South Atlantic Reef Fish Model (SARF) Ecospace Module

SAFMC SSC Model Team

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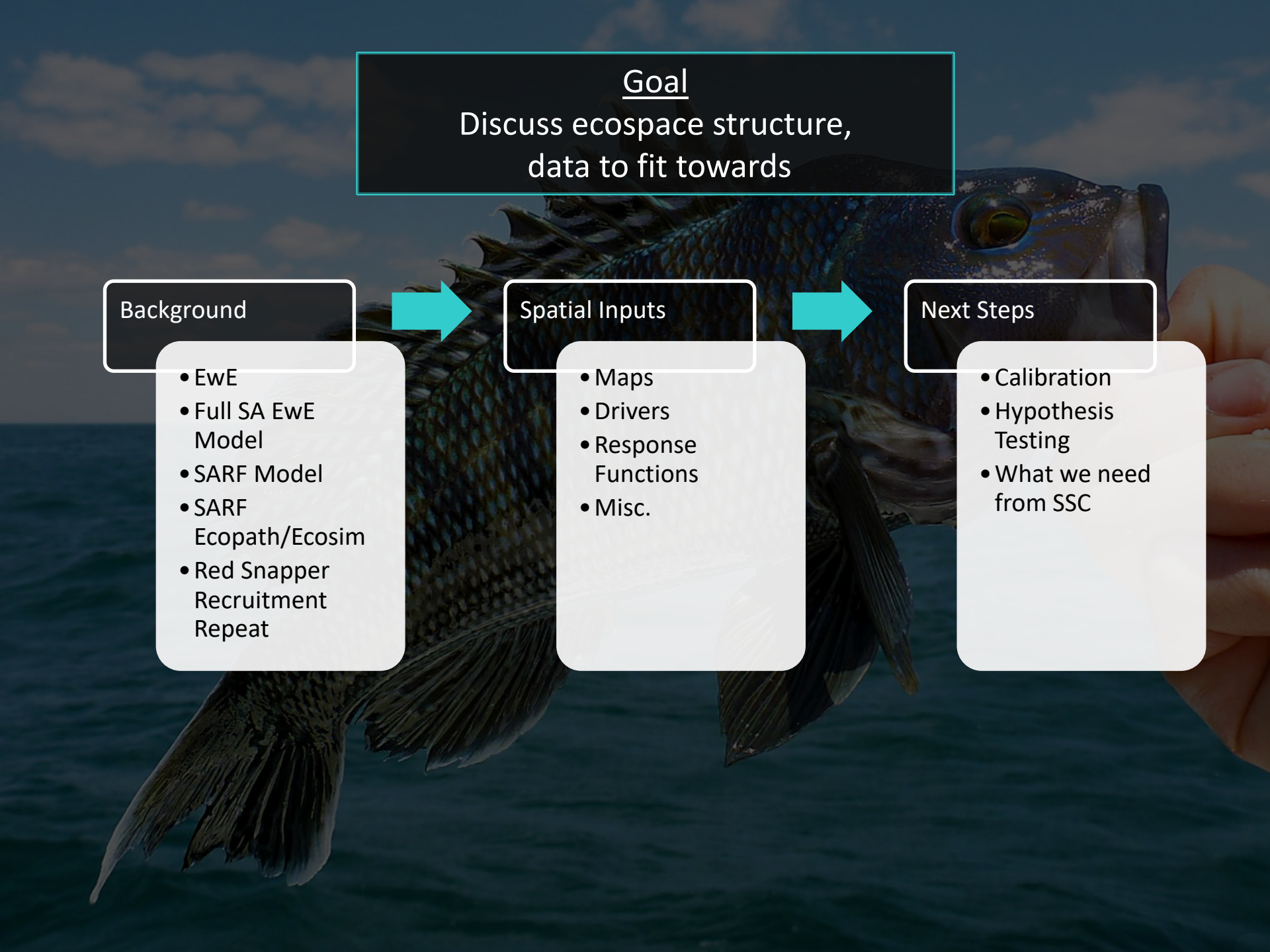
April 2024



Goal

Discuss ecospace structure, data to fit towards

Background

- EwE
- Full SA EwE Model
- SARF Model
- SARF Ecopath/Ecosim
- Red Snapper Recruitment Repeat

Spatial Inputs

- Maps
- Drivers
- Response Functions
- Misc.

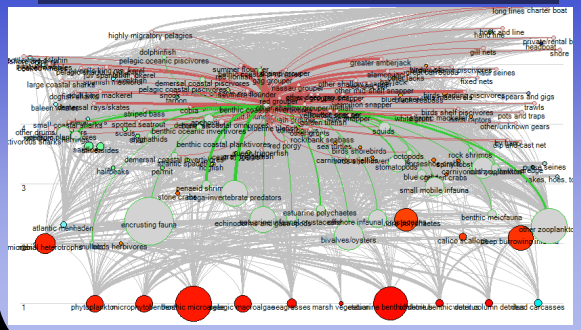
Next Steps

- Calibration
- Hypothesis Testing
- What we need from SSC

Ecopath with Ecosim and Ecospace (EwE)

Ecopath

Snapshot of the ecosystem



<u>Inputs</u>

Species & Biomasses

Diets (links species)

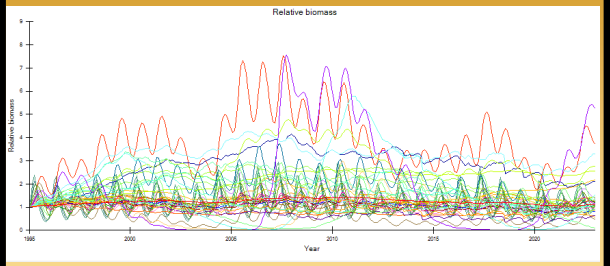
Growth Parameters

Fishing Fleets

Landings

Ecosim

Time dynamics



<u>Timeseries</u>

Chlorophyll *a*

Biomass

Effort

Catch

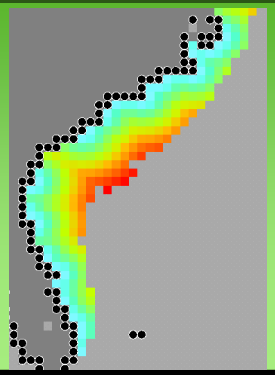
Indices of Abundance

Fishing Mortality

Mediated by Vulnerabilities

Ecospace

Spatial-temporal simulations



<u>Static Maps</u>

Habitat, Depth, Ports, MPAs

<u>Dynamic Maps</u>

Chl. *a*, Temp, Fishing Effort

<u>Habitat Preference Functions</u>

How each species responds to temp, depth, habitat, etc.

Model History

First iterations

2001: 48 groups
2004: 98 groups
2014: 99 groups
2019: 143 groups

A PRELIMINARY ECOPATH MODEL OF THE ATLANTIC CONTINENTAL SHELF ADJACENT TO THE SOUTHEASTERN UNITED STATES

Thomas A. Okey[1] and Roger Pugliese[2]

Exploring the Trophodynamic Signatures of Forage Species in the U.S. South Atlantic Bight Ecosystem to Maximize System-Wide Values

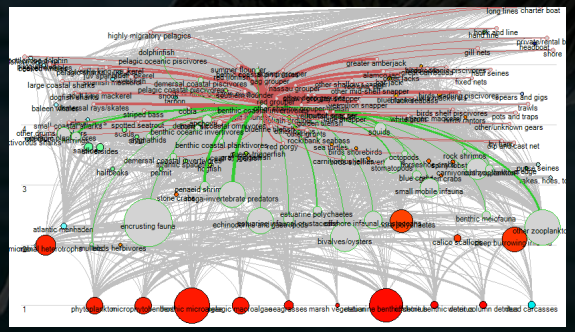
Thomas A. Okey, Andrés M. Cisneros-Montemayor, Roger Pugliese, Ussif R. Sumaila

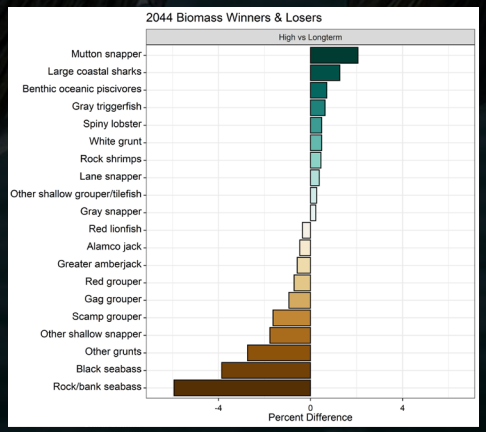
South Atlantic Ecosystem Model
"The Big Model"

2020: 140 groups
- 700+ species
- 250+ diets
- 153 timeseries
- More collaborators than we can count
- Reviewed by SAFMC SSC/Workgroup

2021: Used for Red Snapper Predation Analysis

Present: Prey analyses, Data Repository





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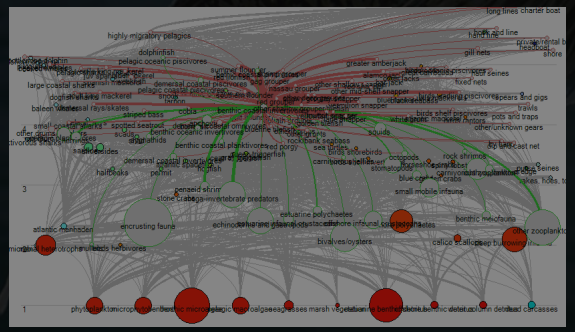


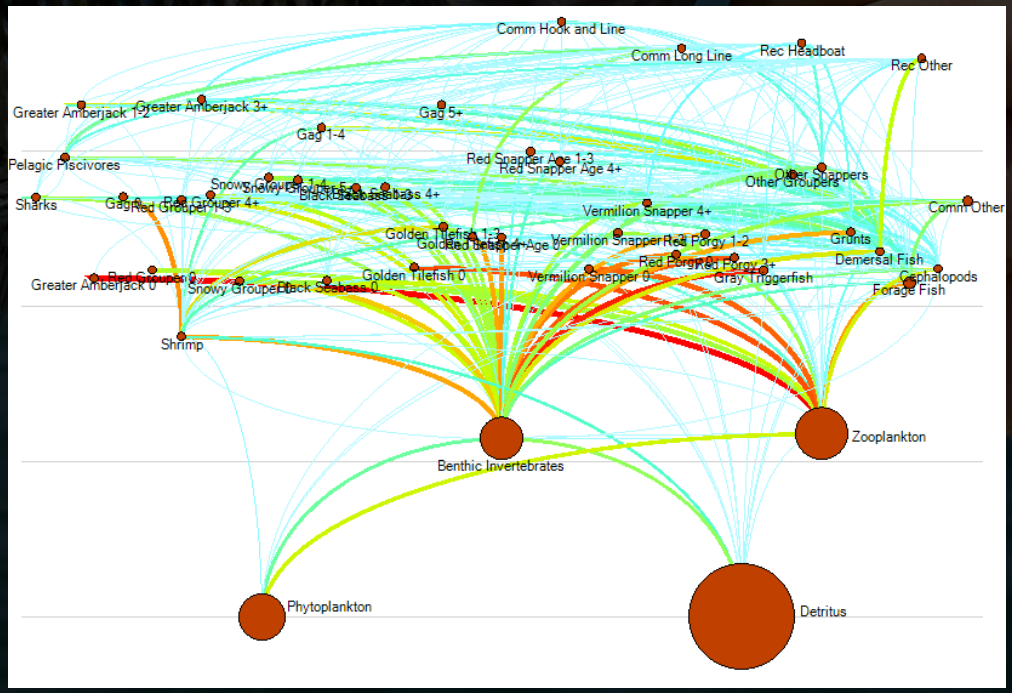
South Atlantic Reef Fish (SARF) Model

- MICE model version of full South Atlantic Model
- 41 groups focused on Snapper-Grouper Complex
- Includes age structure (stanzas)

Sharks
Pelagic Piscivores
Greater Amberjack
Gag
Red Grouper
Snowy Grouper
Black Sea Bass
Golden Tilefish

Red Snapper
Vermilion
Red Porgy
Gray Triggerfish
Other Groupers
Other Snappers
Grunts
Demersal Fish

Forage Fish
Cephalopods
Shrimp
Benthic Invertebrates
Zooplankton
Phytoplankton
Detritus



Data in SARF model

South Atlantic Reef Fish (SARF) Model

- MICE model version of full South Atlantic Model
- 41 groups focused on Snapper-Grouper Complex
  - Includes age structure (stanzas)
- Fleets
- Diets
  - Compressed from “Big” SAR EwE Model
- Landings
- Discards
- Timeseries (almost entirely from stock assessments)
  - Catch
  - Relative biomass
    - SERFS Indices of Abundance (trap and video)
    - Stock Assessments Catch per fleet (C/F = B)
  - Absolute biomass
  - Fishing Effort
  - Fishing Mortality

All timeseries updated with most recent stock assessments including Fall 2024 SEDAR 73 Update

Sharks
Pelagic Piscivores
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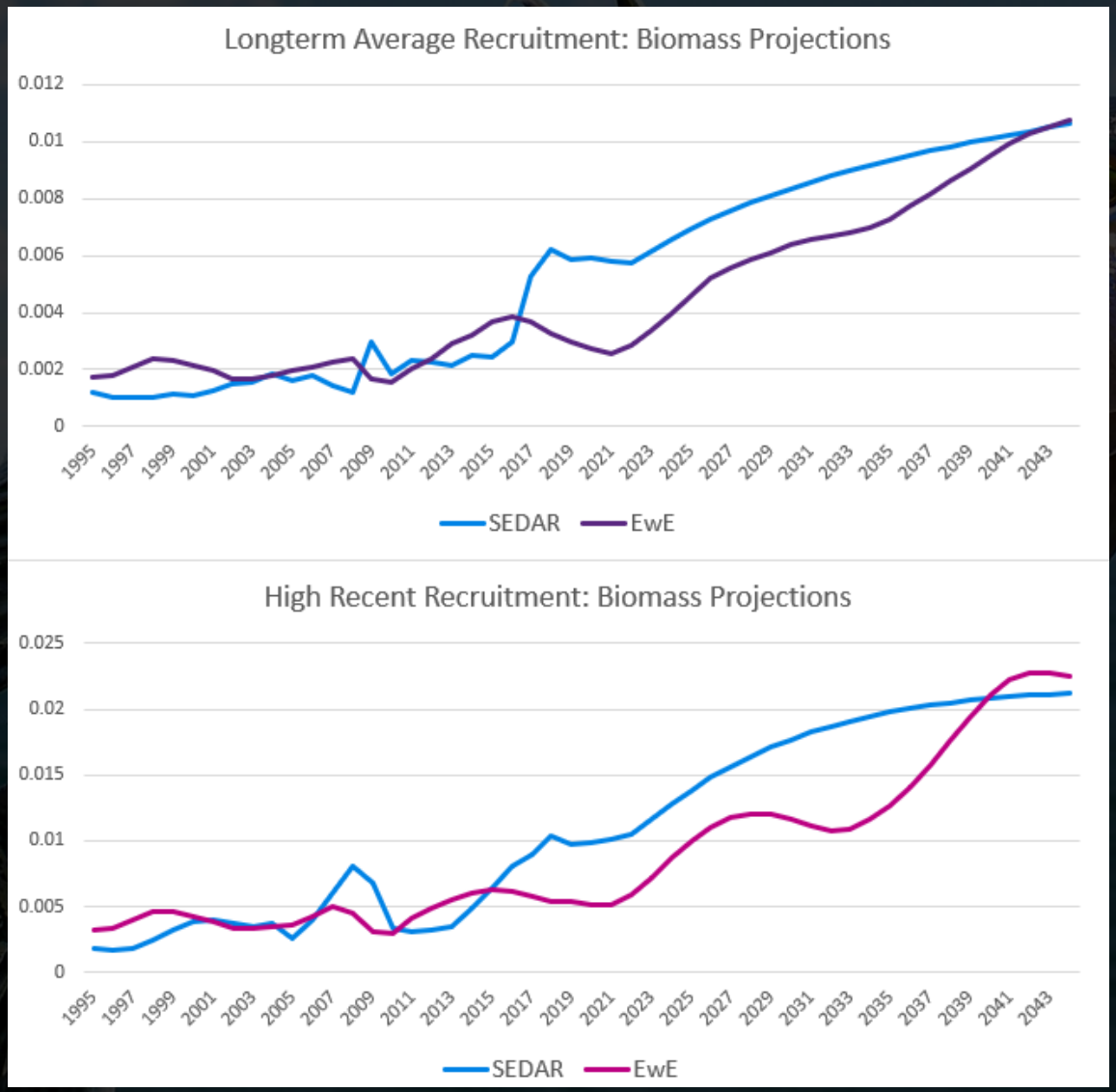
Detritus

