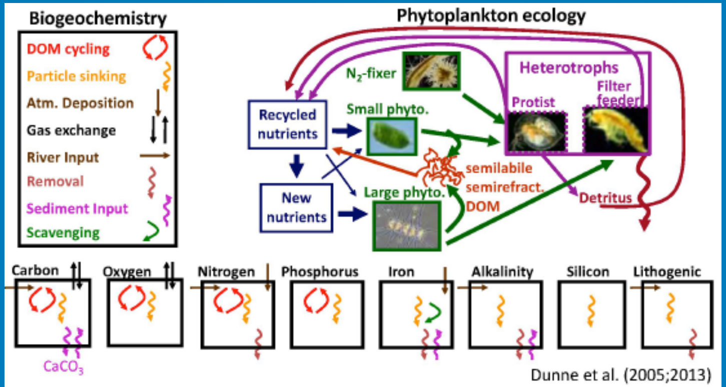
Methods: MOM-TOPAZ

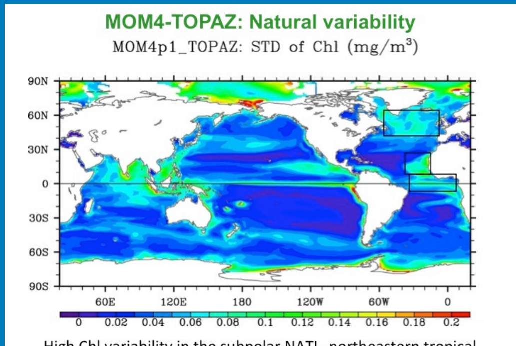
- Yanyun Liu and Sang-Ki Lee (Univ. Miami CIMAS – NOAA_AOML)
- MOM4.1 with TOPAZ biogeochemical model
- Temperature and salinity fields initialized from WOA, integrated for 500 years using CORE2 surface flux fields.
- After 500 years of spin-up, integrated for 1948-2009 using real-time surface flux fields.
- Environmental variables output at 1°x1° resolution by year and season:
  - Surface temperature
  - Temperature at 100m depth
    - Used to calc. temp. difference between surface and 100m
  - Current magnitude (m/s)
  - Oxygen at 100m depth (mg/L)
  - Surface chlorophyll (mg/m^3)
- We chose variables shown previously to be important to the physiology and habitat preference of our HMS pelagic fishes
- Downscaling to 0.08° in GOM. Model domain (100ºW-60ºW, 10ºN-45ºN).



Increased trade wind ([-]AMM & [-]AMO) leads to increased upwelling of nutrients

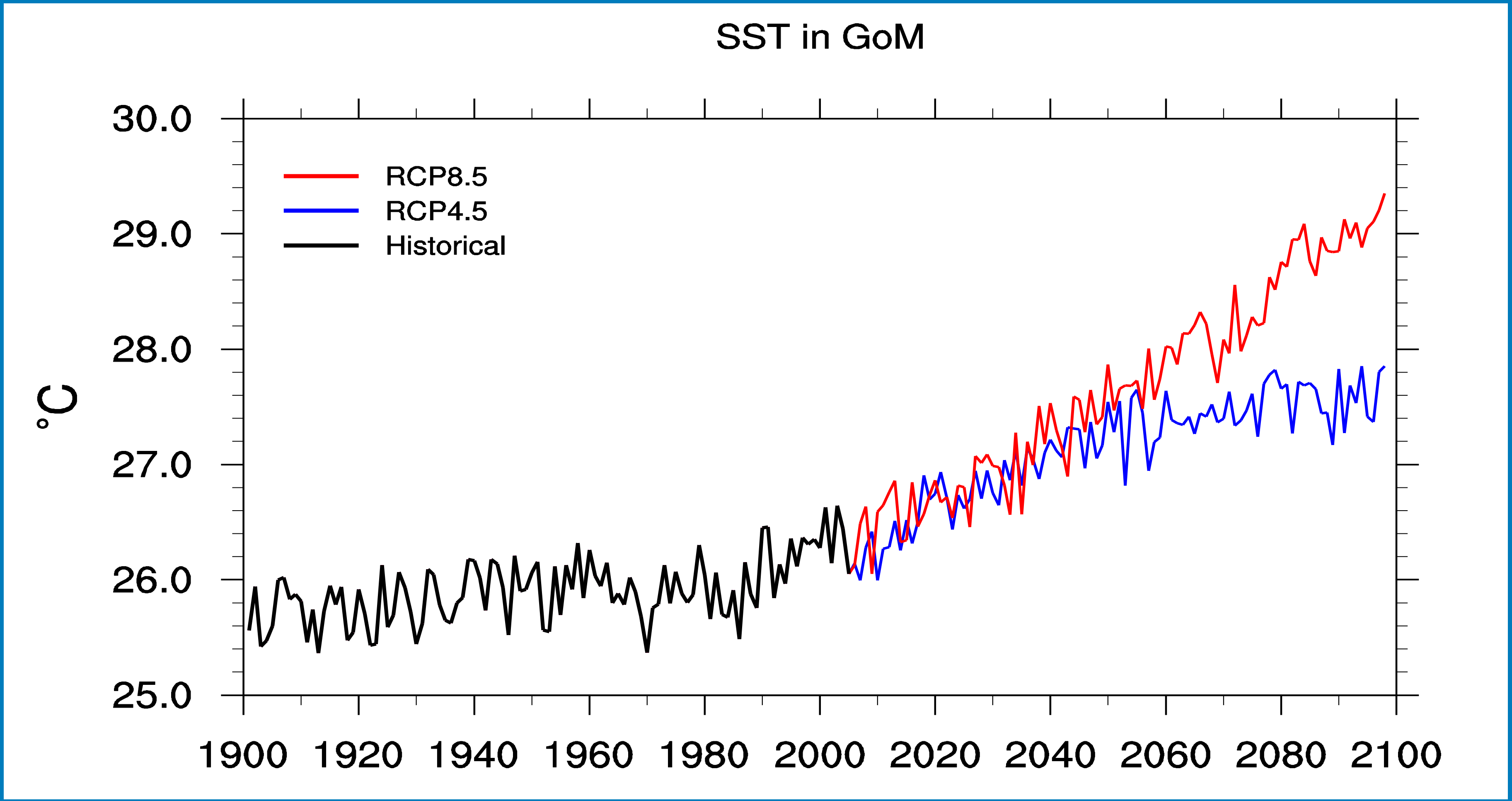


Dunne et al. (2005;2013)



High Chl variability in the subpolar NATL, northeastern tropical ATL, and equatorial ATL.

SST in GoM (Downscaled MOM4)



SST increase under RCP4.5: ~1.5˚C.
SST increase under RCP8.5: ~3.0˚C.

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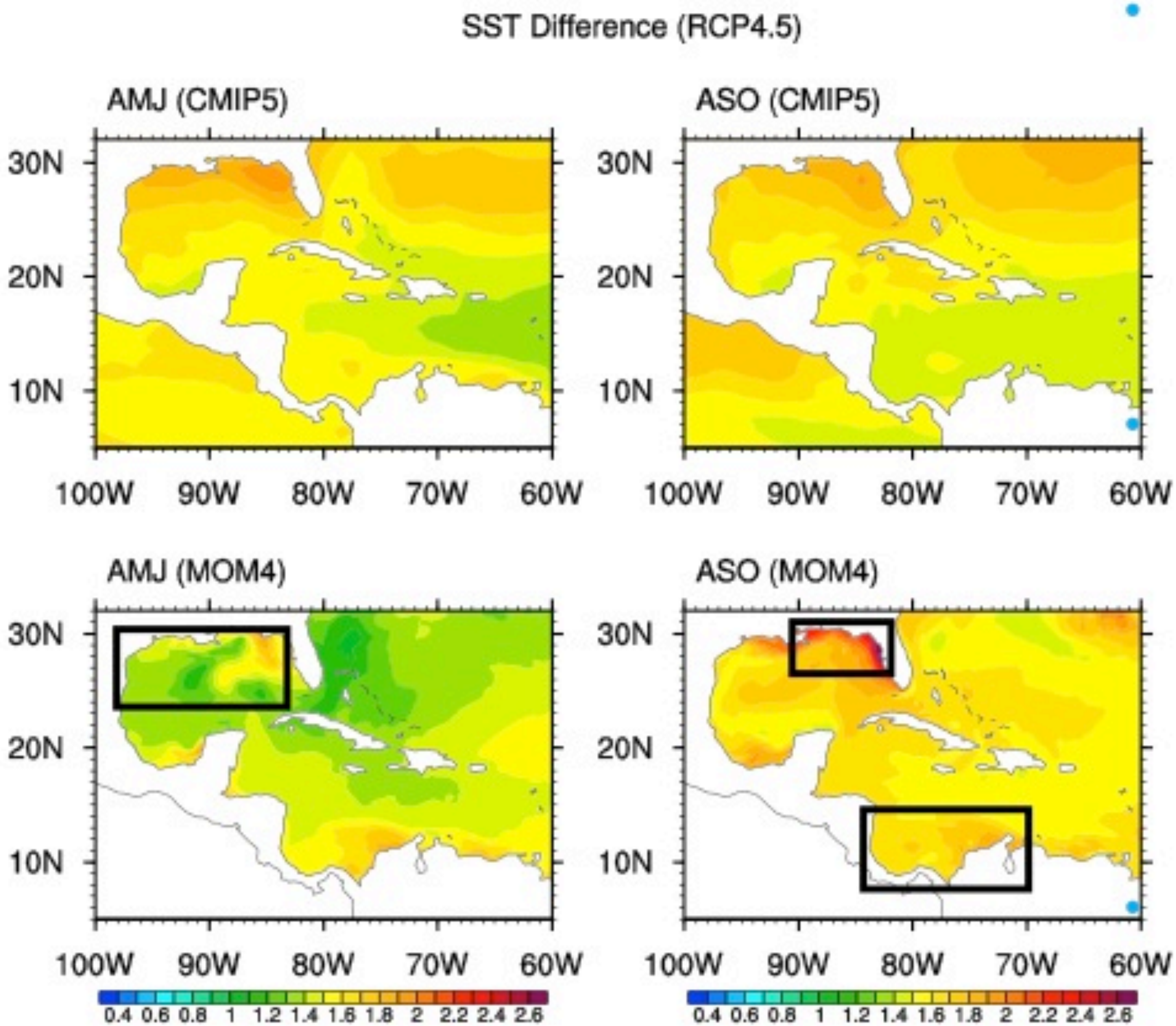
SST difference (late 21C- 20C, RCP4.5)



- Reduced warming in northern GoM in AMJ will mitigate reduction of BFT spawning ground.
- Increased warming along northeastern Gulf shelf & CBN in ASO have a great impact for hurricane activity.
- Increased warming in CBN can cause more coral bleaching events.