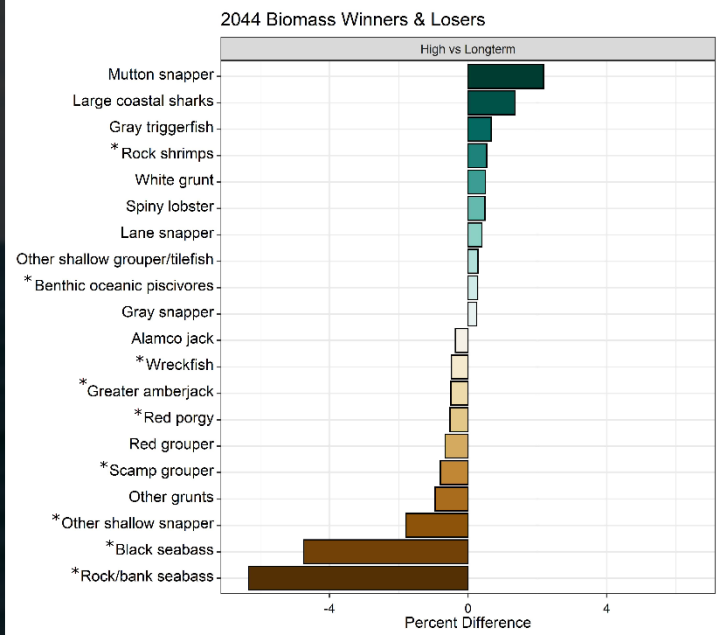
1	Comm Hook and Line
2	Comm Long Line
3	Comm Other
4	Rec Headboat
5	Rec Other

Re-running red snapper analysis

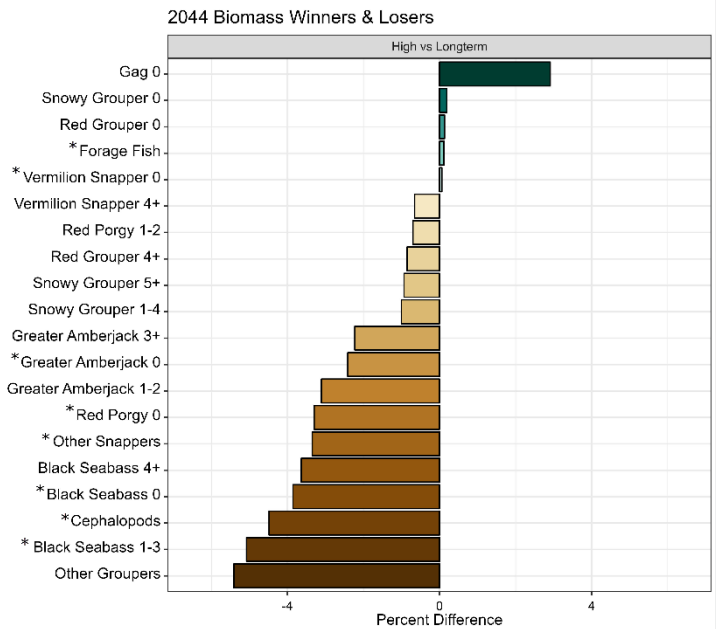


Re-running red snapper analysis – results

2021 SAR EwE Model: High Complexity

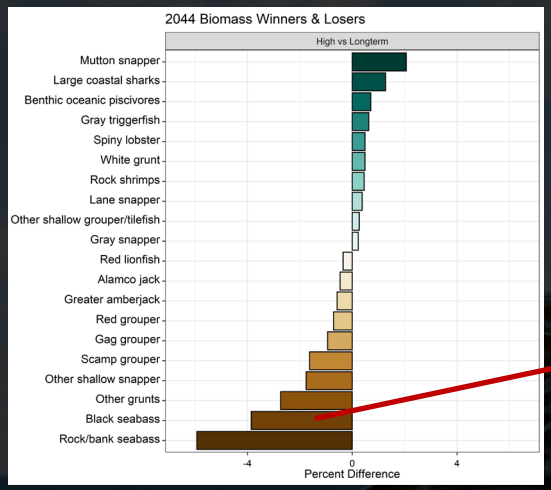


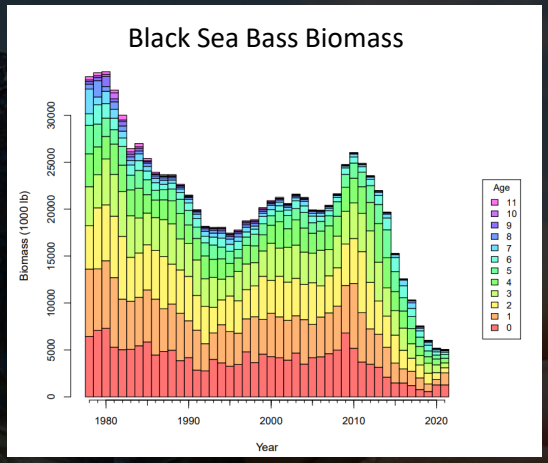
2025 SARF Model: Intermediate Complexity



SARF Model

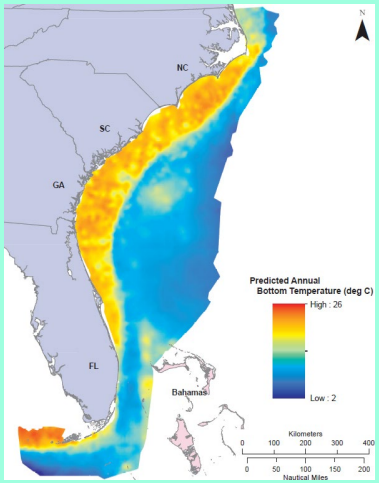
Ecospace/BSB Project





Hypotheses

Some like it hot – but not BSB?



Nearshore depletion

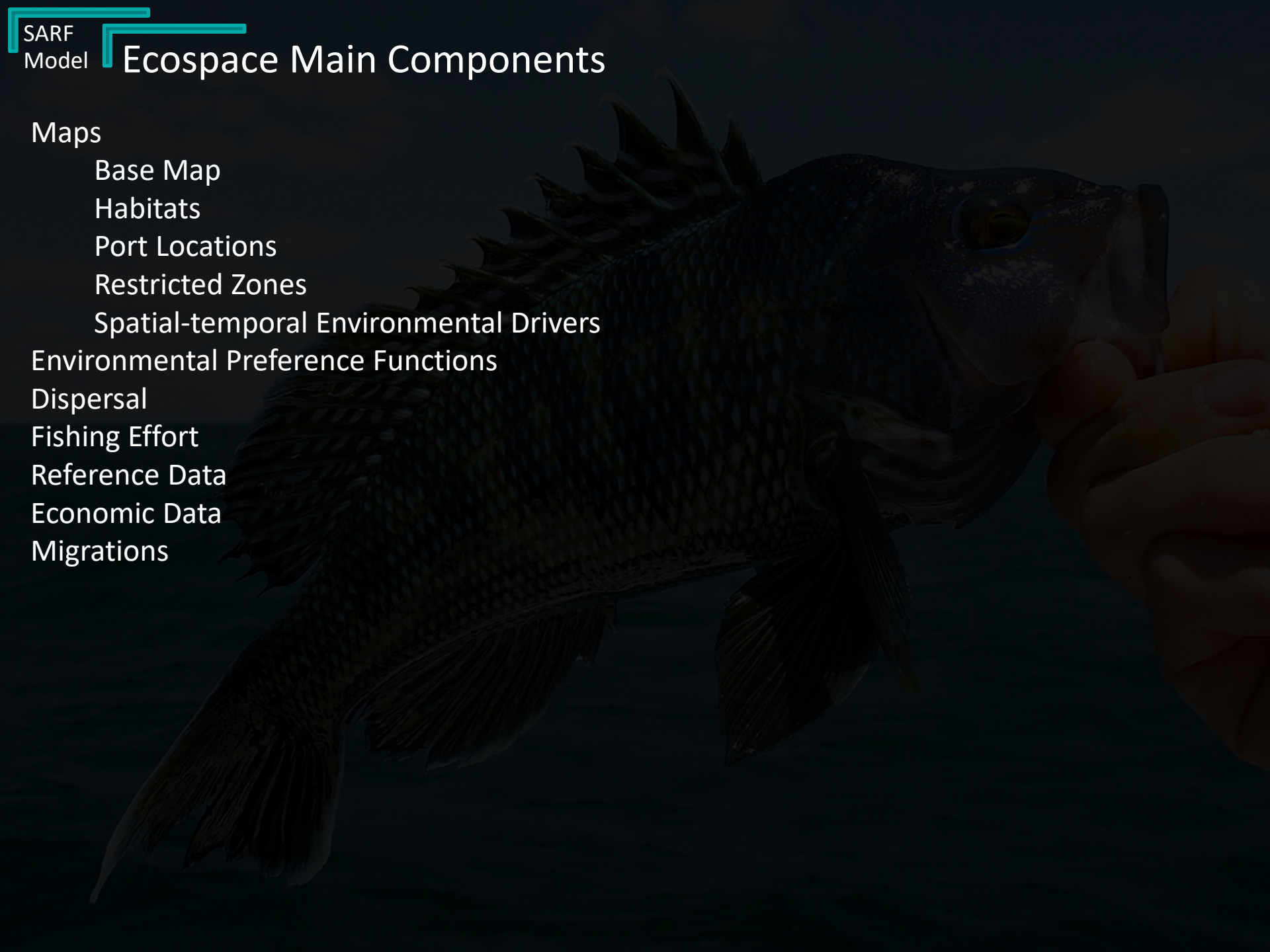
Low recruitment

Red snapper impacts

SARF Model

Ecospace Main Components

- Maps
  - Base Map
  - Habitats
  - Port Locations
  - Restricted Zones
  - Spatial-temporal Environmental Drivers
- Environmental Preference Functions
- Dispersal
- Fishing Effort
- Reference Data
- Economic Data
- Migrations



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Informs “habitat capacity” calculations per grid cell

Grid cell #1

Depth = 8 meters
Distance to shore = 80 NM
Proportion Reef = 1
Bottom Temp = 27C

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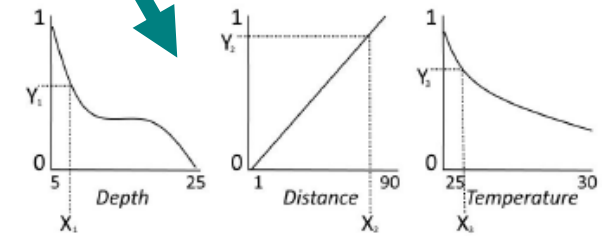

Figure 3-2. Conceptual diagram of habitat capacity values.

A habitat capacity value ($Y_1 \times Y_2 \times Y_3$) is a function of environmental preference values Y_i and environmental parameter values X_i (i.e., depth (m), distance to reef (m), and temperature (°C)) at a single raster cell (Christensen et al. 2014). The relationship between Y_i and X_i is defined by an environmental preference function represented as a solid black line.

SARF Model

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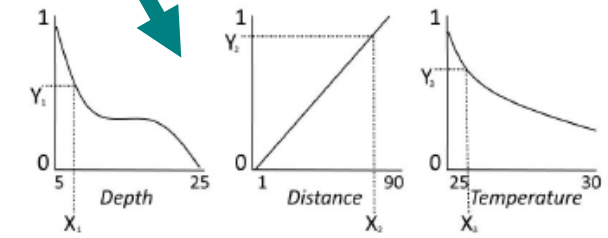

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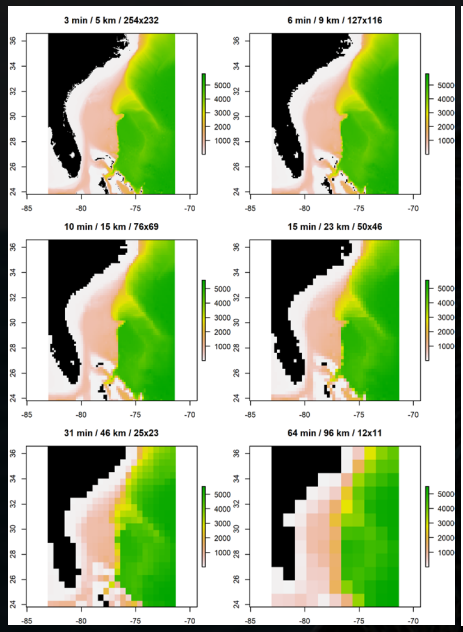
Grid cell #1

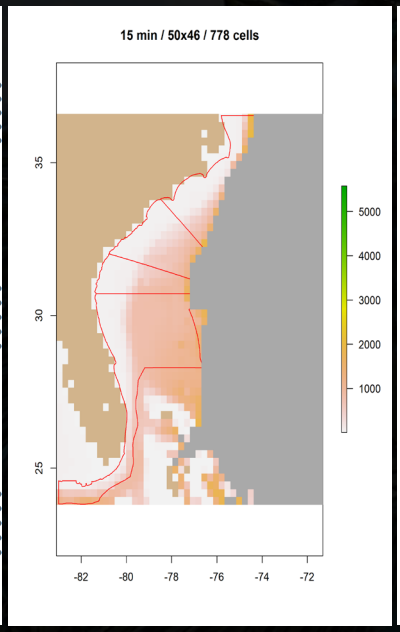
Habitat Capacity Value = 0.5

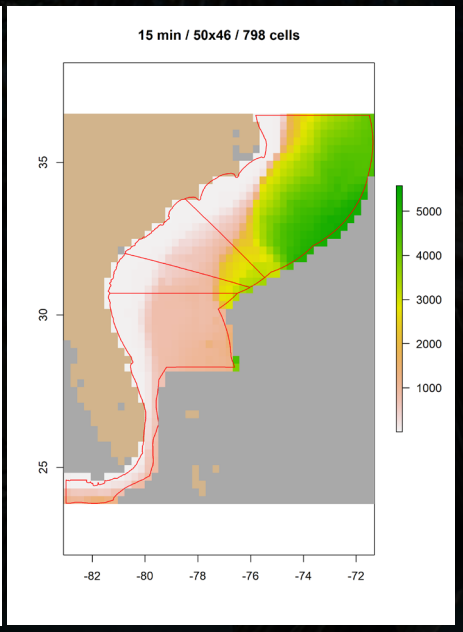
Basemap

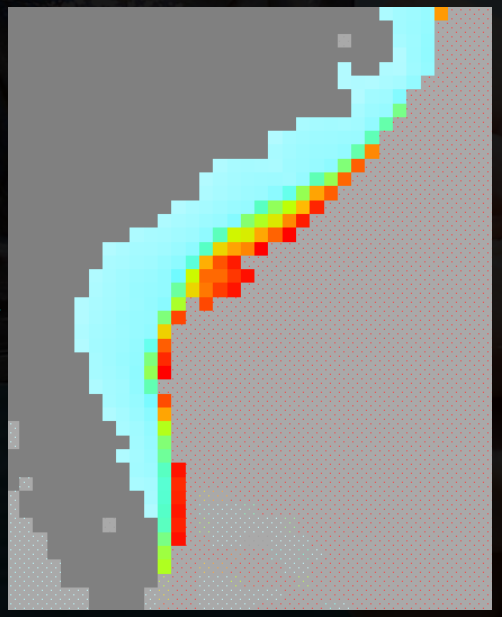
Reviewed

- Resolution
- Boundaries
  - EEZ, 1000m, US Maritime Boundaries, FL Keys









Decisions

- 15min (23km^2) resolution
- Boundaries at shelf (600m) and southern extent of SERFS sampling
- Depth: NOAA bathy database