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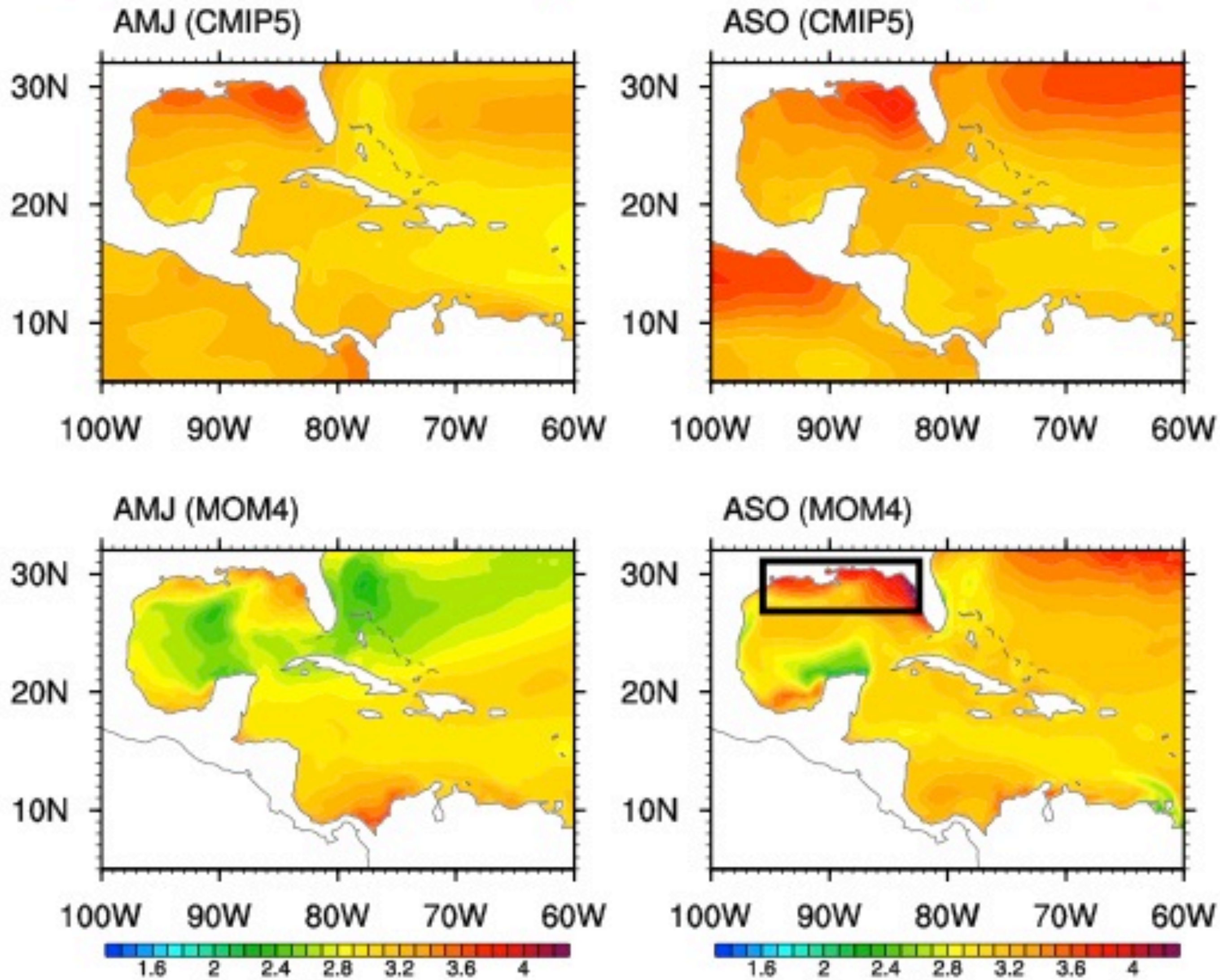
SST difference (late 21C-20C, RCP8.5)

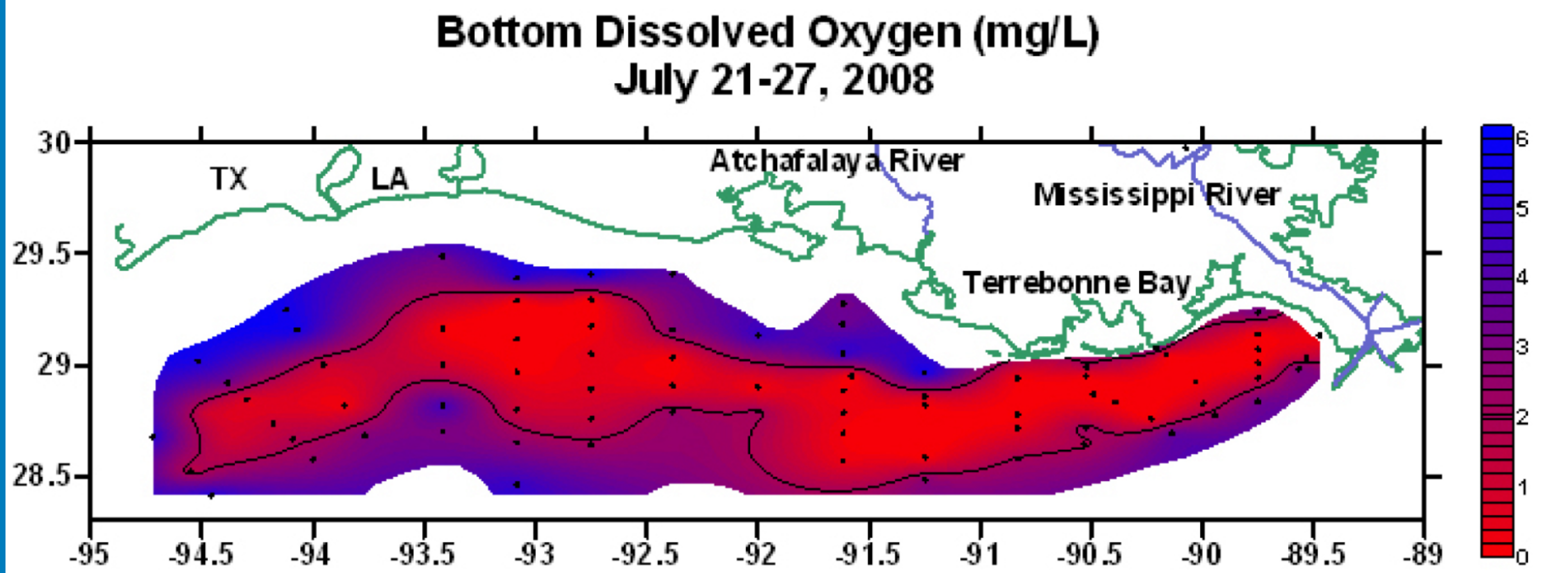


Offshore habitats impacted

Due to the shallow depth (<200m) and the isolation from the deeper GoM, the increased surface heating cannot be dissipated by vertical mixing or by horizontal advection of the relatively cooler interior ocean.

Lee & Liu

Oxygen Loss Another Issue



Map of bottom water oxygen levels in mg/L (or ppm). Black line is less than 2 = Hypoxia. Data source: N. Rabalais, Louisiana Universities Marine Consortium, map by B. Babin.