Habitats – Natural Reef

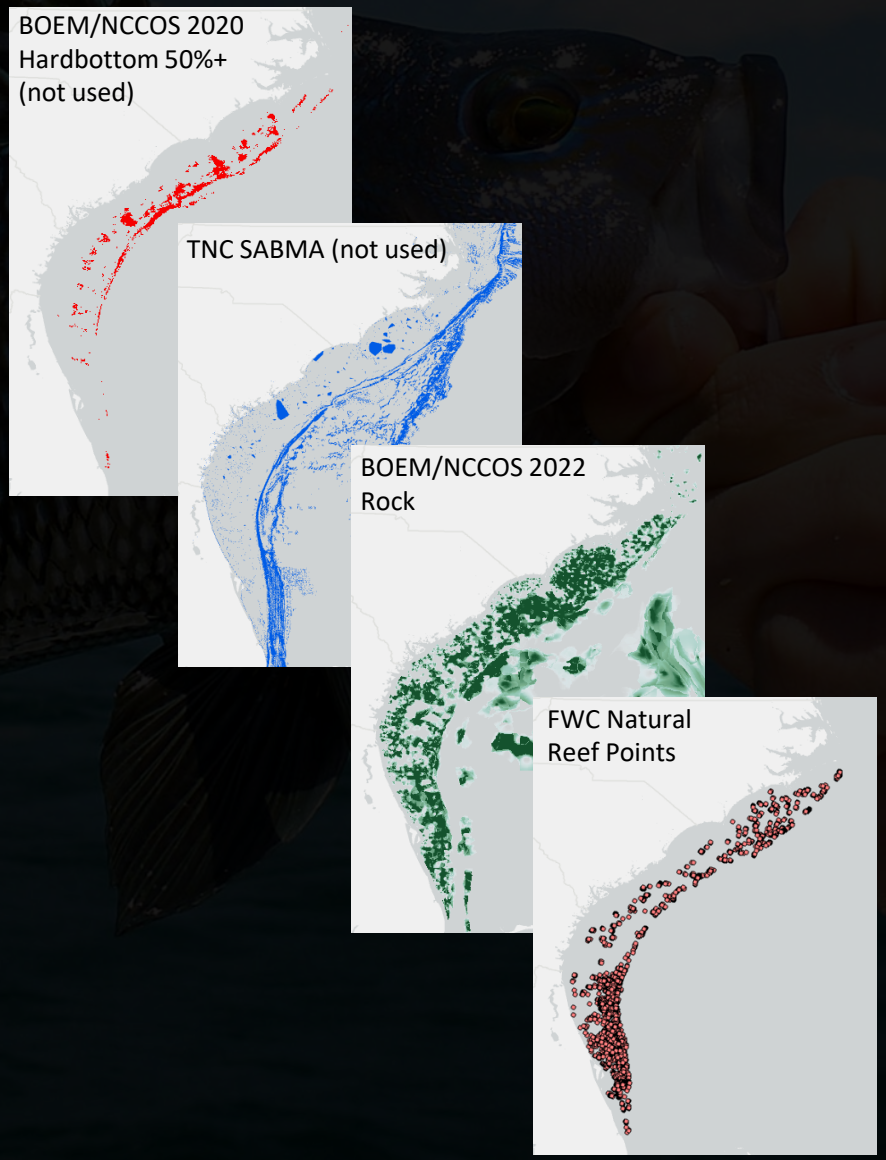
<u>Reviewed</u>

- BOEM 2020-002 NCCOS Predicted Hardbottom[1]
- TNC South Atl. Bight Marine Assess
- BOEM 2022-038 NCCOS Predicted Hardbottom[2]
  - Rock layer
- Natural Reef Points from FWC FIM/GAJ Count
  - SERFS sampling sites
  - FWC sites
  - USGS data
  - "Known Unknowns" from captain surveys
    - -skewed geographically, duplicated

<u>Decision</u>

Using BOEM/NCCOS 2022 rock layer and FWC Natural Reef Points separately as habitat layers

Checked that rock layer covered SERFS sampling sites, TNC hardbottom data compilation, natural points map from FIM, and areas of highest hardbottom likelihood from BOEM2020



1) Pickens & Taylor 2020
2) Poti et al 2022

Habitats – Artificial Reefs

Reviewed

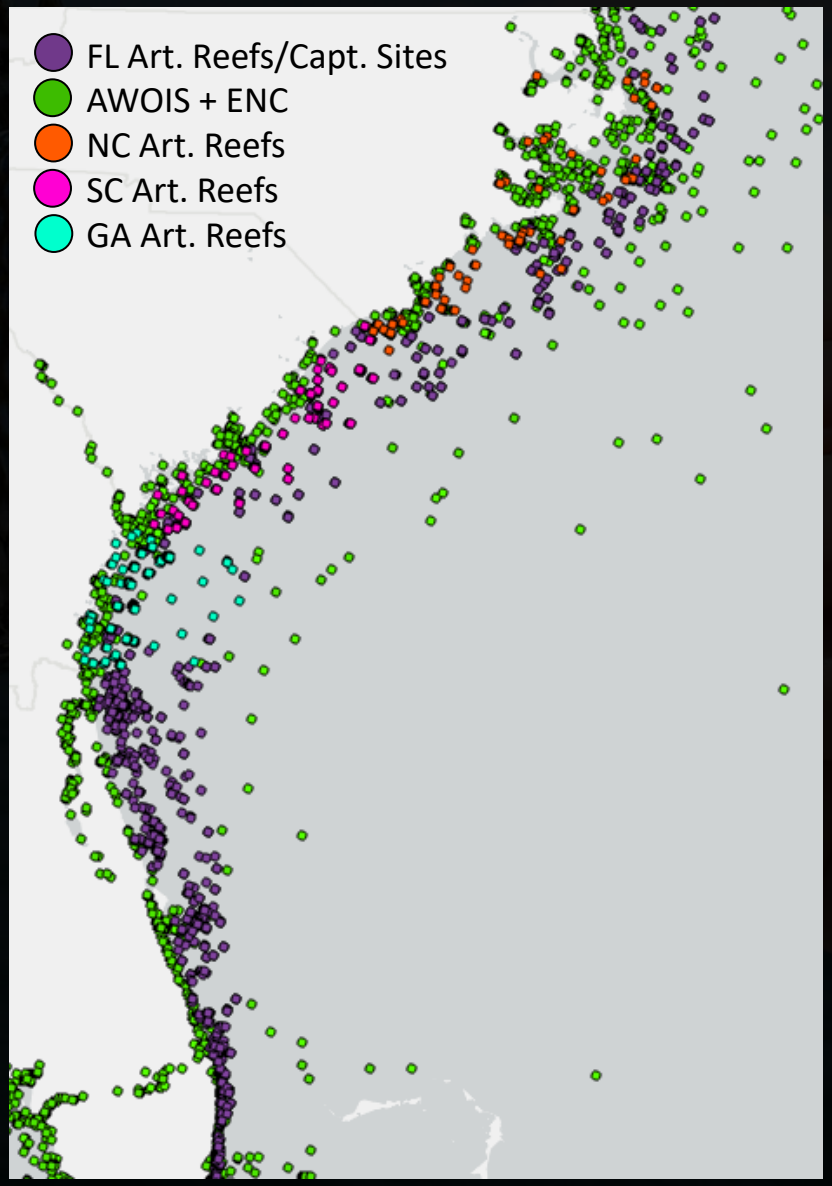
Artificial Reef layers from FWC FIM/GAJ Count

- Shipwrecks - AWOIS + ENC (both NOAA)
- Each state's artificial reefs layers
- "Known Unknowns" within 0.5 Nautical Miles of artificial reefs

Decision

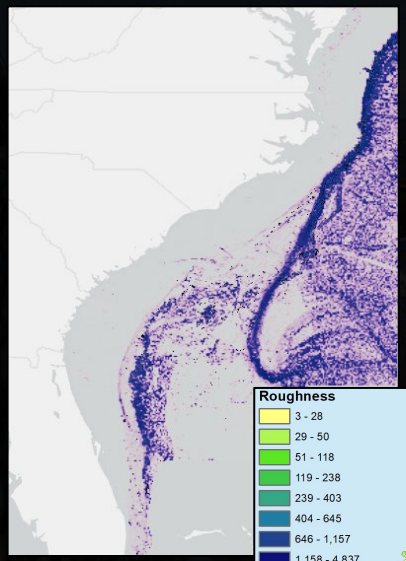
Combine all point data into master map of artificial reef locations

-Expected large number of repeated sites from multiple data sources
-Summed points and proportioned to grid cells (0-1)
-Rescaling to smaller value???

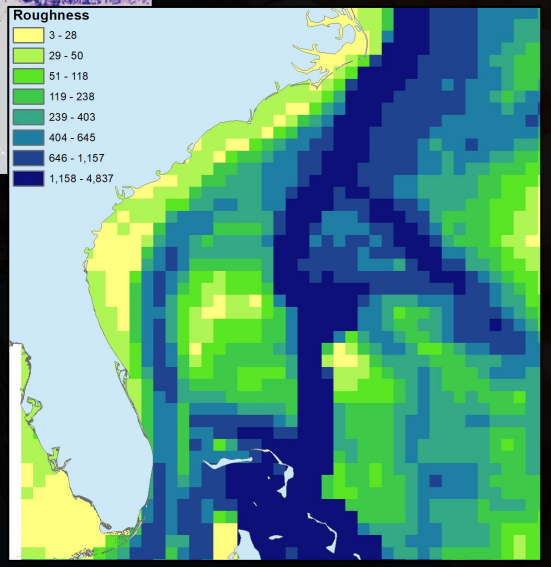


Roughness

BOEM/NCCOS



ETOPO 2022



Roughness Map

Serves as a coarse estimate of flat vs. rugose terrain relative to study area given resolution

<u>Reviewed</u>

-BOEM/NCCOS 2022 Roughness and Rugosity layers

Incomplete over shelf

-NOAA Global Relief Model Topography (ETOPO 2022)

Estimate terrain characteristics following Wilson et al. (2007)

Initially considered:

- Roughness (largest inter-cell difference between pixel and 8 neighbors)
- Ruggedness (mean of the differences between pixel and 8 neighbors)
- Topographic Position Index (difference between pixel and mean value of 8 neighbors)

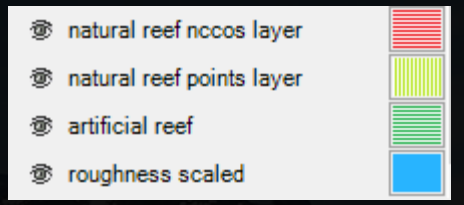
<u>Decision</u>

Roughness from ETOPO 2022

Wilson, M.F.J., O'Connell, B., Brown, C., Guinan, J.C., Grehan, A.J., 2007. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. Marine Geodesy 30: 3-35.

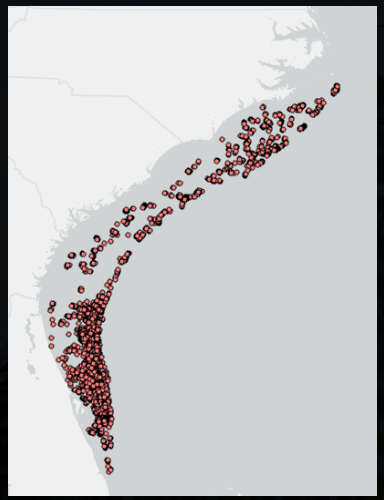
SARF Model > Ecospace > Maps

Habitats - all

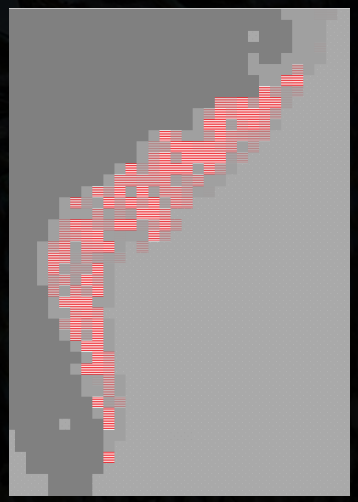


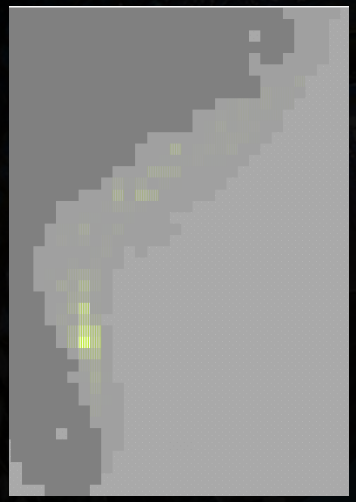
BOEM/NCCOS 2022 Rock

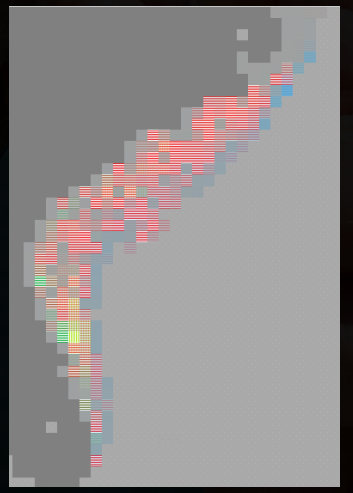
FWC Natural Reef Points



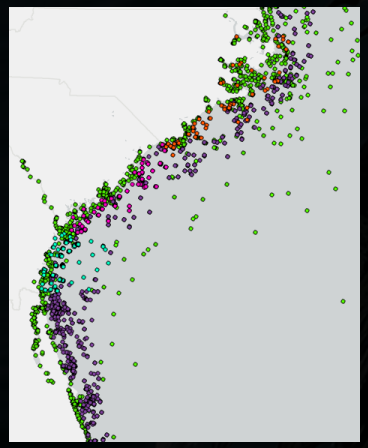
Ecospace Habitat Maps



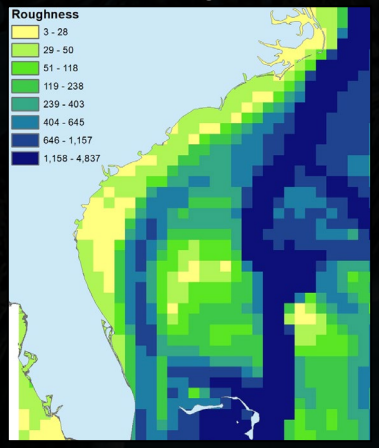


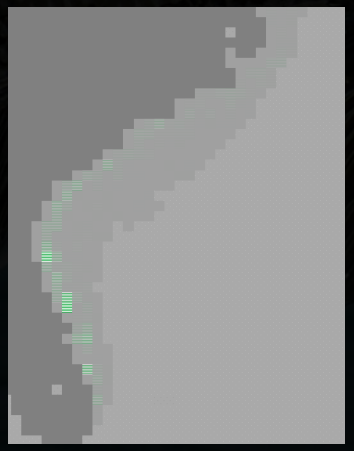


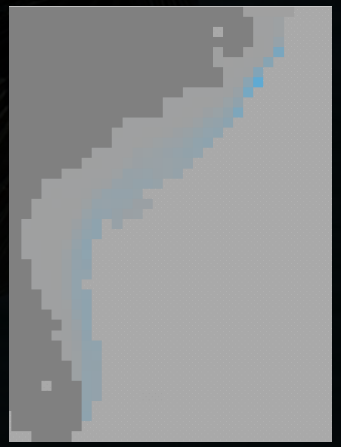
Combined Artificial Reef Points



ETOPO 2022 Roughness







Port Locations

Purpose: informs spatial fishing effort predictions

<u>Reviewed</u>

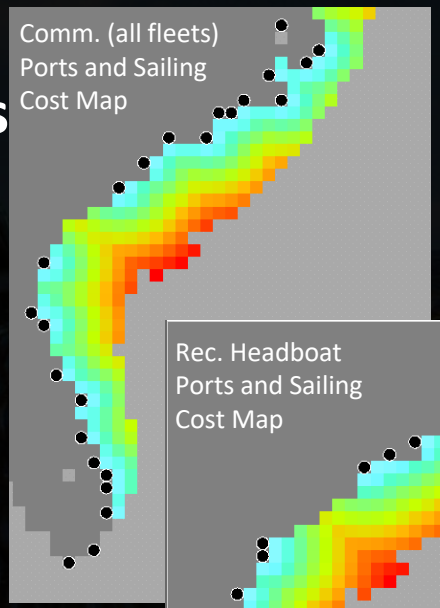
2016 NOAA Port Review
- Top 50 commercial ports by pounds landed