Modeling this in progress

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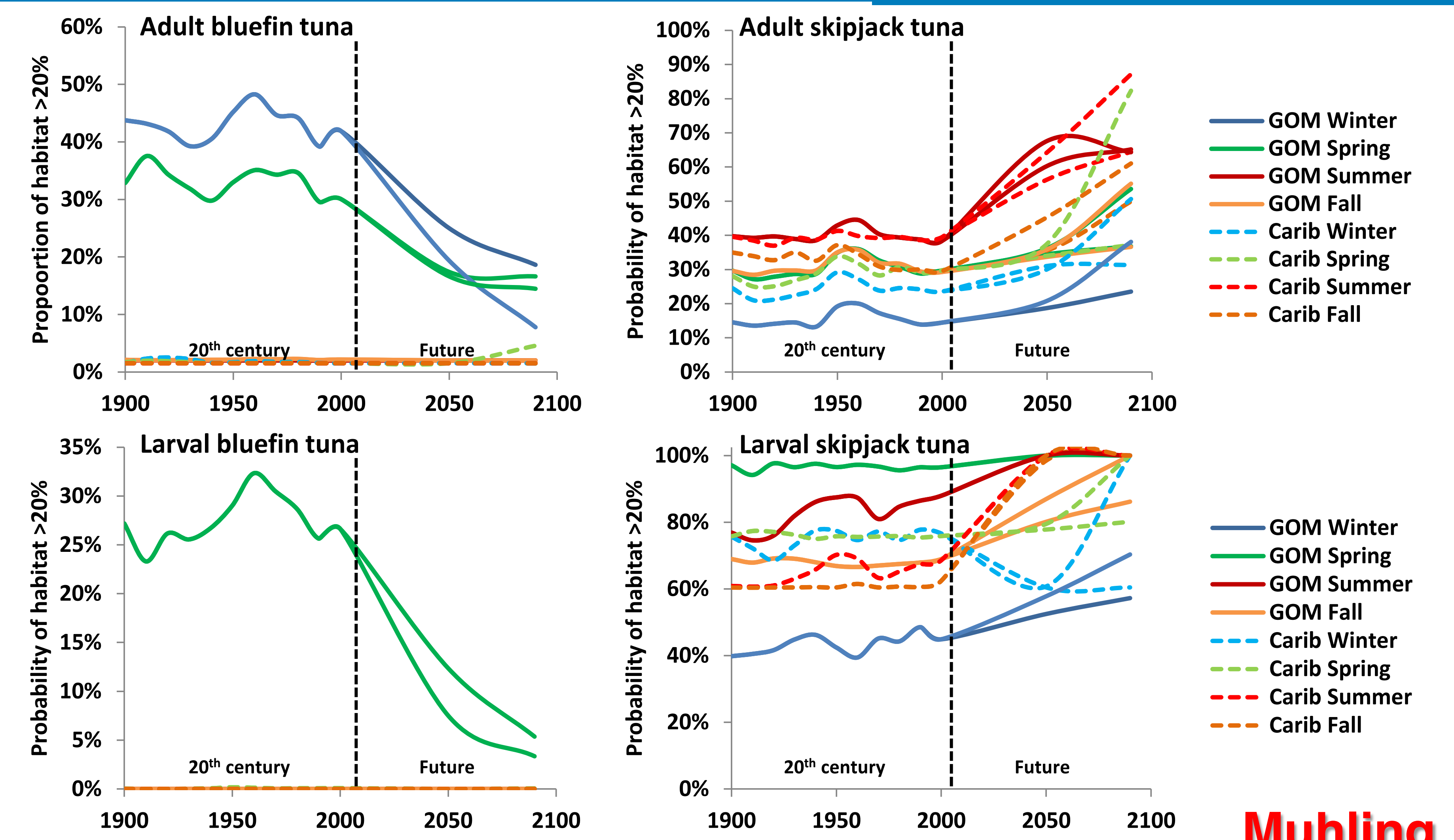
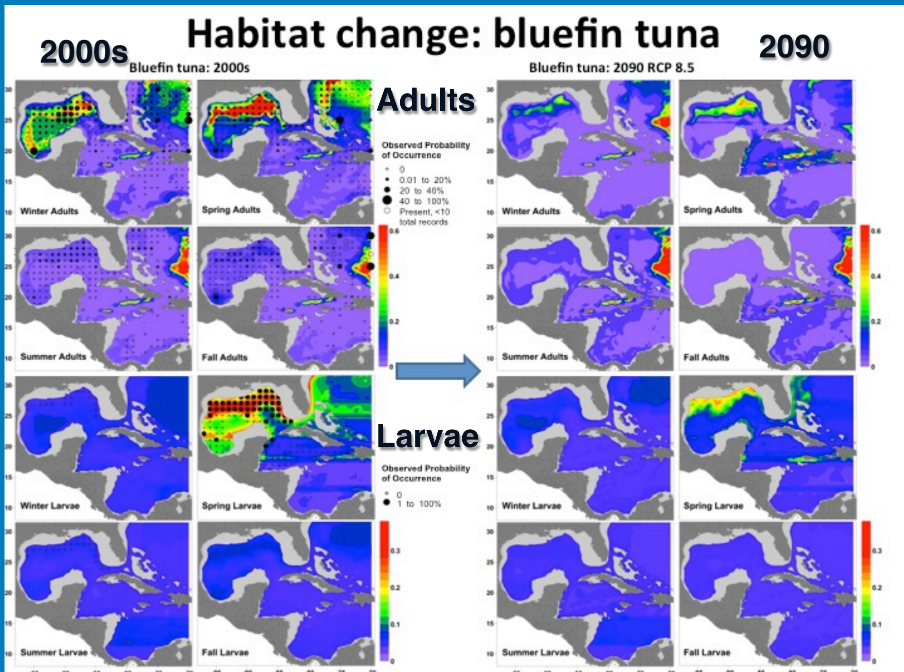
Future Climate on Bluefin and Skipjack Tuna

Adult and larval habitats in GOM & Caribbean Sea



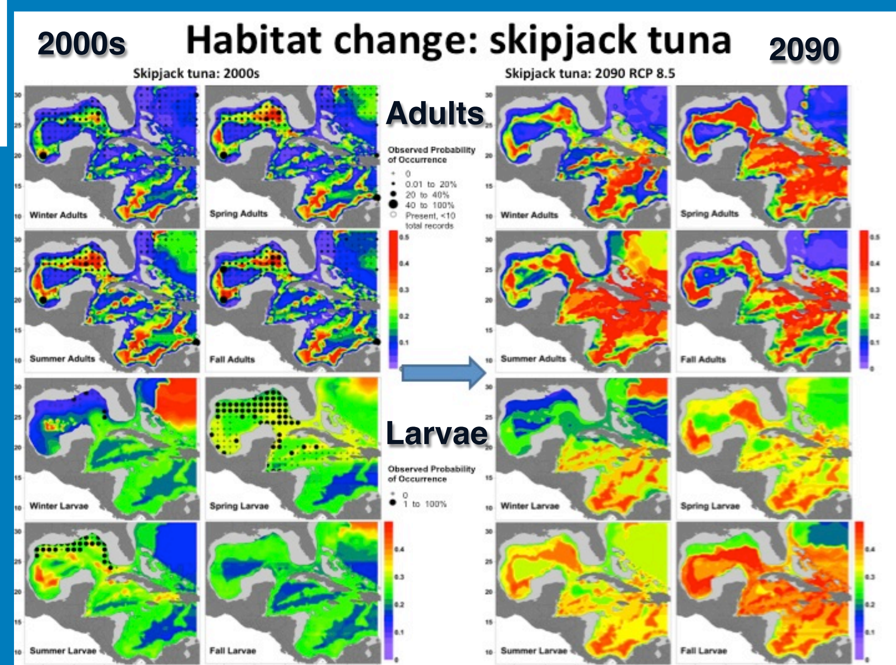
Muhling

Climate Change & HMS



Some losers

Some winners



Muhling et al.,

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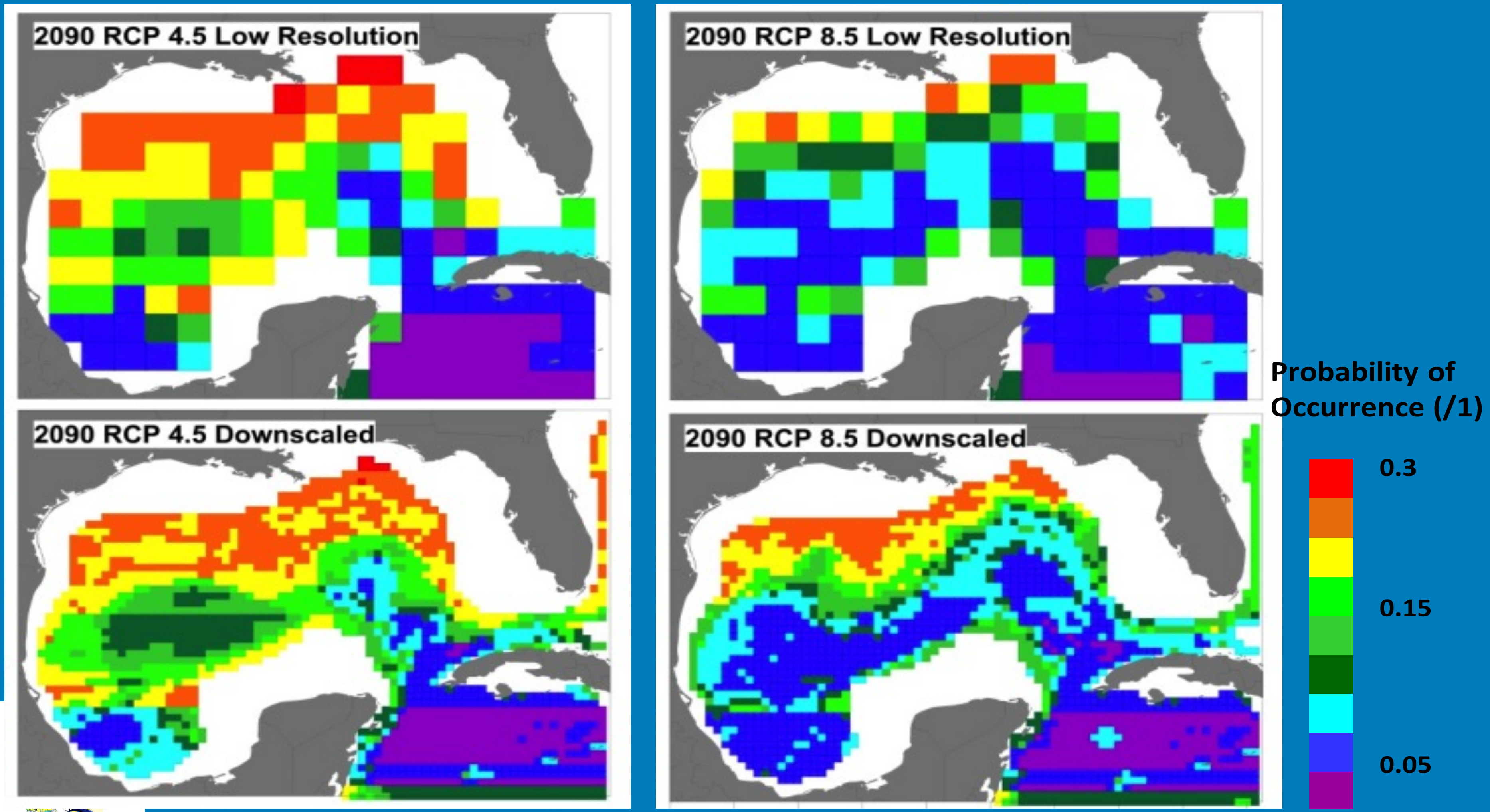
Resolution Issues

Bluefin Tuna Larval Habitat: End of 21st Century

We Used Downscaled



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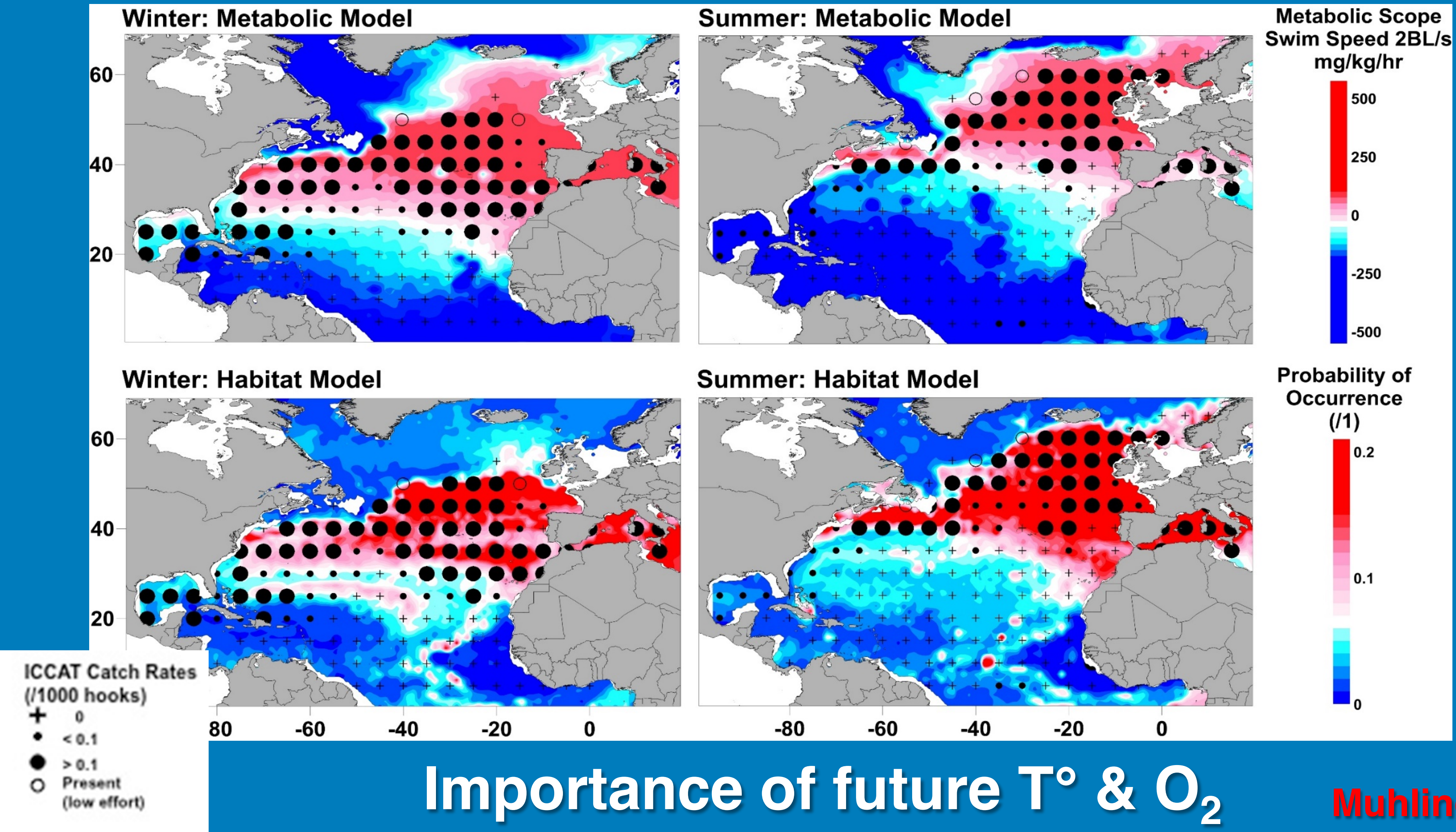
Predicting Adult Bluefin Distributions

Two different model approaches under evaluation

- Mechanistic metabolic scope model -> captive tuna (0_2)
- Correlative habitat model using catch locations

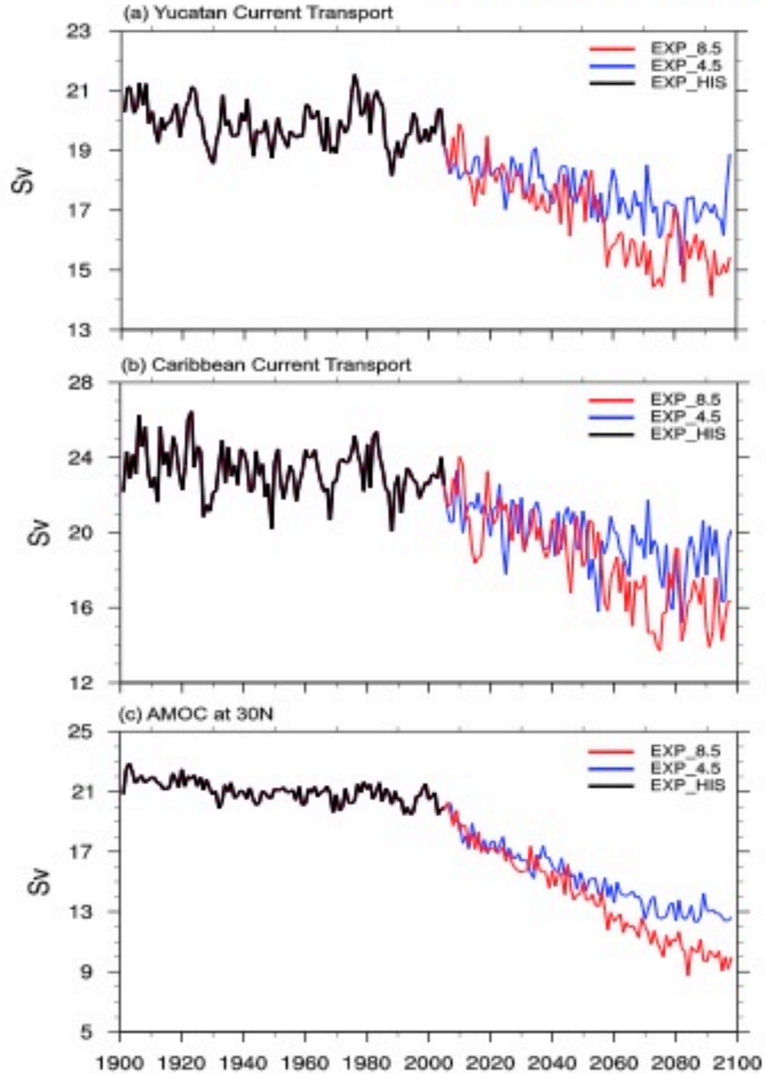


Importance of future T° & O_2

Muhling +

Other Climate Modeling

YC/CC transport & AMOC



- YC/CC transport will be significantly reduced during 21st century (under RCP4.5/ RCP8.5 scenarios), which is consistent with the slowing down of the AMOC.

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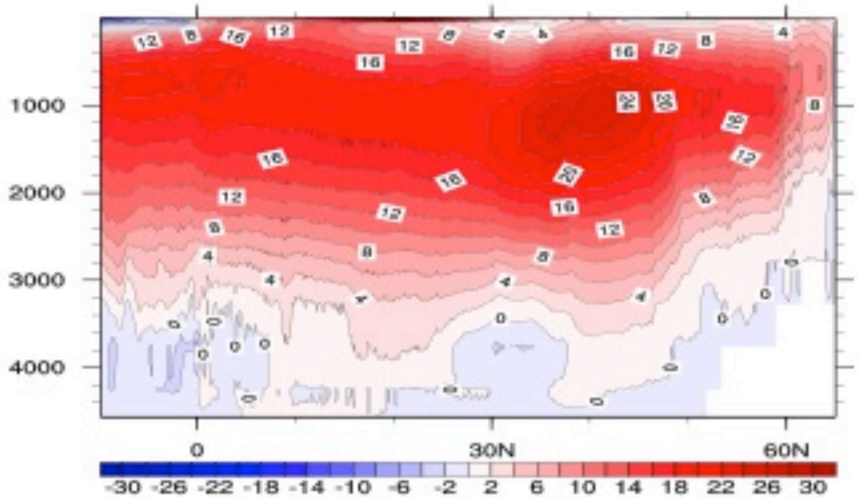
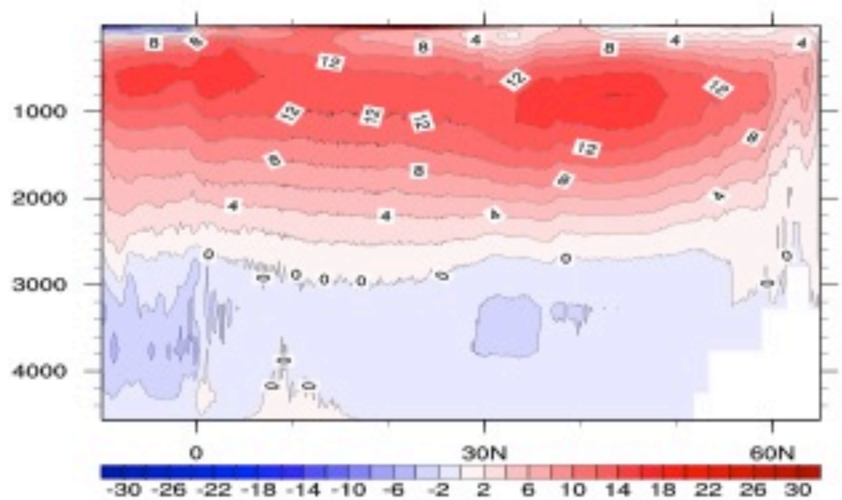
Atlantic Meridional Overturning Circulation (AMOC)

Historical (Late 20C)

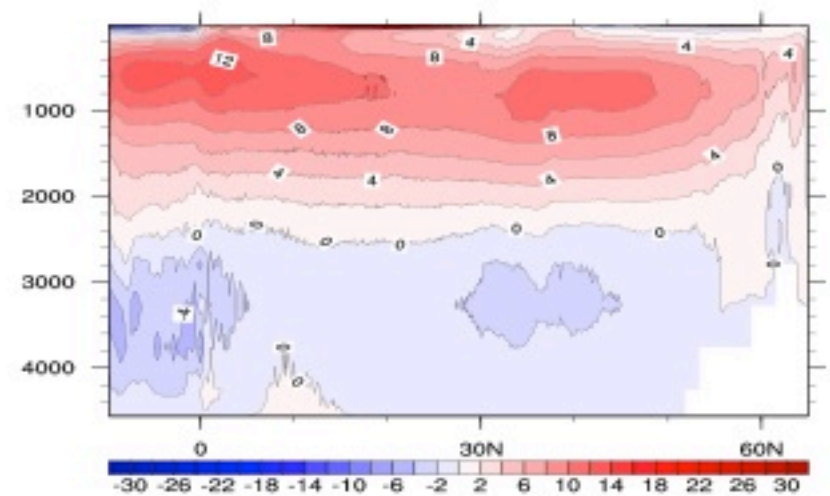


- Reduction of YC transport is consistent with the slowing down of AMOC.