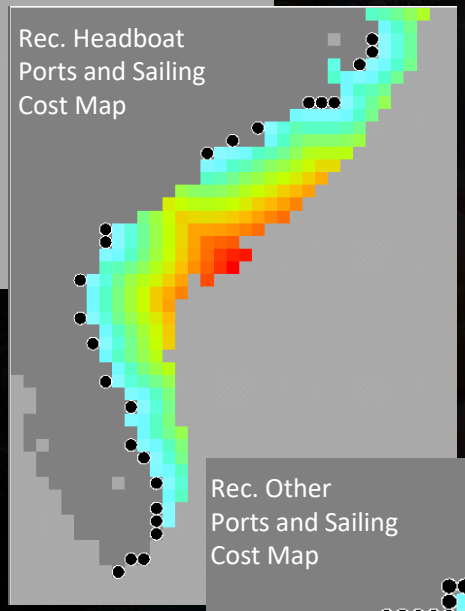
ACCSP Commercial Catch
- Top 10 counties per state by catch, trip count, total $

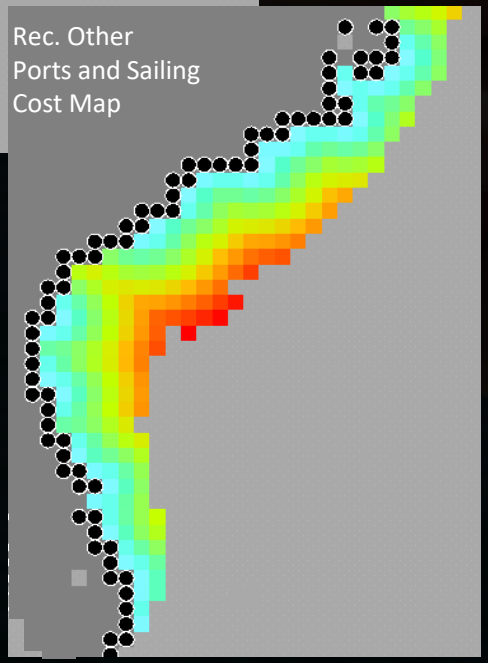
MRIP Public Fishing Access Site Register
- Headboat Counts
- Private Recreational Access Point Fishing Pressure
  - Estimate of anglers per 6 hours based on use surveys, resident boats, amenities, cost, parking spots, etc.

-Using all major commercial ports for all 3 commercial fleets
-Using all headboat ports for Rec. Headboat fleet
-Summed Access Point Fishing Pressure across all modes and times
- -Looked at top 80% of recreational access points for each state
  - -Spanned almost the whole coast
- -Using entire coastline for private recreational ports

Can we rank ports? No. Tried clustering ports to see if that would average the cost across the ports. No difference in sailing cost maps.



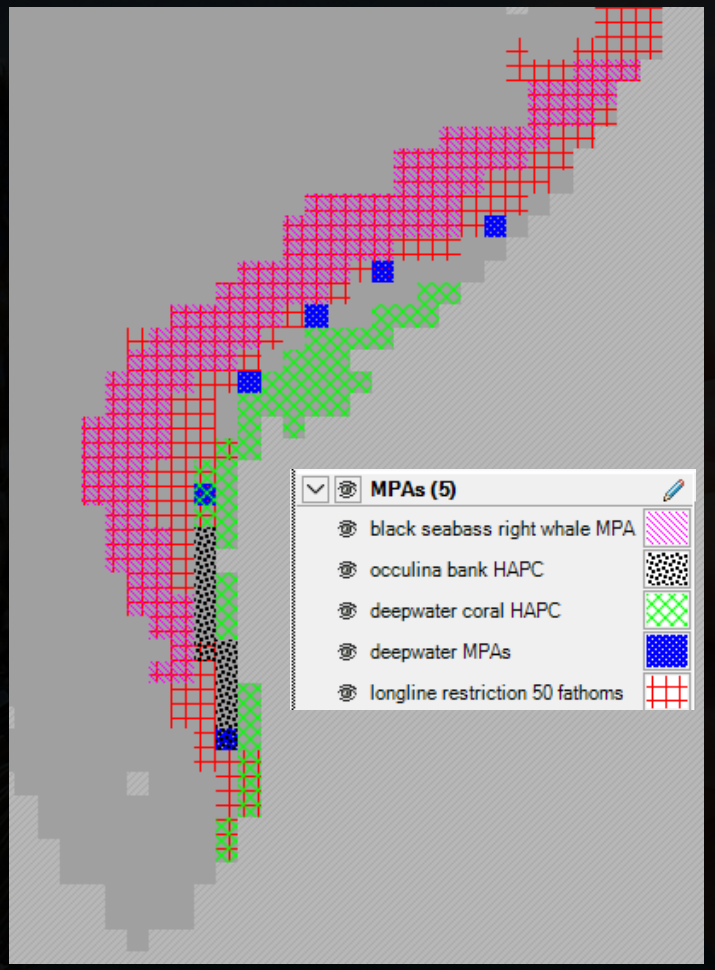




Restricted Zones

Reviewed

- Deepwater MPAs (6)
  - Excluded: East Hump (Keys), Charleston DAR (too small)
- Bottom Longline Restricted Zones
- Black Sea Bass/Right Whale Restricted Area
- Deepwater Coral HAPC
- Oculina HAPC: added but will stay turned off for now
- Oculina Experimental Closed Area: too small
- Spawning SMZs: too small



- Closures are specific to fleets and seasons
-Manually carved out area in Florida between Bottom Longline Restricted Zone and Deepwater Coral HAPC (Oculina HAPC)
-Dynamic: will be introduced into model simulation the month/year they were established

MPA	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1: Comm Hook and Line	2: Comm Long Line	3: Comm Other	4: Rec Headboat	5: Rec Other
1: black seabass right whale MPA	⛔	⛔	⛔	⛔	✓	✓	✓	✓	✓	✓	⛔	⛔	✓	✓	⛔	✓	✓
2: occulina bank HAPC	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	✓	✓	⛔	✓	✓
3: deepwater coral HAPC	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	✓	⛔	⛔	✓	✓
4: deepwater MPAs	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔
5: longline restriction 50 fathoms	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	⛔	✓	⛔	✓	✓	✓

Spatial-temporal environmental drivers

Purpose: EwE's habitat capacity model determines the area each species can use in each cell by functional responses to multiple environmental factors. ST drivers inform habitat capacity calculations for each functional group at each time step in each cell.

Reviewed

- HYCOM
- MODIS
- Copernicus Marine Services (EU)

  Global Ocean Physics Reanalysis: **GLORYS**

  -Designed for compatibility with climate projections

  -Available: SST, bottom temp, Chl. a, salinity, nitrates, O2, net primary production, phytoplankton, and more

Decision

Using: SST, bottom temp, Chl. a

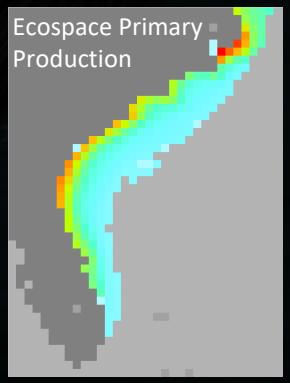
Monthly time steps through 2023

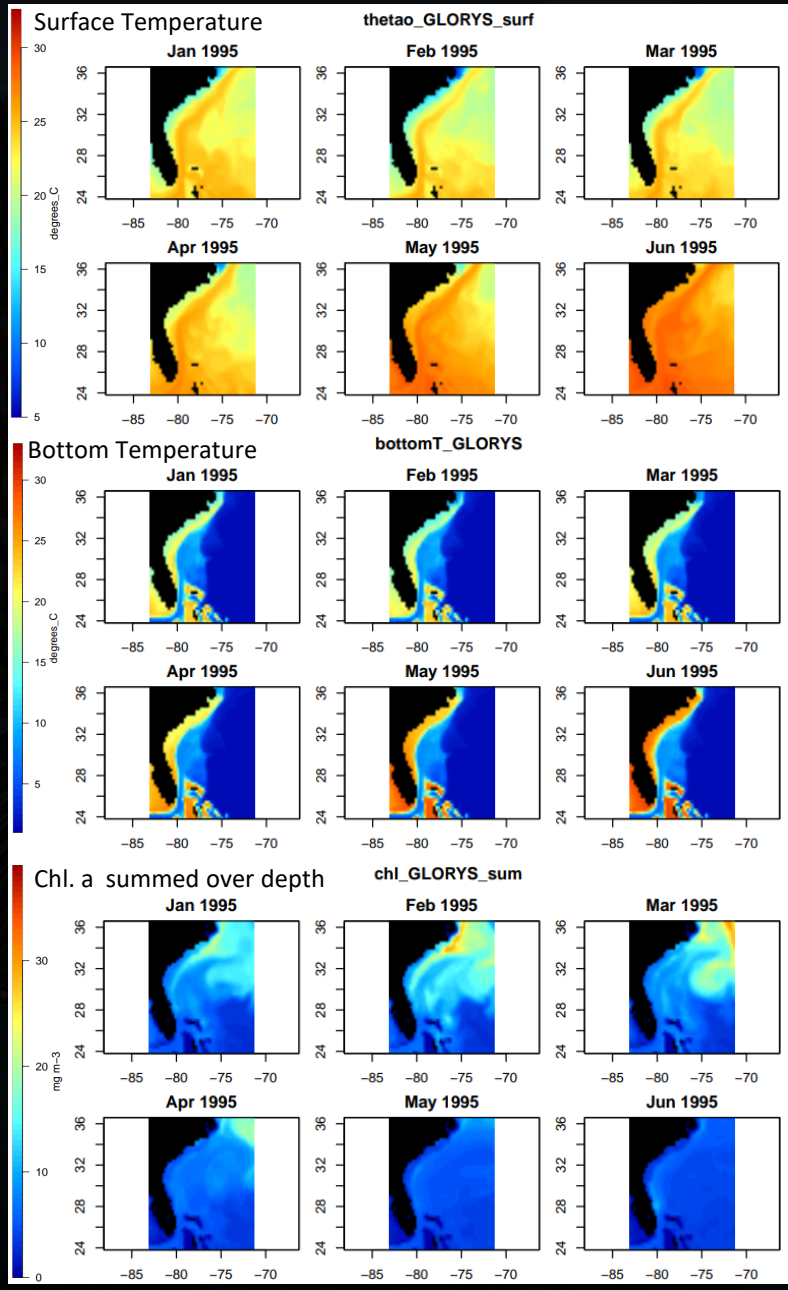
Will use for basemap of Primary Production

Testing options:

-Average over all months and years

-Average of Ecopath base year (1995)





SARF Model | Ecospace

Environmental Preference Functions

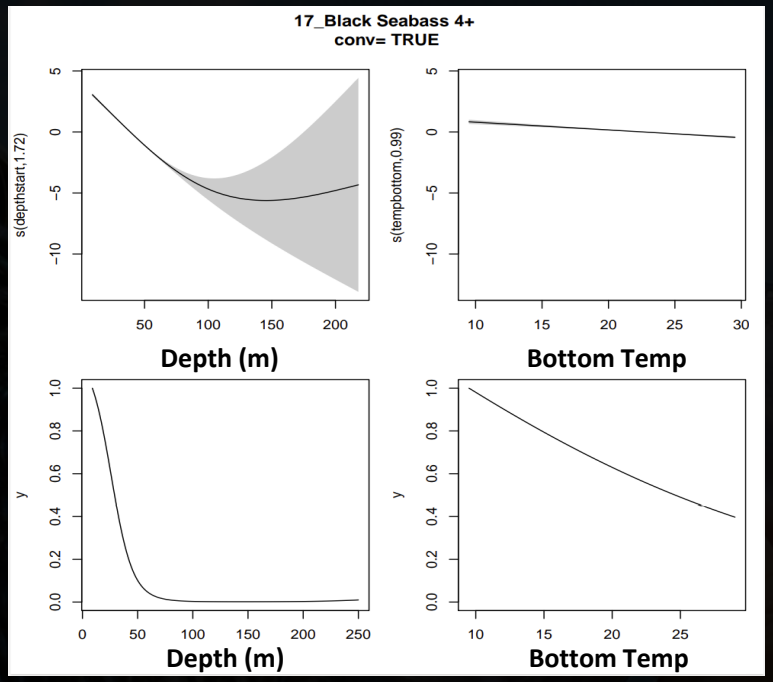
Purpose: capture each species' predicted presence across the range of each environmental driver

Depth and Temperature

- For species that enter traps
  - SERFS Chevron Trap data
    - Has length data for multi-stanza groups
    - Checking against trap age data*
- For species that don't enter traps
  - SERFS Video data
- For species deeper than SERFS*
  - ROV Surveys from NOAA
  - South Atlantic Deepwater Longline
    - Age data for multi-stanza groups
- For all other species
  - Aquamaps