RCP4.5 (Late 21C)



RCP8.5 (Late 21C)



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Always Thinking About Transition & Outreach !

Our partners at NOAA are routinely using satellite data and habitat modeling for their research and management decisions. Contributed $400K per year ship time +

Others in and outside of NOAA are using this too.

New Ecosystem Advisory: Environment + Vulnerabilities

Transition and Outreach

Expanded Our Research

+ International collaborations
  1° Mexico and Spain; 2° Japan, Jamaica, Cuba*
+ Found other spawning areas not previously reported
+ Use of genetics for egg and larvae ID
+ Evaluation of circulation models for climate work
+ Expanded to other resources (reef fish, tarpon, bonefish, coral)
+ Expanded to other ecosystem issues
  - Issues related to larval survival & recruitment
    - Food, growth and age issues -> revised growth curve
  - Oil impacts (British Petroleum Deepwater Horizon)
  - Metabolic models*
  - Climate change workshop*
    - Ecosystem Advisory*

* New 2015-2016

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Climate Variability and Fisheries Workshop: Setting Research Priorities for the Gulf of Mexico, South Atlantic, and Caribbean Regions.

St. Petersburg, FL Oct. 26-28, 2016

- Academic, government and industry researchers, including fisheries resource managers, economists, social scientists, fishing industry representatives and non-governmental organizations.
- Predominately from the three US fishery management regions and the NOAA National Marine Fisheries Service (NMFS).

www.secoora.org/fishclimateworkshop

Objectives (See Poster)

1) Share the state-of-the-science and examples of apparent climate change and its potential impacts on fisheries resources (all relevant species and habitat in the broadest sense including protected resources such as marine mammals, turtles, and corals) in each region;

2) Discuss how climate variability may impact fish distribution, catch, socioeconomics, and management;

3) Identify and prioritize research and monitoring needs related to climate variability and fisheries for each region;

4) Consider needs common to all regions, and discuss strategies for applied, collaborative research across geographies and disciplines;

5) Learn from others working on the links between fisheries and climate in other regions; and

6) Identify opportunities for addressing priority needs

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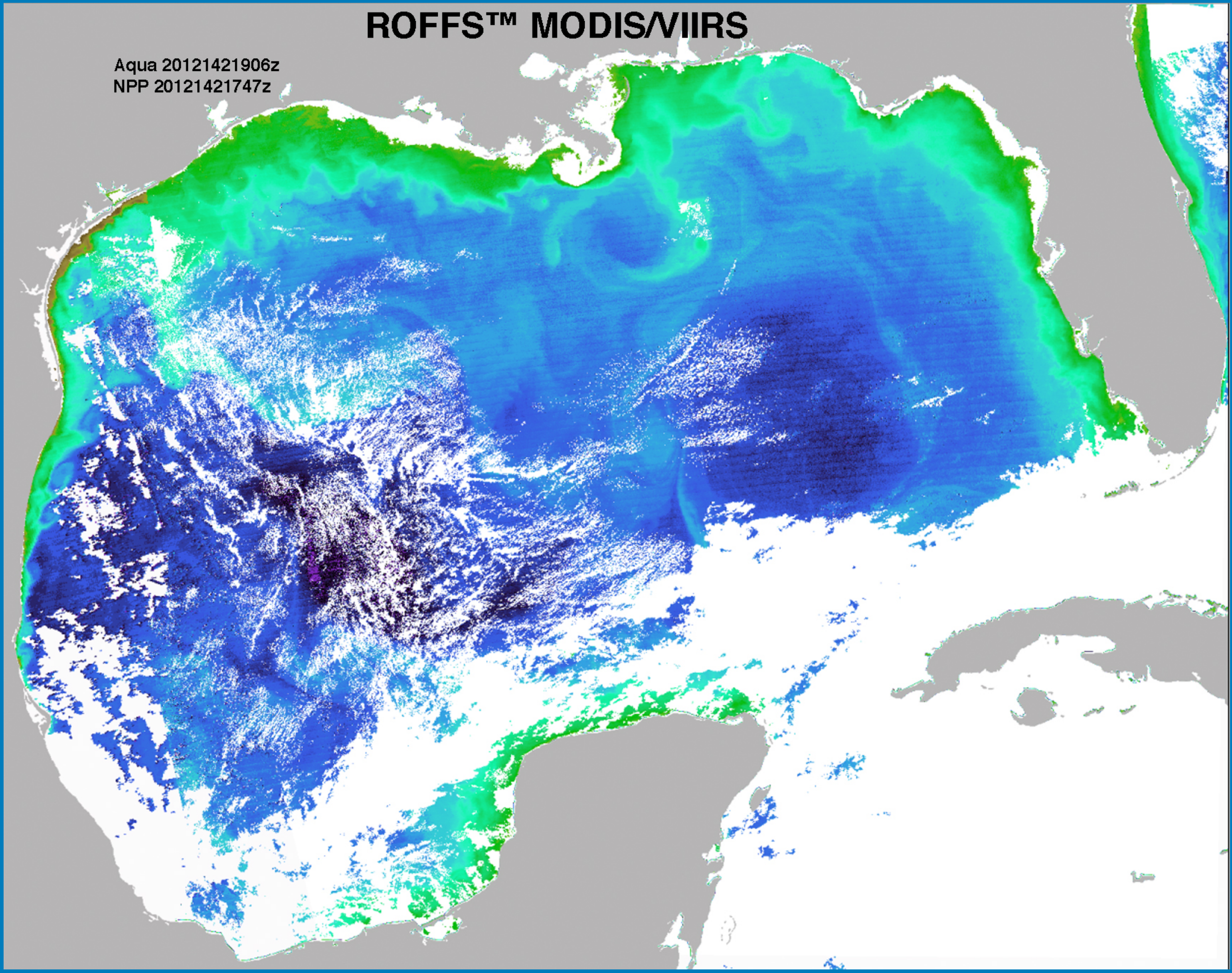
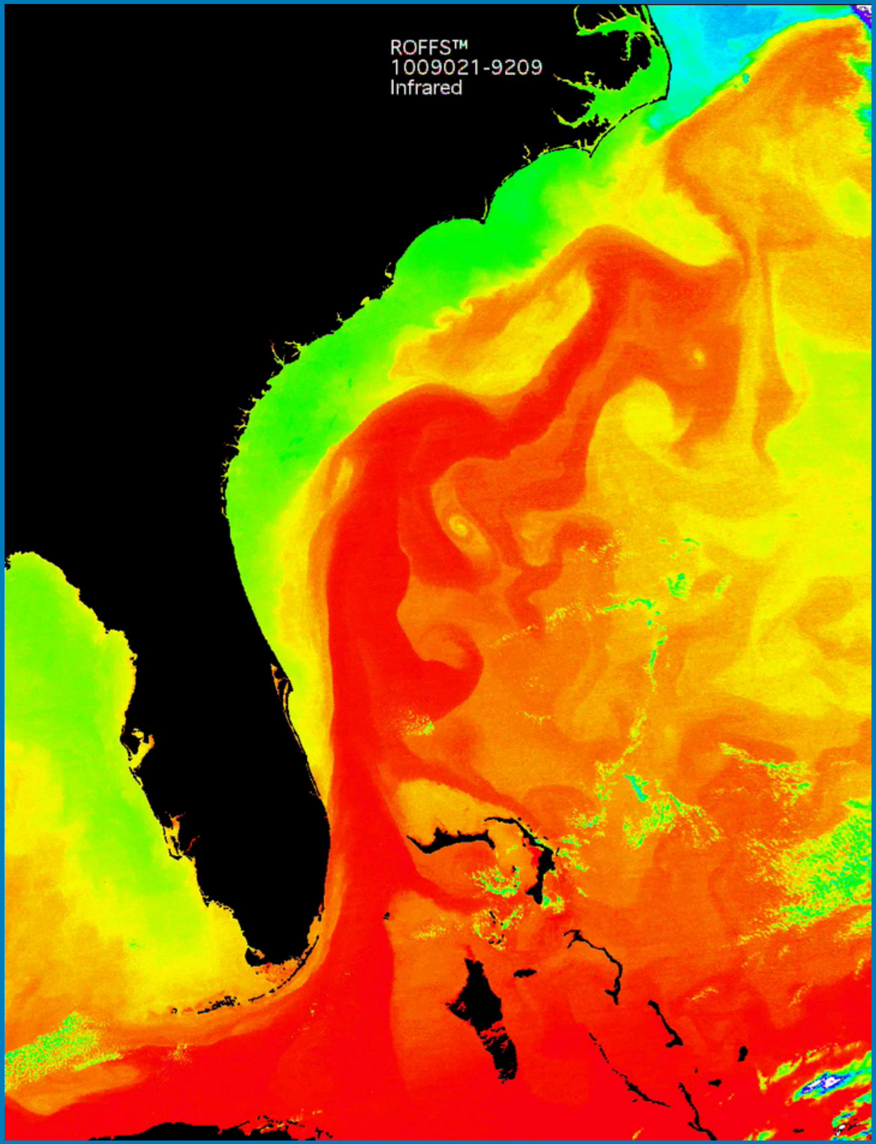
http://secoora.org/fisheriesclimateworkshopsummary

Merging Data: MODIS/VIIRS Composite



YES WE NEED NASA DATA

Thanks & Questions?