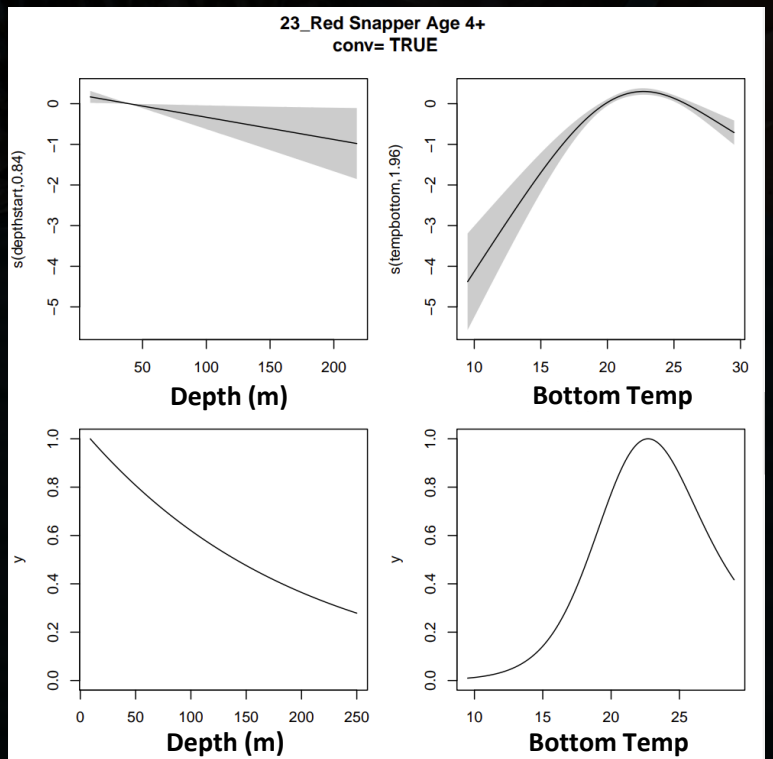
-Fitted binomial GAM model for each species/length stanza
-Predicted across the range of habitat values to create environmental preference functions

*ongoing work



GAMs

Preference Functions

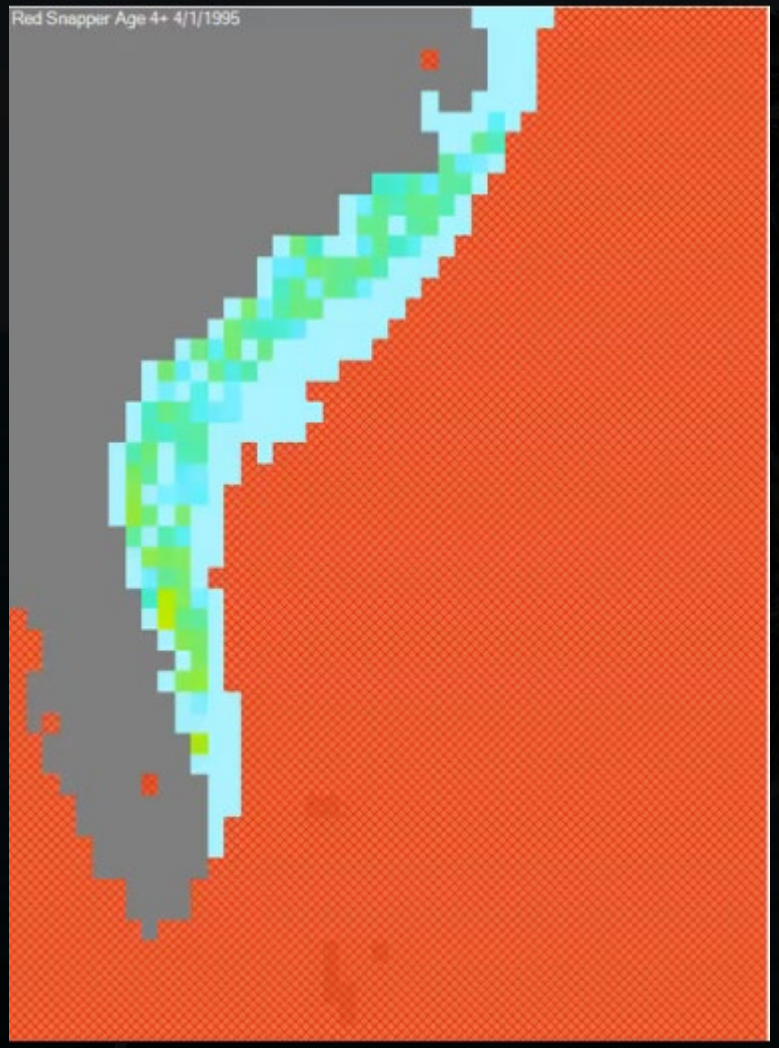


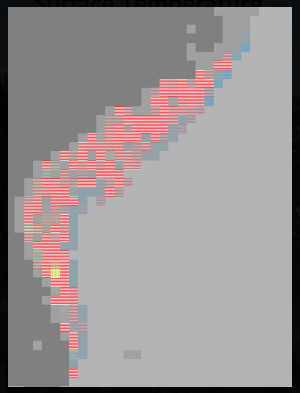
GAMs

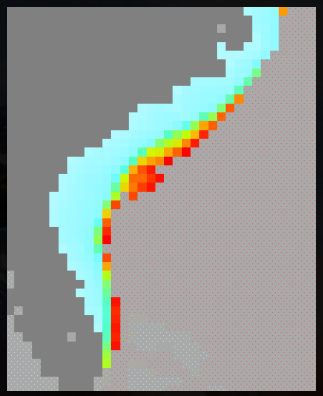
Preference Functions

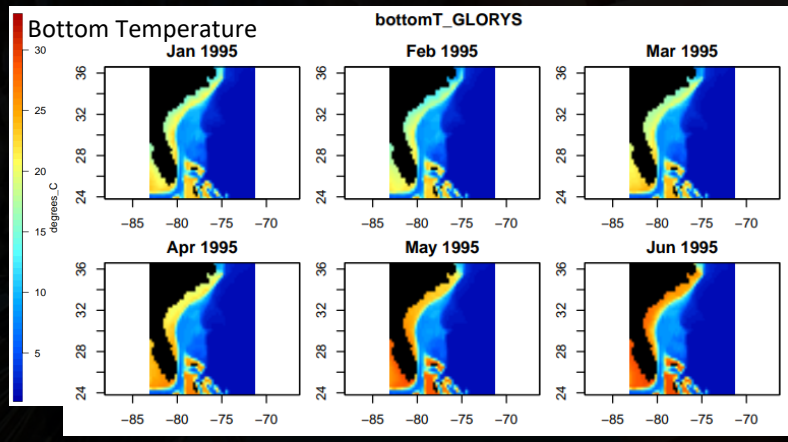
Habitat Capacity – Prelim Run

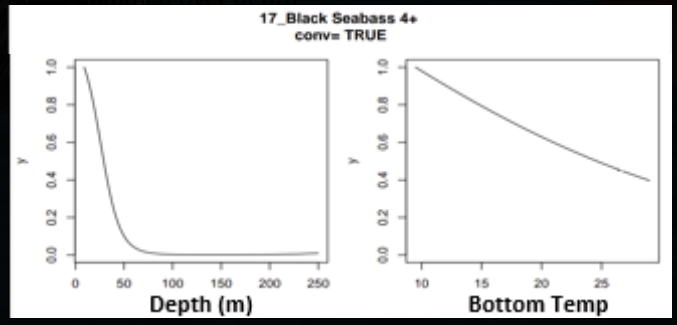
Computed Habitat Capacity – Red Snapper Age 4+





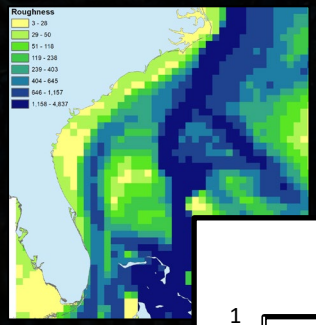






Roughness Functional Responses Pt. 1

ETOPO 2022



<u>Purpose</u>

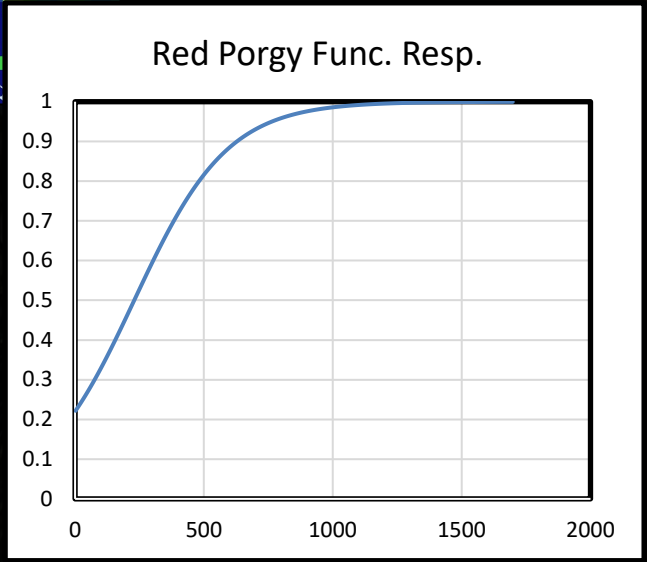
-Capture functional response to structural complexity

-Fill in the gaps between reef maps

-Distribute species across depth and habitat features

<u>SERFS Video Presence/Absence data (2015-2019) + ETOPO 2022</u>

- Used as response variable to estimate roughness functional response per species
  - Initially considered GAMs with a sampling year random effect, but it didn't appear necessary
- Fit GLMs with roughness and depth covariates, then added to Ecospace by controlling depth (i.e., setting depth to mean value)



Roughness Functional Responses Pt. 2

<u>What about age structure? Can you add roughness to other GAMs?</u>

Adding roughness as covariate to the GAM models: overfit the model and influenced depth functions

-Could be that roughness and depth have a different relationship in different states

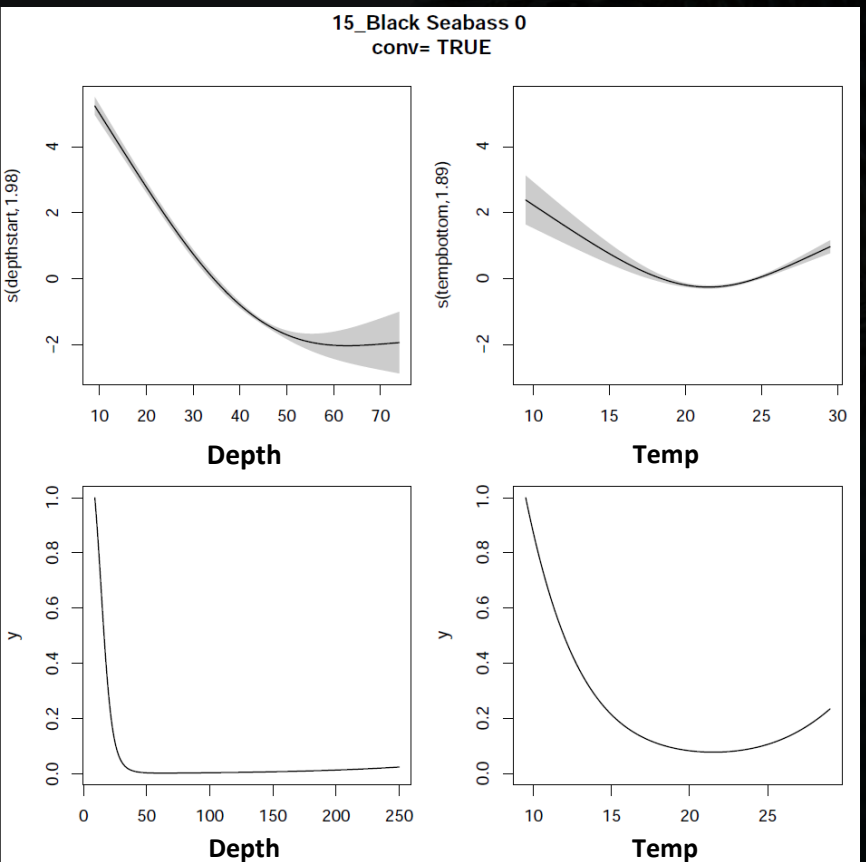
-Could be that the roughness grid we're querying isn't matching up with the actual roughness of sample sites

<u>In progress</u>

-In calibration, will plot roughness vs. non-roughness GAM depth/temp predictions to look for major differences

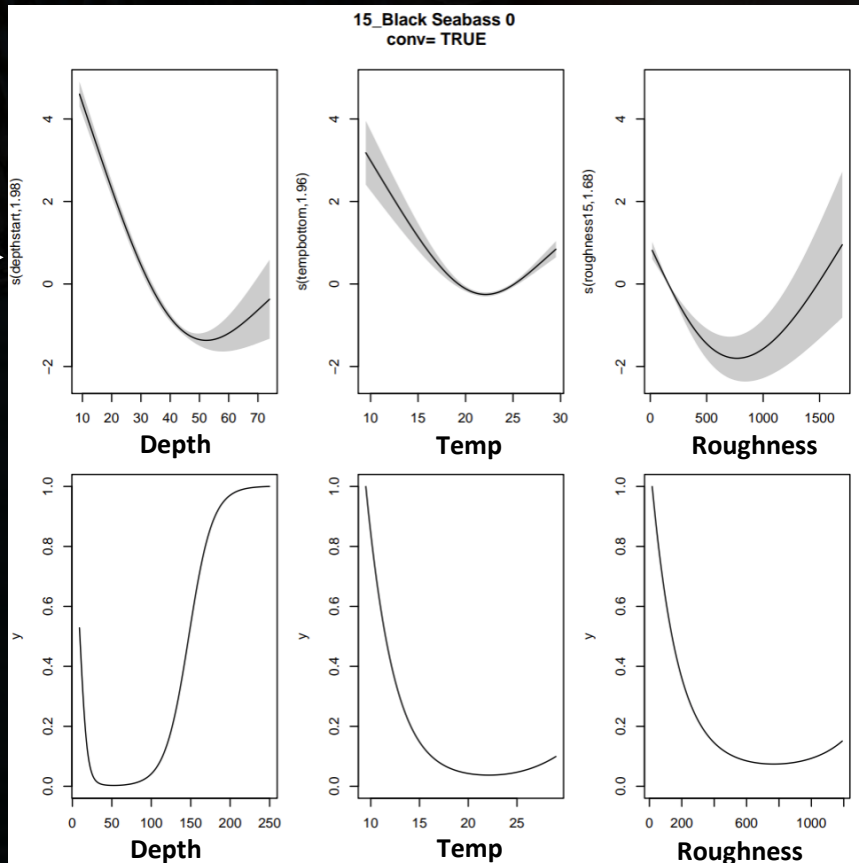
-Can re-run GLMs by age stanza with SERFS chevron trap data

-Looking into roughness functions from ROV data



GAMs

Preference Functions



Dispersal

Purpose

Controls rate at which biomass of each group can move between cells

- Low dispersal oyster: benefit from static MPAs, stuck with problems
- High dispersal tuna: can escape problems, likely to leave safety

Reviewed

Literature Review of Tagging Studies

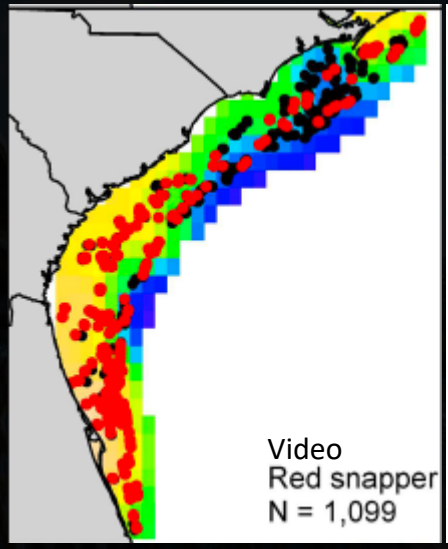
- 20+ studies, SEDAR reviews
- Distance traveled/time at large
- Compared against 300-30-3 rule of thumb and other models

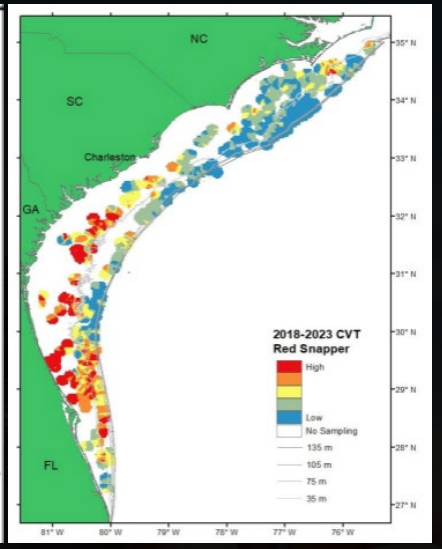
Compared against Holden Harris' Dispersal Rate Estimator

- Relative swimming speed from body characteristics, swimming mode
- Scales speeds to known home ranges within model

	Group name	Base dispersal rate
1	Sharks	4745.00
2	Pelagic Piscivores	4507.75
3	Greater Amberjack 0	365.230
4	Greater Amberjack 1-2	365.230
5	Greater Amberjack 3+	365.230
6	Gag 0	34.9300
7	Gag 1-4	34.9300
8	Gag 5+	34.9300
9	Red Grouper 0	34.9300
10	Red Grouper 1-3	34.9300
11	Red Grouper 4+	34.9300
12	Snowy Grouper 0	34.9300
13	Snowy Grouper 1-4	34.9300
14	Snowy Grouper 5+	34.9300
15	Black Seabass 0	25.2400
16	Black Seabass 1-3	25.2400
17	Black Seabass 4+	25.2400
18	Golden Tilefish 0	3.00000
19	Golden Tilefish 1-3	3.00000
20	Golden Tilefish 4+	3.00000
21	Red Snapper Age 0	40.9700
22	Red Snapper Age 1-3	40.9700
23	Red Snapper Age 4+	40.9700
24	Vermilion Snapper 0	10.00000
25	Vermilion Snapper 1-3	10.00000
26	Vermilion Snapper 4+	10.00000
27	Red Porgy 0	9.00000
28	Red Porgy 1-2	9.00000
29	Red Porgy 3+	9.00000
30	Gray Triggerfish	18.1600
31	Other Groupers	34.9300
32	Other Snappers	10.00000
33	Grunts	3.00000
34	Demersal Fish	20.0000
35	Forage Fish	50.0000
36	Cephalopods	20.0000
37	Shrimp	3.00000
38	Benthic Invertebrates	3.00000

SARF Model | Ecospace | Misc. | **Reference Data**





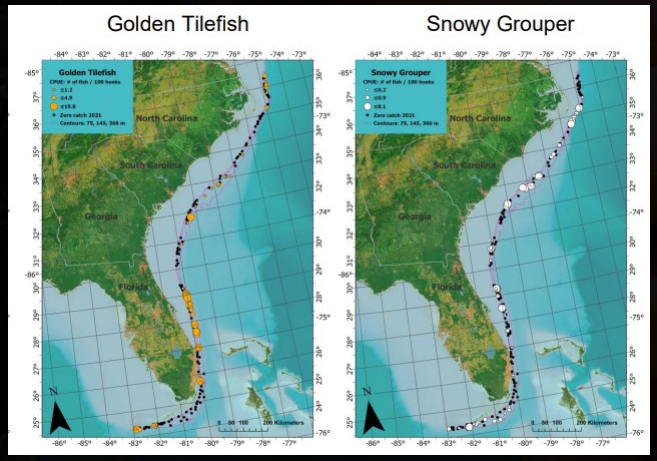
Purpose

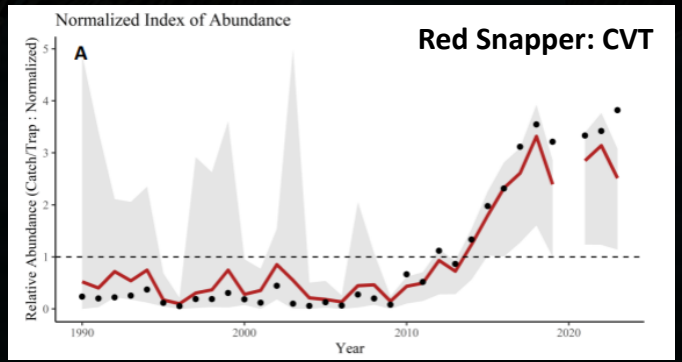
Compare model outputs vs. maps/trends in R
Potentially use directly in model if needed

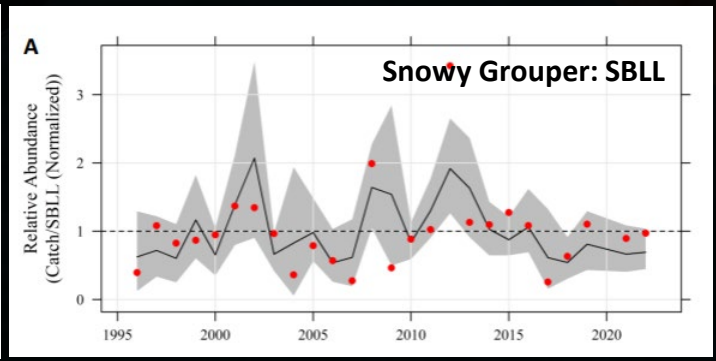
Reviewed

SERFS Video Predicted Probably of Presence Maps[1]
SERFS Chevron Trap heat maps
South Atlantic Deepwater Longline distribution maps

SERFS Video indices of abundance
SERFS Chevron Trap indices of abundance
Short Bottom Longline abundance trends
Long Bottom Longline: insufficient data for trends
ROV inside/outside MPA abundances



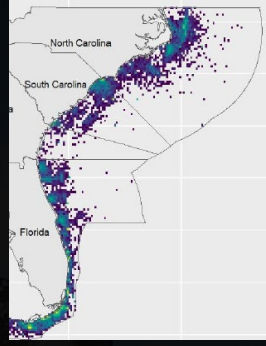




[1]Bacheler NM, Schobernd ZH, Berrane DJ, Schobernd CM, Mitchell WA, Teer BZ, et al. (2016) Spatial Distribution of Reef Fish Species along the Southeast US Atlantic Coast Inferred from Underwater Video Survey Data. PLoS ONE 11(9):e0162653

Fishing Effort - Reference

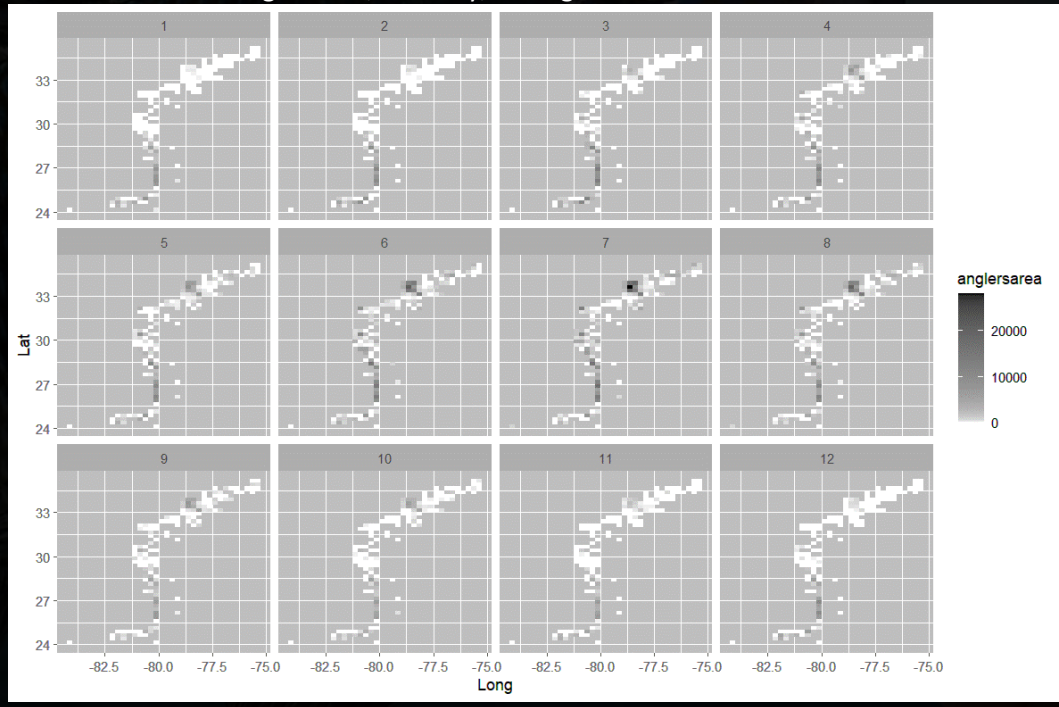
SEFHEIR 2022



Purpose

Reference data to compare to Ecospace effort predictions
Can use maps to constrain effort if the model predicts catch in places it shouldn't be
Assess seasonal trends in effort

Headboat vessel + angler data, monthly, average 2013-2023



Reviewed

Recreational

MRIP directed effort by month
- Seasonality

Headboat logbook trip data
- 2013 onward due to changes in reporting
- Vessel and angler data combined
- By year or by month (avg. '13-'23)

SEFHEIR data: 2021 onward

Commercial

ACCSP Catch data by FAO fishing area (total lbs)
- Relative trend (confidential data)
- Gear-specific annual catch maps for BSB/RS
- Gear-specific average maps for other groups

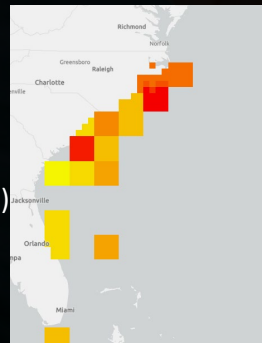
Vessel Operating Units (VOU) data
- 1995/1996: drastic spike in gear records due to upcoming permit changes

ACCSP Commercial Trip Count data
- Duplicates trips when one trip catches multiple species

In progress

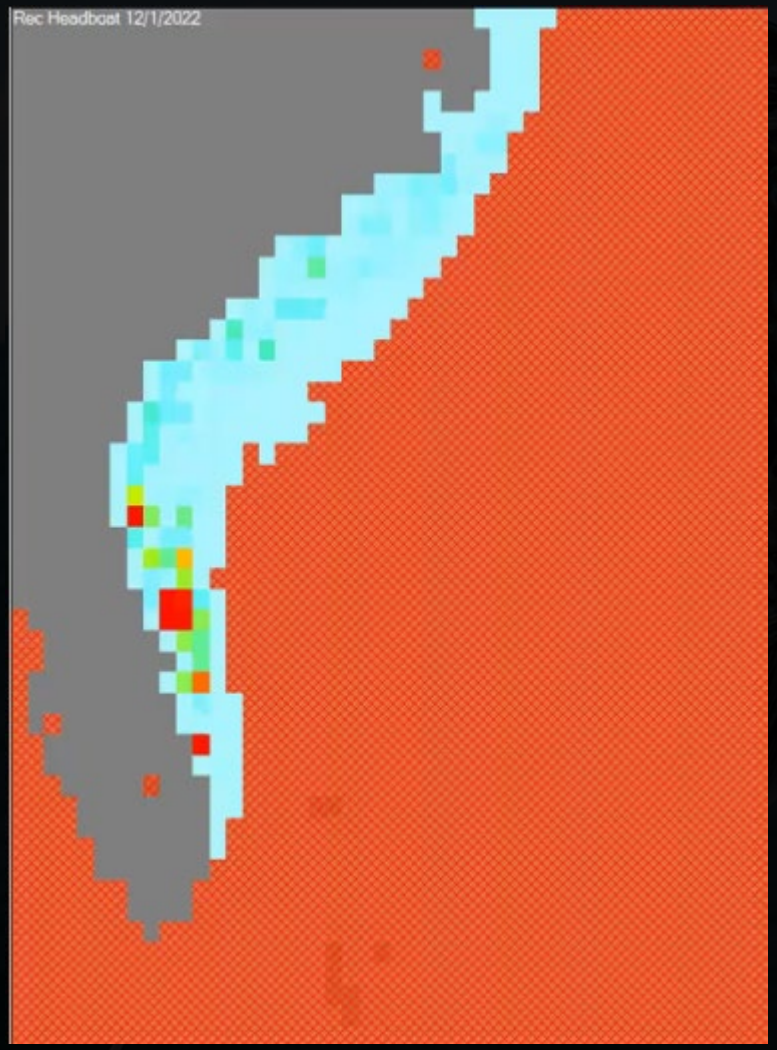
Coastal Fisheries Logbook data for trip by gear by month for SG fishery
Requesting accumulated landing series from ACCSP