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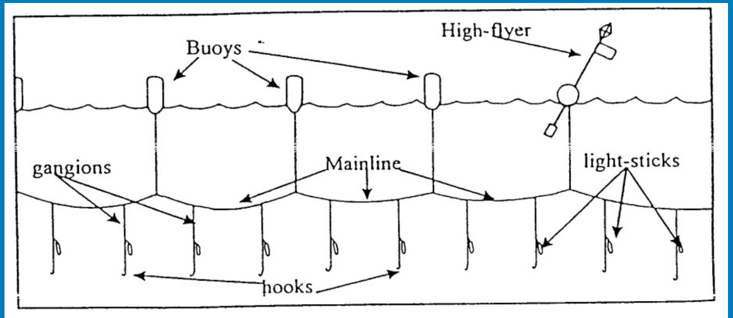
Extra Slides for Q&A

Habitat Modeling: Adults

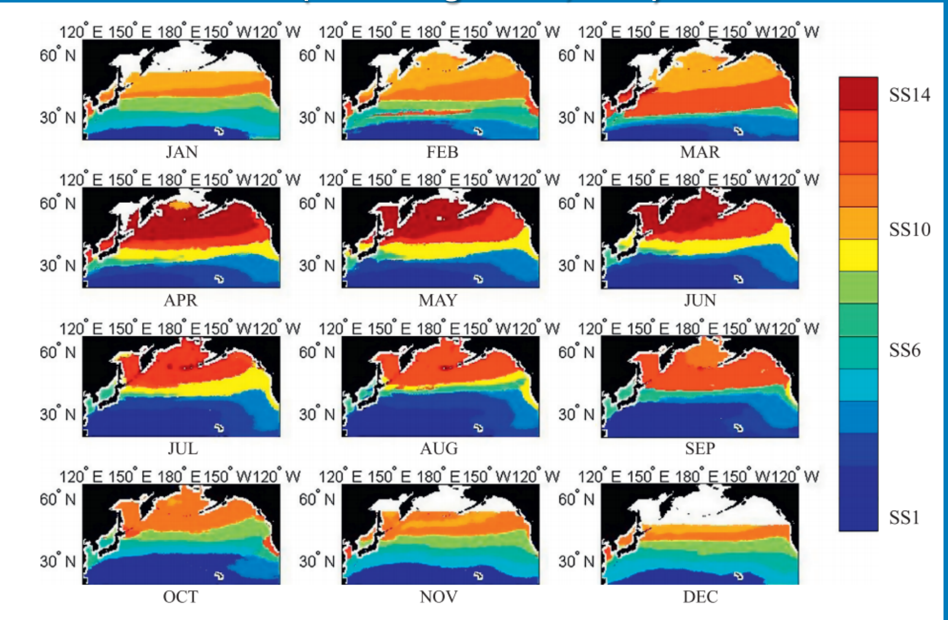
- The most comprehensive source of adult data is from fisheries-dependent longline fishery records
  - *Logbook program*: all US fishing vessels are required to submit catch logbooks detailed catch composition and gear deployed for each longline set. Mandatory since 1992
  - *Observer program*: government observers are placed on fishing vessels, and record more detailed information on size, weight and sex of fish. Program began in 1992, but coverage is very limited
  - *ICCAT Task 2 database*: Reports by countries to ICCAT
- Many issues with the data, target species, reporting reliability, gear changes, management changes (e.g. quotas, closed areas), not include recreationally caught fish…….., but it is the primary data one uses.



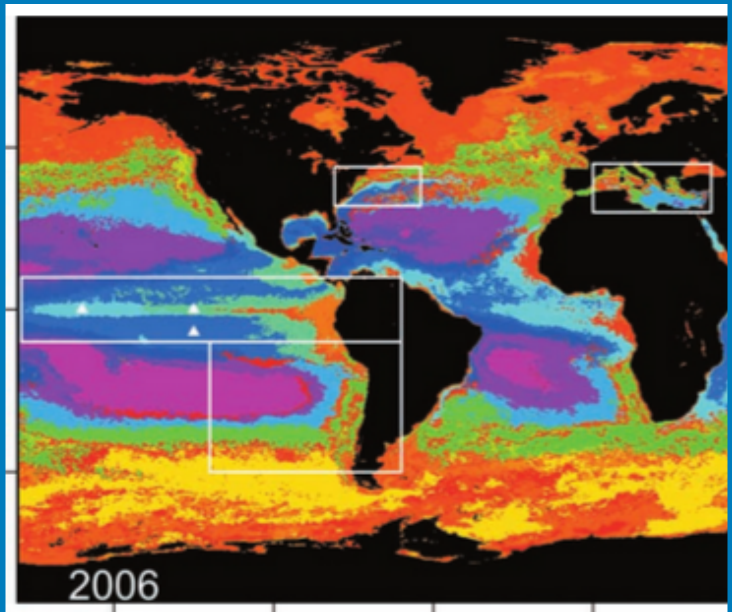
HMS Pelagic Habitat Modeling North Atlantic Ocean

- Mesoscale to basin-scale changes in circulation, productivity and food webs have been shown to exert significant effects on multiple trophic levels
- However, exact mechanisms and key variables not always clear
- One approach: instead of investigating one or more environmental variables separately, define multivariate habitats and track variability and change
  - "Dynamic biomes" (Matthew Oliver & Andrew Irwin, 2008) – NASA Funded
  - "Seascapes" (Maria Kavanaugh et al., 2014) – NASA Funded
- We aimed to extend these methods to define discrete pelagic habitats in the North Atlantic based on HMS + examine variability on multi-decadal timescales

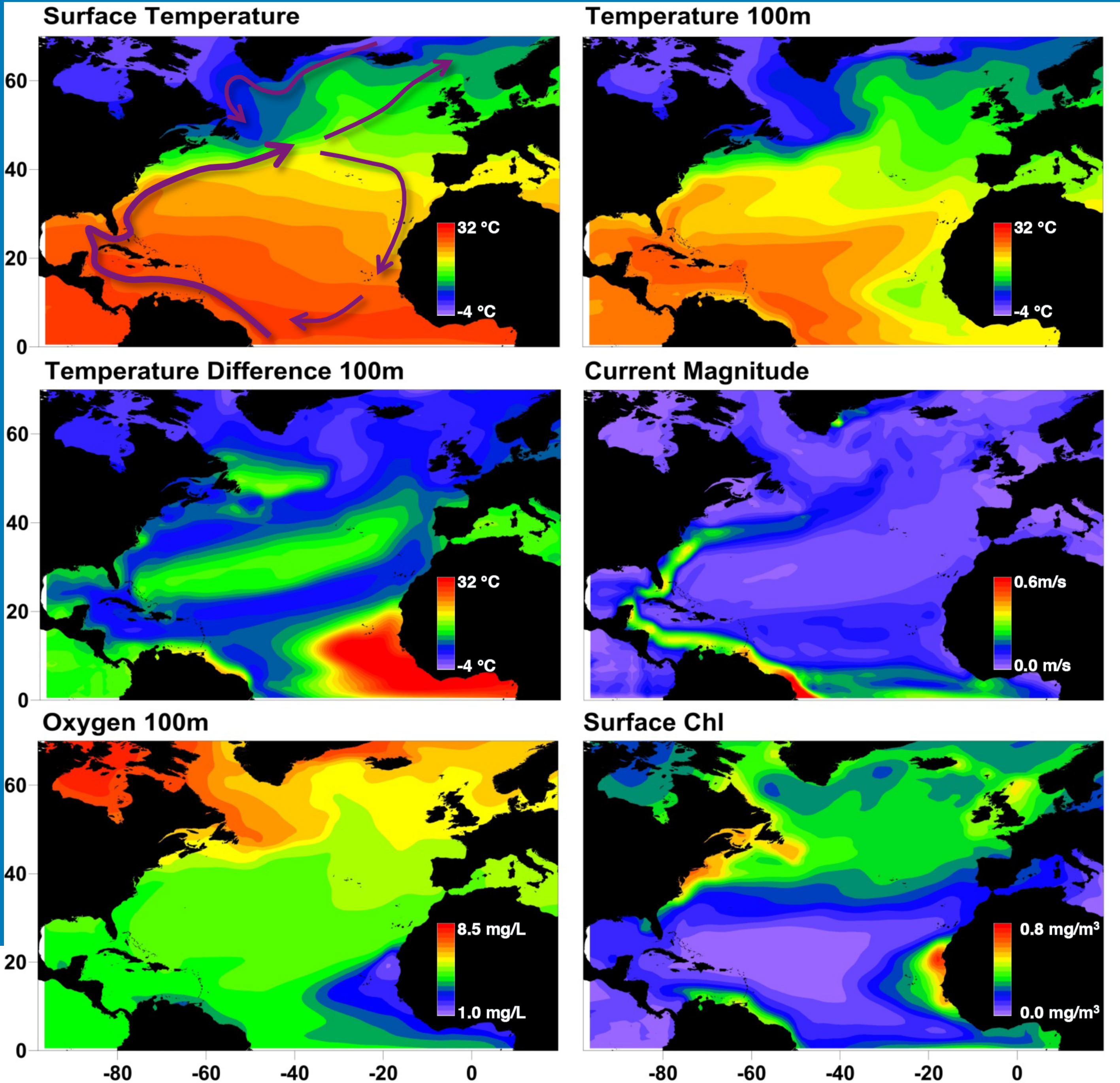
Pacific seascapes based on satellite-derived SST, chl and PAR (Kavanaugh et al., 2014)



Global dynamic biomes from satellite-derived ocean color products (Oliver & Irwin, 2008)



Environmental Variables: annual means



- Temperatures increase with latitude, but not uniformly
- Colder at depth more anoxic off Africa: upwelling
- Current magnitude shows major currents
- Chlorophyll higher off northeast US, north of 40°N, and off west Africa