Grunts
Hook and Line
Catch (Proportion)
Avg. 1995-2023

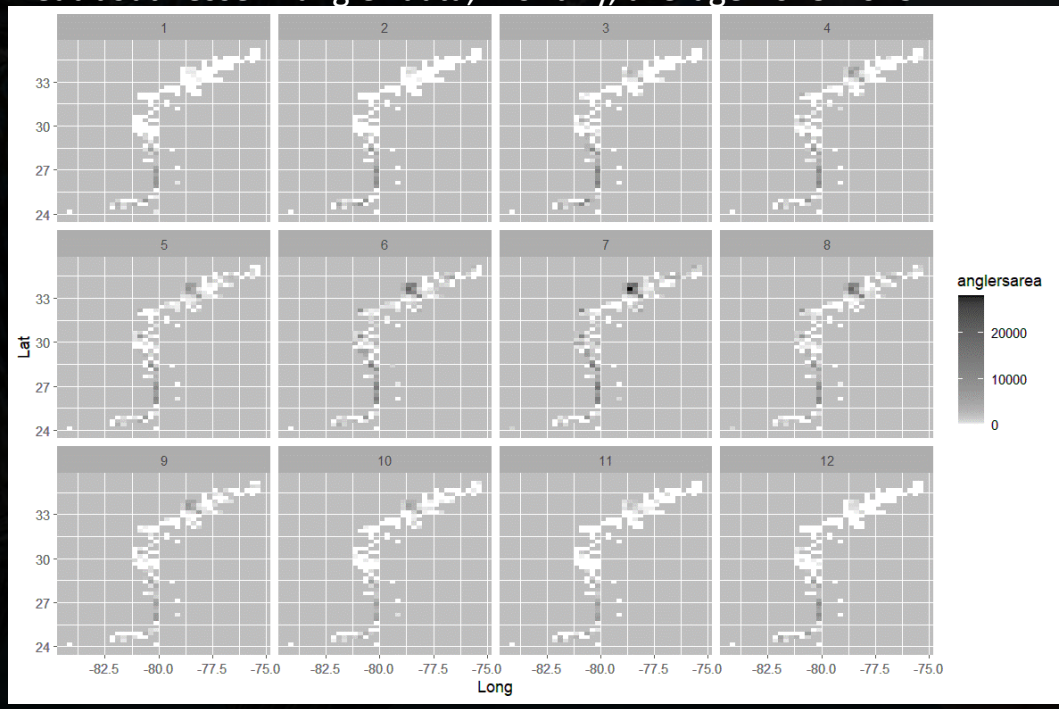


Fishing Effort - Reference

Headboat Effort Estimates – Preliminary Run



Headboat vessel + angler data, monthly, average 2013-2023

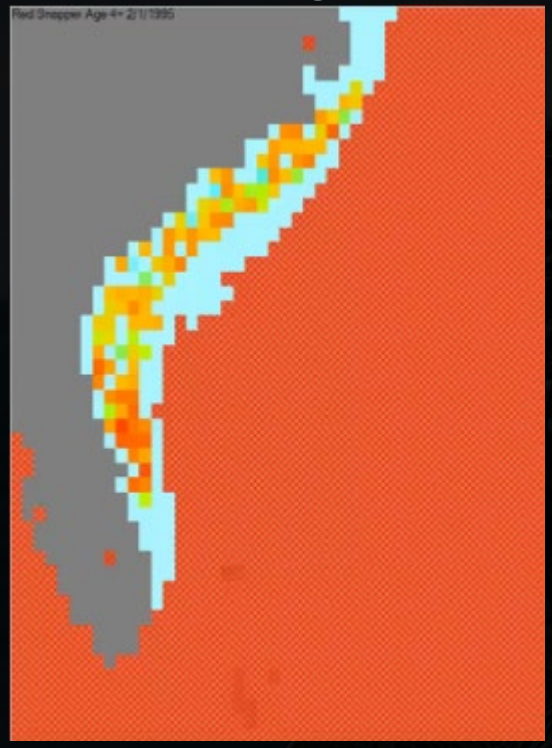


SARF Model

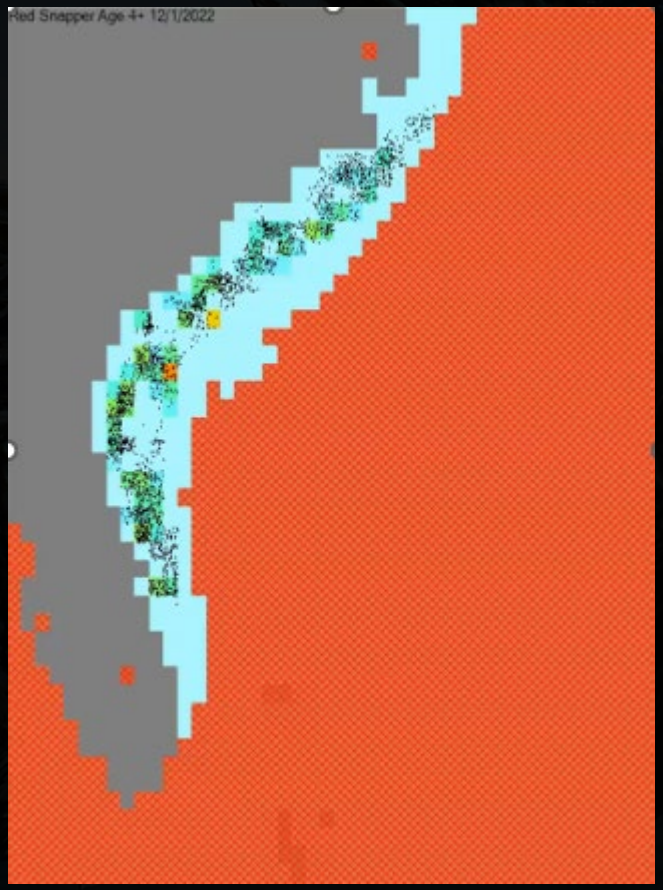
Ecospace

Preliminary Runs – Red Snapper

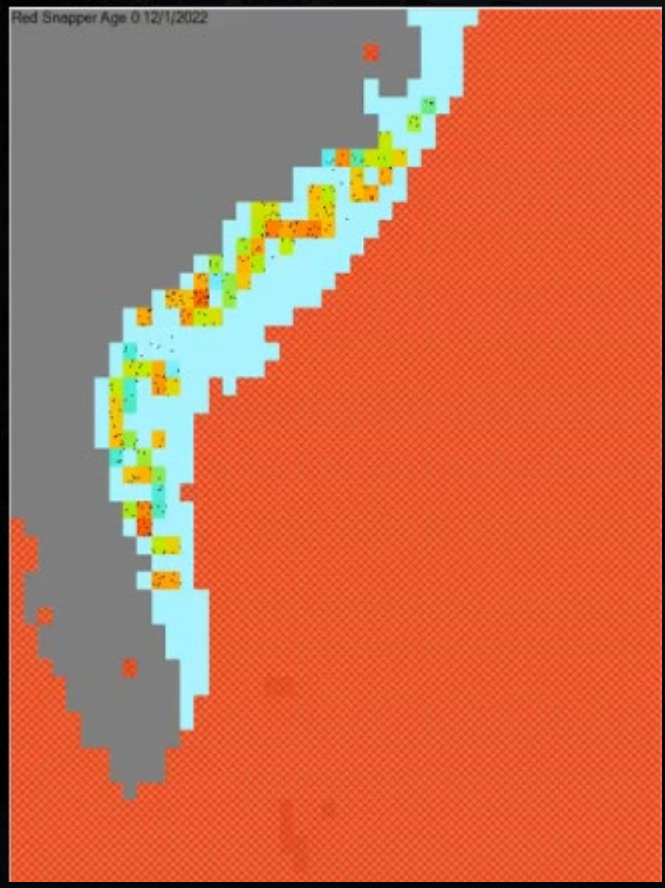
Catch – Age 4+



Biomass – Age 4+



Biomass – Age 0



SARF Model Ecospace

WG Meeting

Discussions

- Artificial reefs as dynamic maps?
  i. Data from state GIS services and "Artificial reef footprint in the United States ocean" (Paxton et al. 2024) indicate that the extent of known artificial reefs deployed after 1995 is approximately 0.84km^2. The decision was made to continue using artificial reefs as a static habitat layer, and in addition to explore the sensitivity of model outputs to using artificial reefs as a spatial-temporal variable.
- Explore scaling habitat suitability to better reflect realistic proportions of hard bottom.
  i. Habitat layers are additive, so model team is externally scaling habitat maps proportionally so as to not create unrealistic habitat capacity.
- Explore sailing costs as a potential method to enable closed seasons and represent small MPAs.
  i. Model Team has created the associated sailing cost maps and will explore this during ecospace calibration and sensitivity testing.
- Explore the inclusion of age structure for gray triggerfish.
  i. The Model Team will reassess adding age stanzas to gray triggerfish should the species stand out as a significantly important prey or high economic value group during calibration.
- Write up the methodology for future reference and consistency in creating mice models.
  i. Document the species included and excluded in the model.
    1. A spreadsheet documenting the inclusion/exclusion process during the SARF Model development is available in the Model Group Google Drive linked below.
  ii. Document data treatment
    1. Ongoing
- Validate environmental data against known events (next slide)
- Visualize preference functions for depth and bottom temperature over histograms of the model data (next two slides)

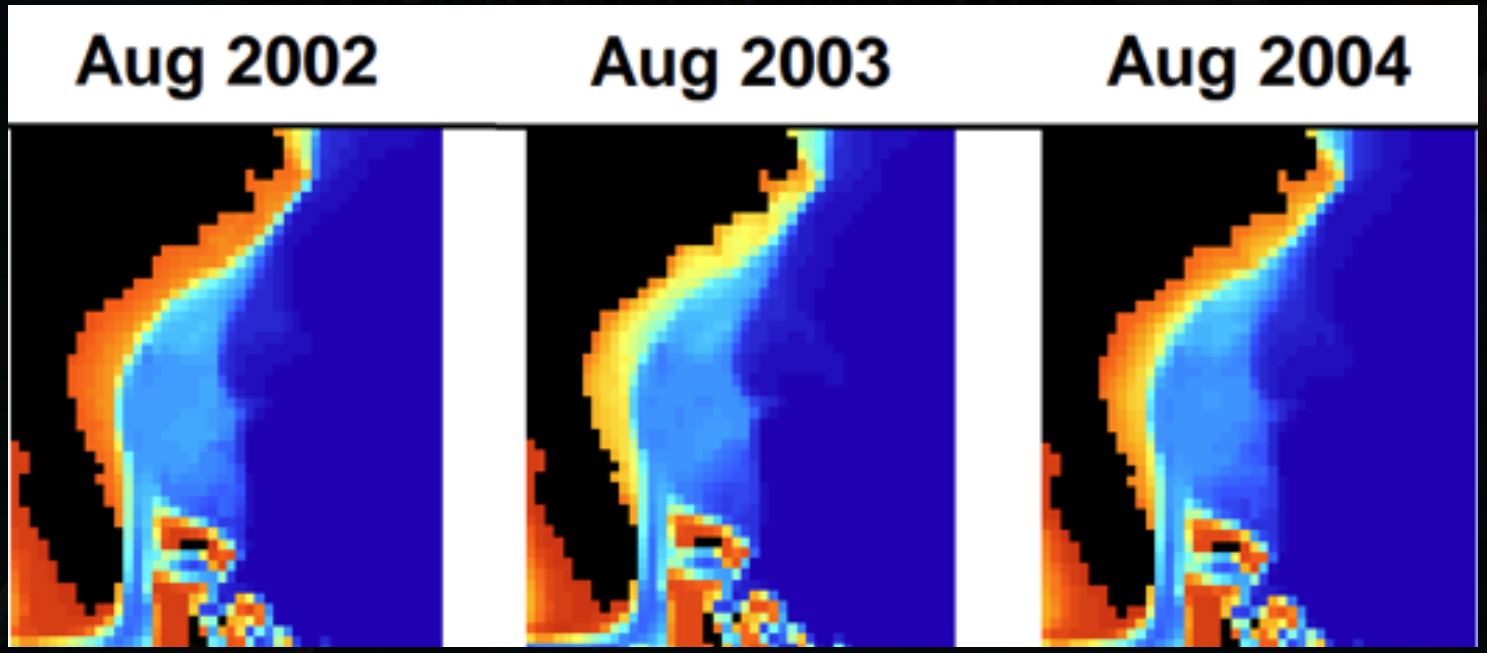
SARF Model

Ecospace

WG Meeting - diagrams

Temperature anomalies

The WG and SAFMC staff provided a list of large- and small-scale temperature anomalies documented during the model time period (e.g., a strong coast-wide cold water upwelling in August of 2003). The model team compared monthly bottom temperature maps from the year of the event and the years before and after. Results indicate that the GLORYS bottom temperature captured all but one known temperature anomaly events. The only reported cold water upwelling not visible in the GLORYS data was reported to have occurred overnight with temperatures returning to normal “a few days later”. It was considered acceptable that such a short-lived event would not be captured in the monthly average bottom temperature. A short description and visual analysis of the full list of events is available on the Model Group Google Drive.

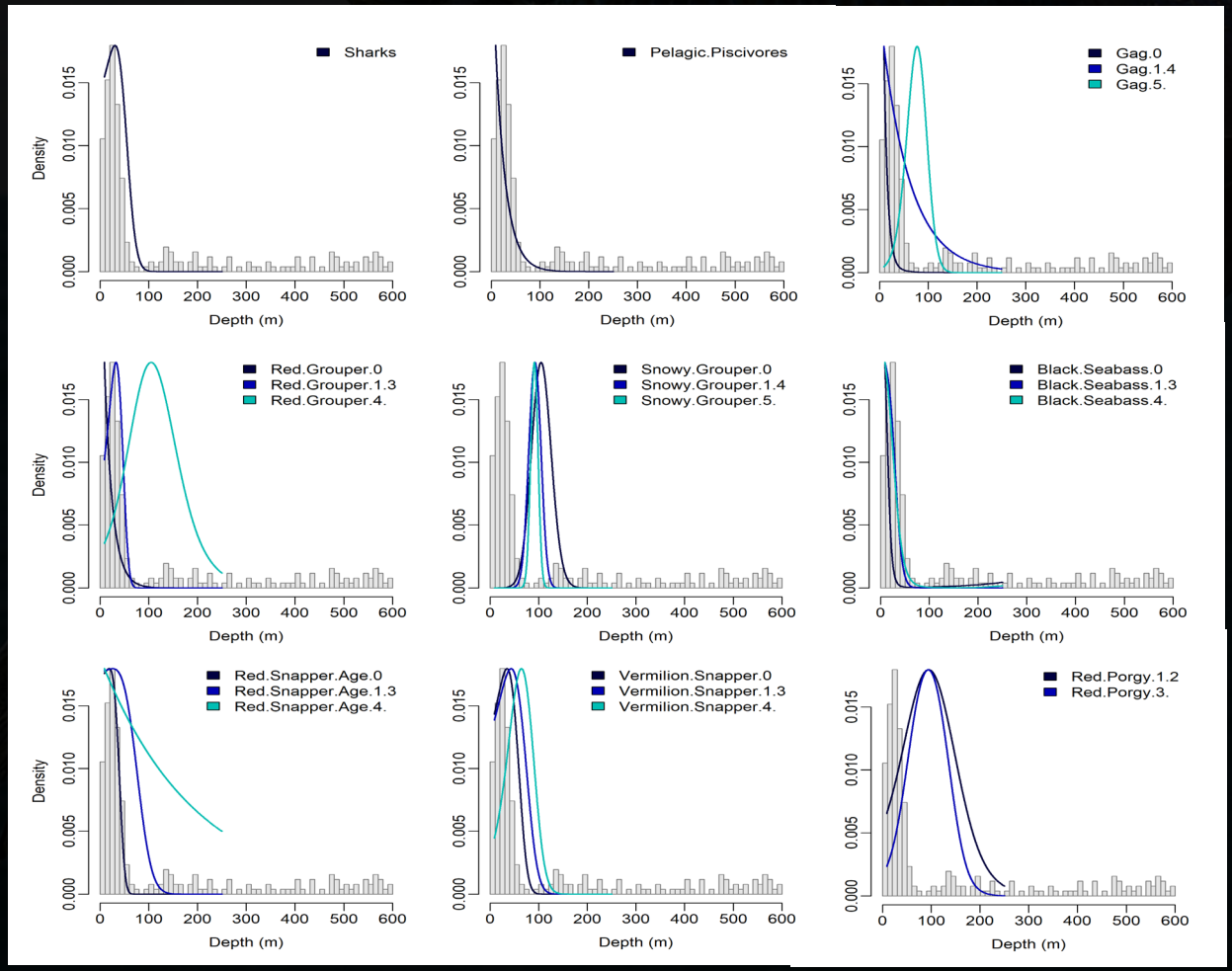


SARF Model Ecospace

WG Meeting - diagrams

Depth values in basemap vs. depth preference functions

All updated figures will be available on the Model Group Google Drive as preference functions are updated for Age 0 stanzas and deepwater species.