Schematic of major current systems

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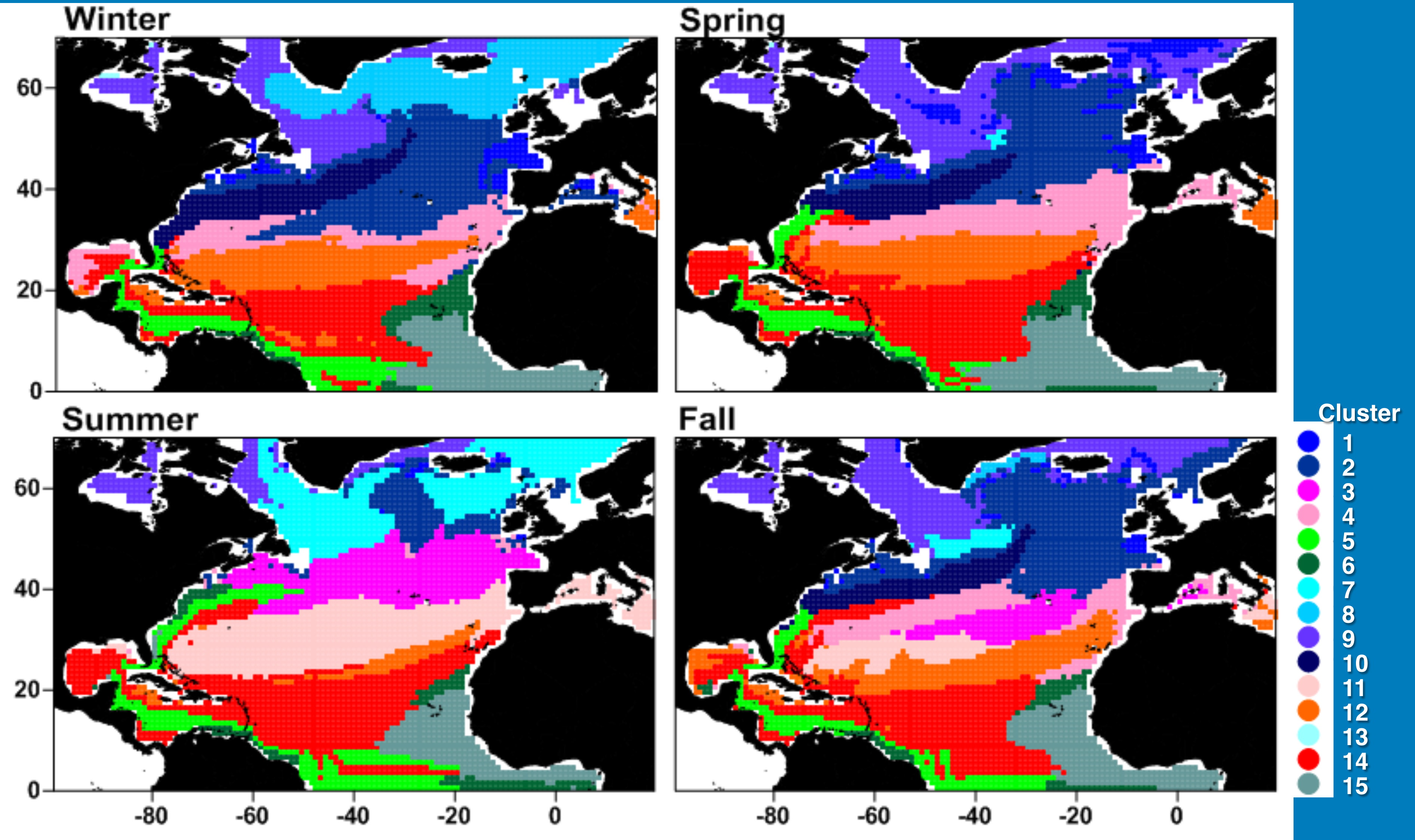
Methods: Habitat Definition

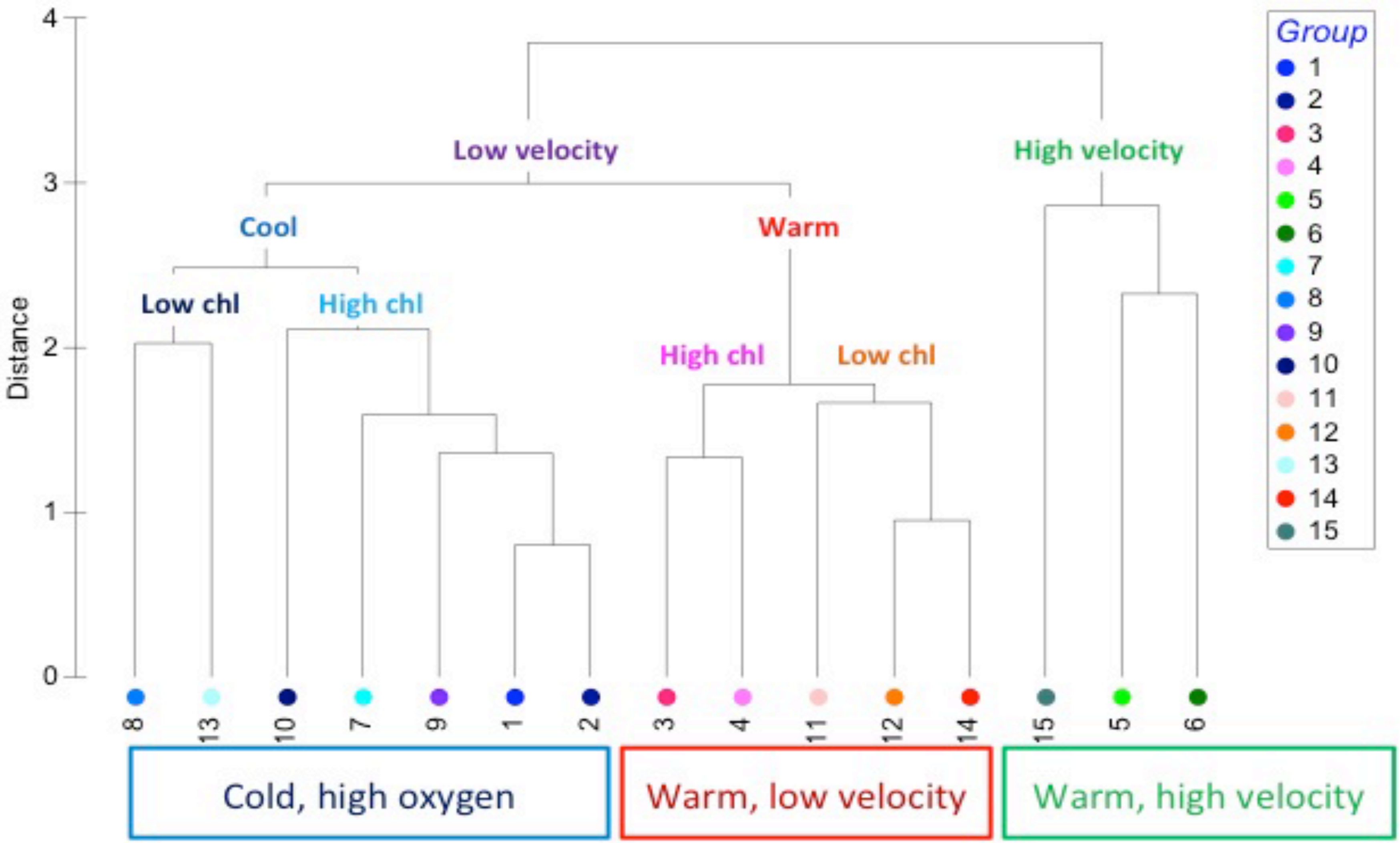
- Characteristics of each latitude/longitude point in space and time defined in terms of environmental variables.
- Ward clustering (Matlab) used to define 15 pelagic habitats in terms of environmental characteristics
- *Spatial extent* (km^2) of each habitat calculated by year and season in ArcGIS, as well as *mean latitude.*
- Used ordination techniques (PCO) to highlight habitats which varied synchronously through time, or inversely.
- PCO also used to highlight years which were very similar, or different, to each other

Habitat Clusters

- Clusters structured by latitude, but note effects of Gulf Stream, upwelling off Africa
- Gulf Stream results in tilt of northern habitats towards NE Atlantic
- Habitats often move poleward during summer, or are replaced by others

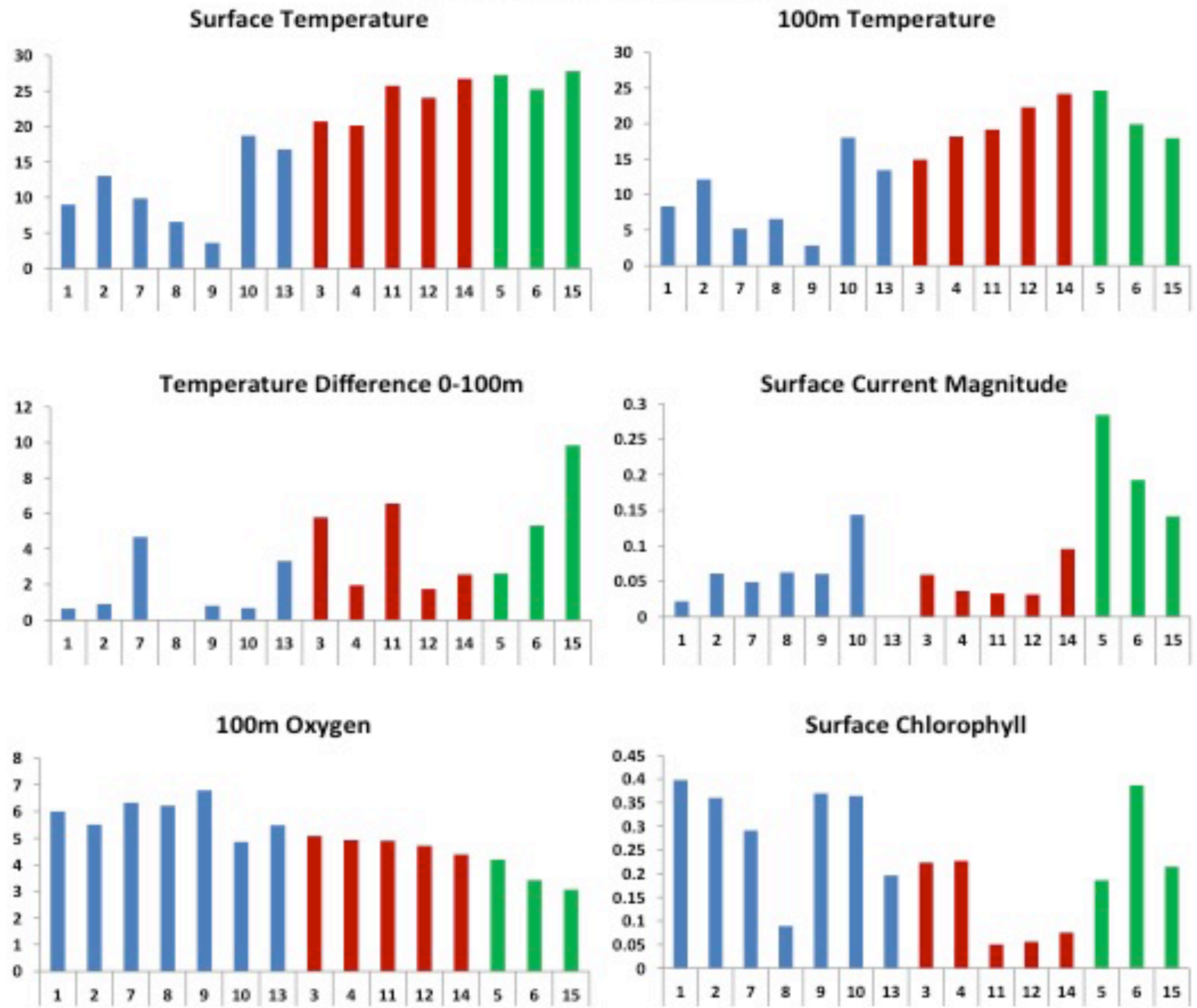


Habitat Clusters-2



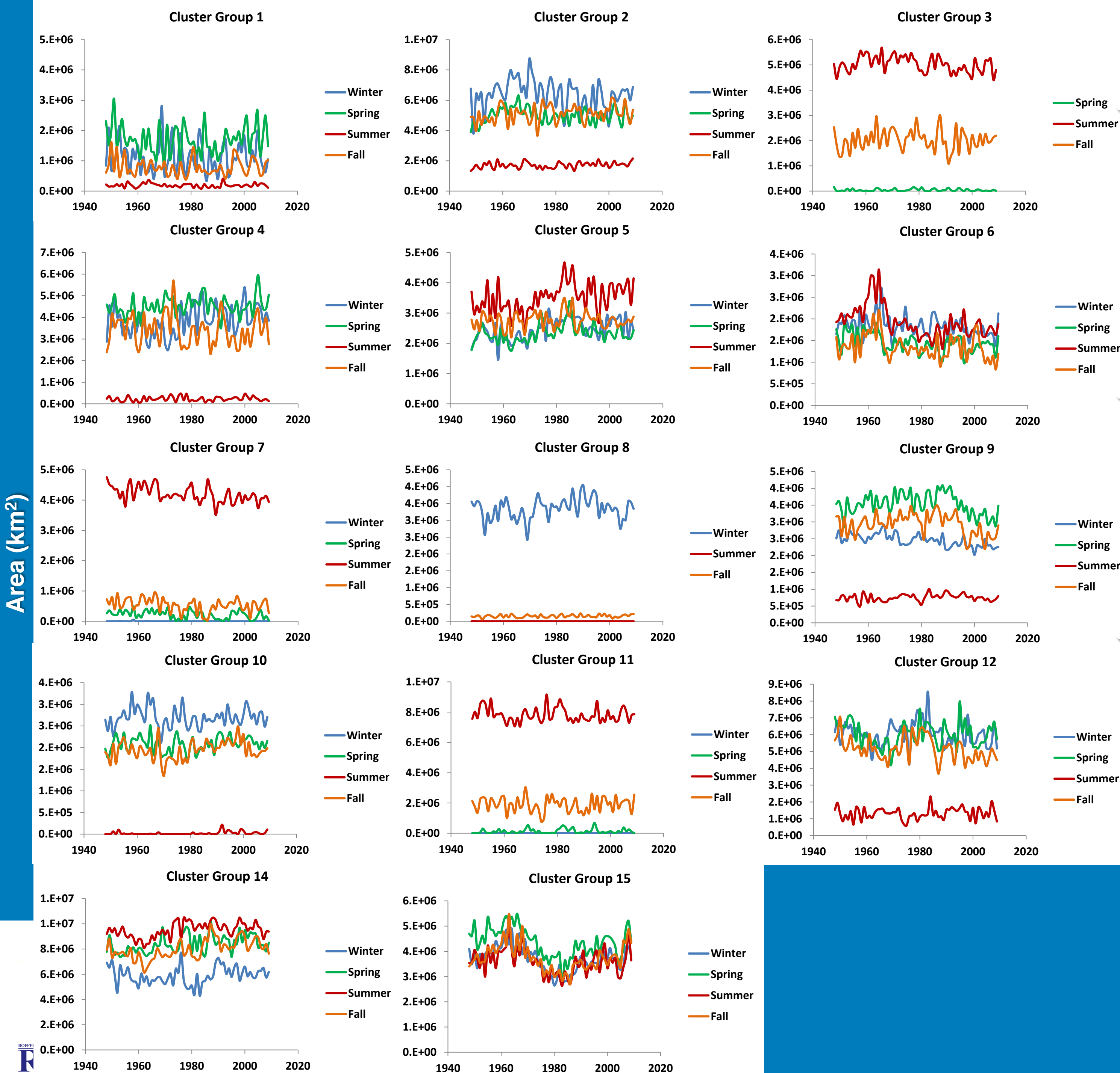
Habitats primarily differentiated by current velocity, then by temperature

Habitat Characteristics



- Habitats primarily differentiated by current velocity, then temperature

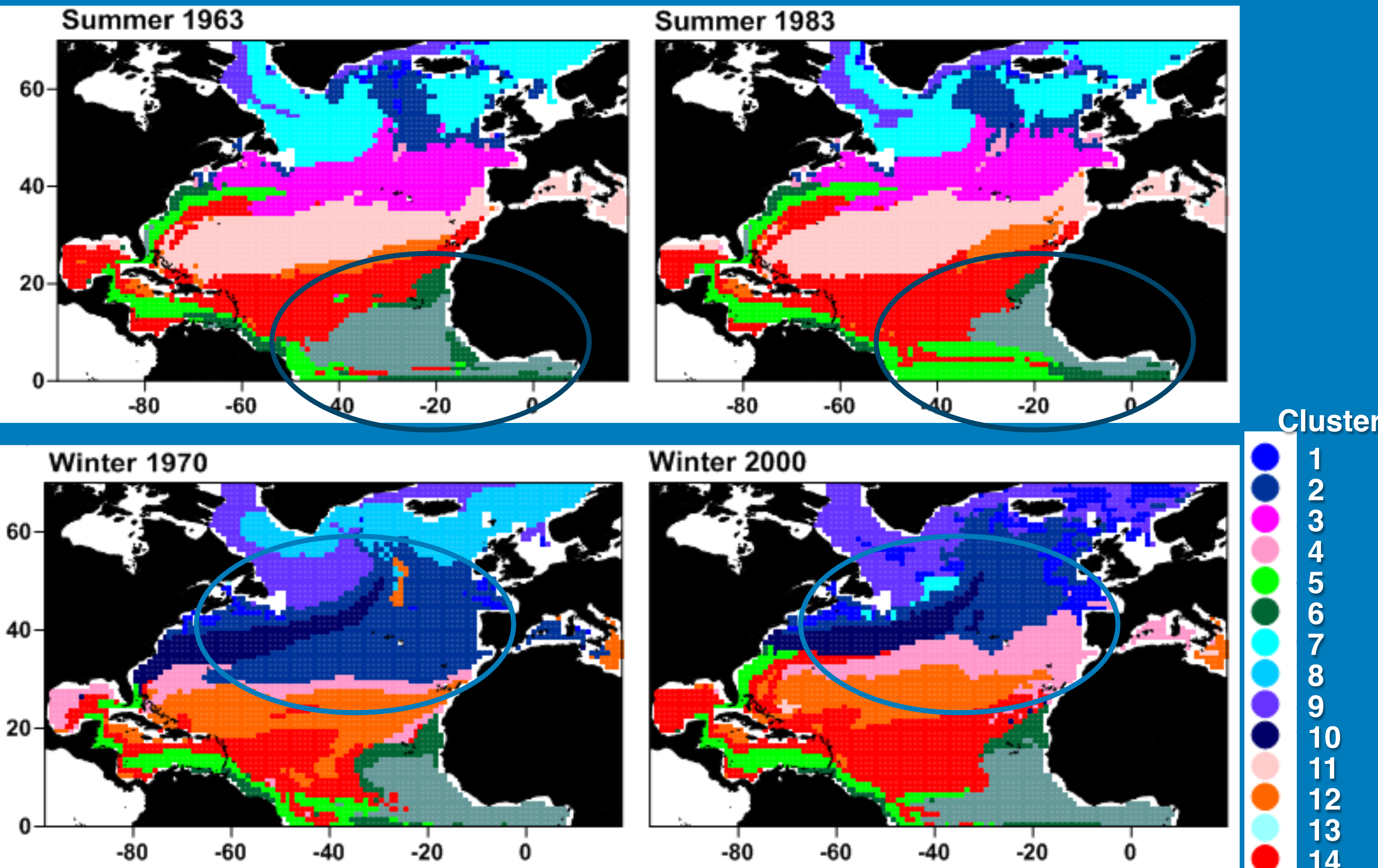
Spatial Extent



- Substantial inter-annual variability in habitat extents
- Some show decadal-scale variability (5,6,15),
- Some more inter-annual noise

Dissimilar years

- Picked two years with high dissimilarity from PCO ordination:
  - Summer 1963 and 1983; Winter 1970 and 2000
- During summer, 1963 has much higher extent of #15 (upwelling), less #14 (warm, low chlorophyll)
- During winter, 1970 has more # 2 (cold), less #4 (warm, low chlorophyll)
- Next step: what's driving (or correlated with) this variability?



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