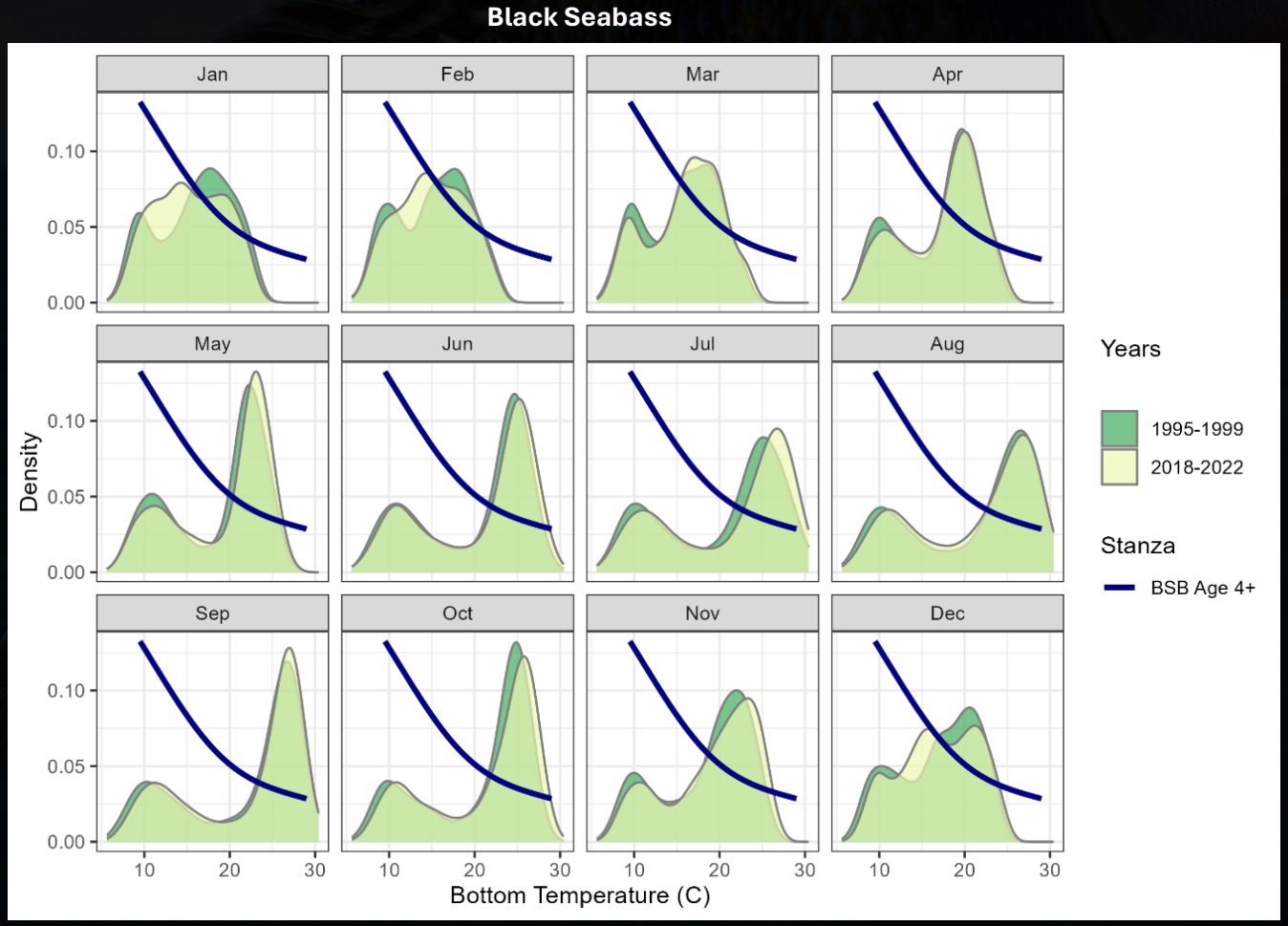


SARF Model Ecospace

WG Meeting - diagrams

Bottom Temp values in ST Drivers vs. bottom temp preference functions

All updated figures will be available on the Model Group Google Drive as preference functions are updated for Age 0 stanzas and deepwater species.



SARF Model Ecospace

WG Meeting - diagrams

Bottom Temp values in ST Drivers vs. bottom temp preference functions

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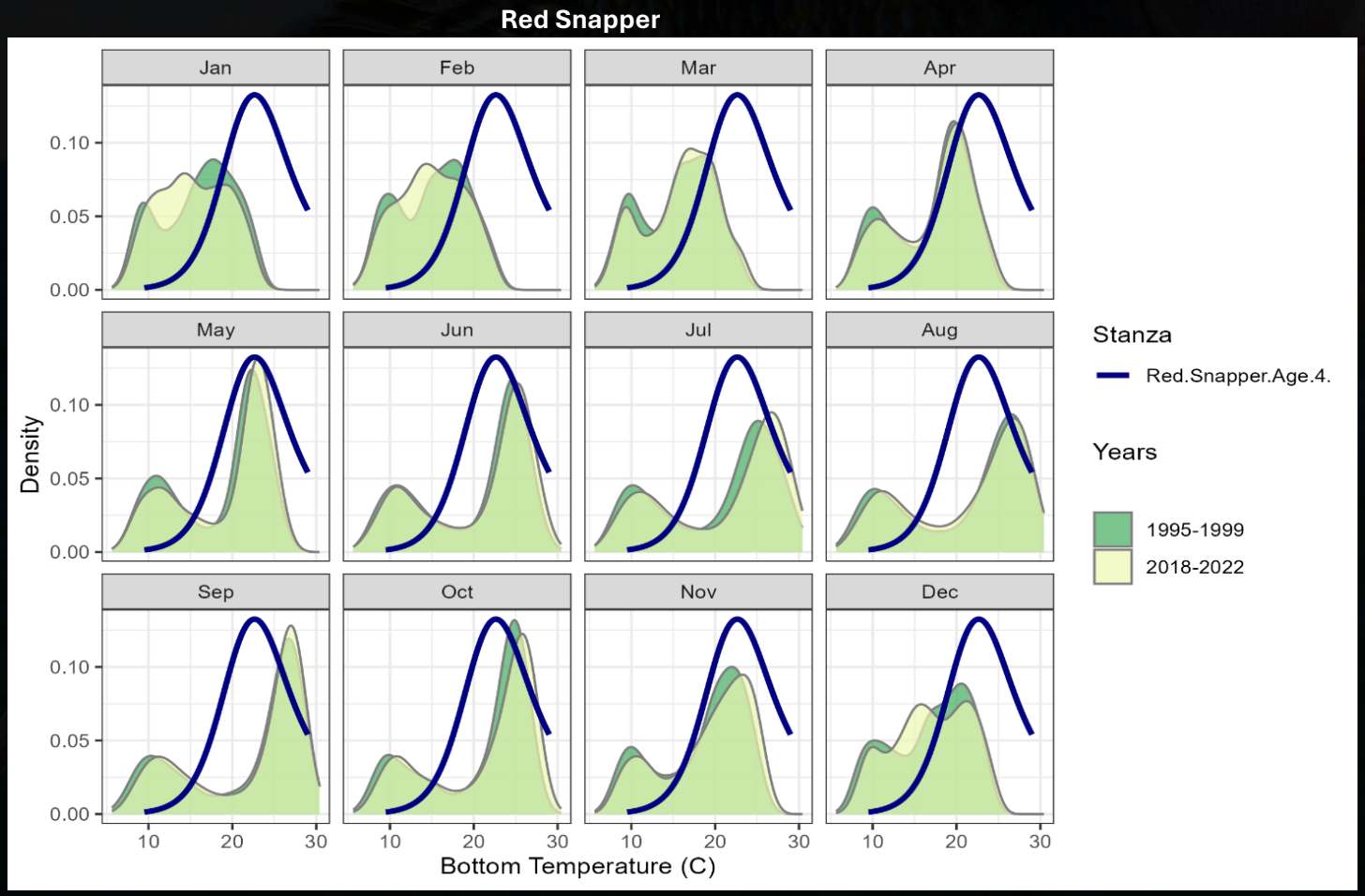

Objectives:

- Statistically compare model predictions with observed data, accounting for uncertainty
- Compute an overall cost function for minimization
- Reveal the most sensitive parameters in Ecospace
- Identify a confidence set of model configurations
- Identify a best run configuration
- Automated and computationally efficient

What do we mean by calibration?

EwE console application

The EwE console application (CA) allows for parameters to be defined in text files and model runs executed using script (R, Python).

Parameters available:

- Ecosim vulnerabilities
- Environmental preference functions
- Dispersal rates
- Mediation functions
- Ecosim time series effort forcing
- Other run settings, input/output, directories

Command file format

```
<EWE_MODEL_FILE>, C:\...\WFS FEM 2.10 ewevOct23.eweaccdb, System.String
<SPATIAL_CONFIG_FILE>, C:\...\WFS FEM STconfig2.xml, System.String

-----Scenarios and Ecospace run type-----
<MODEL_RUN_TYPE>, 1, System.Int32
<ECOSIM_SCENARIO_INDEX>, 4, System.Int32
<ECOSPACE_SCENARIO_INDEX>, 3, System.Int32
<ECOSPACE_USE_IBM>, True, System.Boolean
<N_ECOSPACE_YEARS>, 38, System.Int32, Run length in years

-----Output and saving-----
<ECOSPACE_USE_CORE_OUPUT_DIR>, False, System.Boolean
<ECOSPACE_OUTPUT_DIR>, C:/.../run0001, System.String, Updated
<ECOSPACE_USE_ANNUAL_OUTPUT>, True, System.Boolean,
<ECOSPACE_SAVE_AVERAGED_BIOMASS>, True, System.Boolean,
<ECOSPACE_SAVE_MAP_BIOMASS>, True, System.Boolean

-----Constructed Parameter Tag Lines-----
<ECOSIM_VULNERABILITIES_INDEXED>(1),999.9, Indexed.Single
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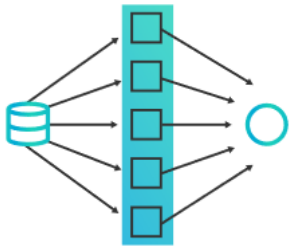
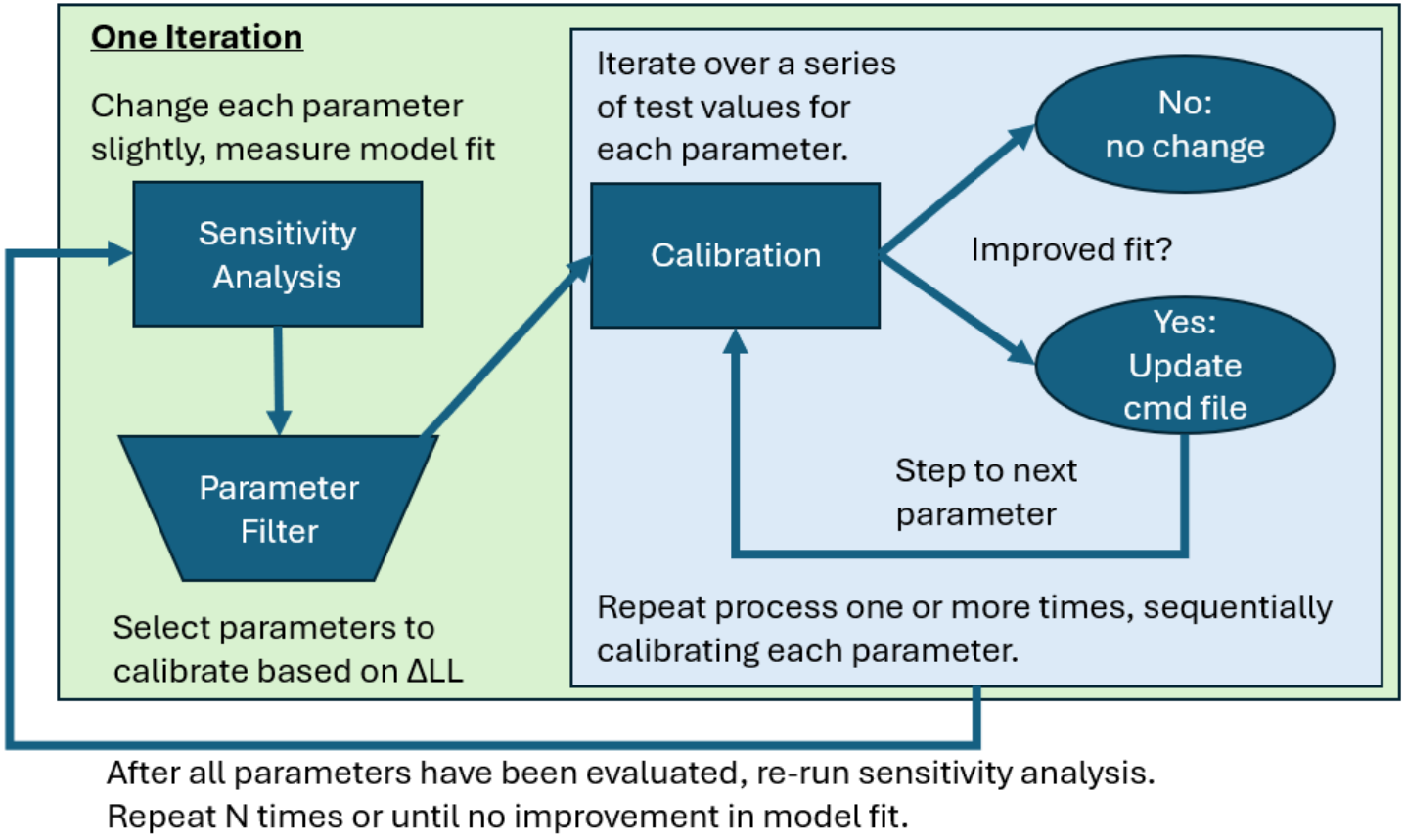


Using the CA, Ecospace runs can be executed in parallel using R or Python

Ecospace Calibration Procedure

The calibration procedure consists of a series of iterations, with different parameters calibrated in each iteration.

Within each iteration, parameters are 'calibrated' sequentially, beginning with the most sensitive parameter.



Ecospace Calibration Procedure

The calibration procedure consists of a series of iterations, with different parameters calibrated in each iteration.

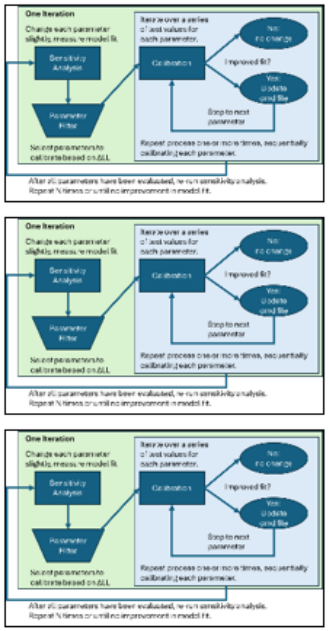
Within each iteration, parameters are ‘calibrated’ sequentially, beginning with the most sensitive parameter.

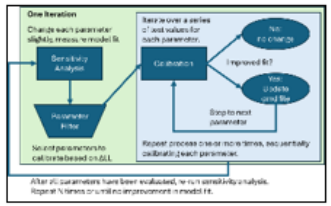
This can be done in phases, to focus on key aspects of model behavior.

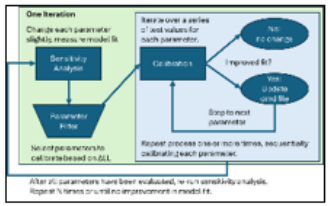
Phase 1:
Fit spatial patterns
(environmental responses)

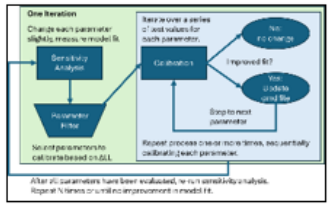
Phase 2:
Fit temporal patterns
(vulnerabilities)

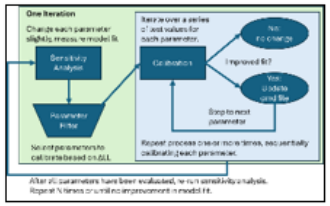
Phase 3:
Fit other patterns
(M0 forcing)

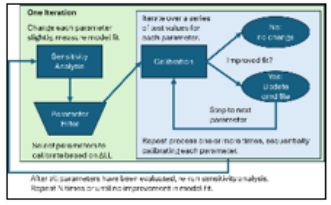


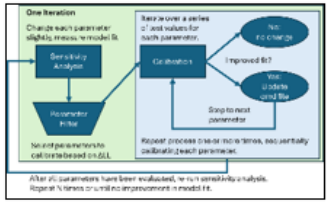












Model 1 → Model 2 → Model 3

Next Steps

SSC Discussion

- What data we're calibrating towards
  - Fitting to Ecospace to time series, or spatial maps (SERFS species distribution maps or other)
- Ecospace structure: Habitat maps, ST drivers, fishing effort maps

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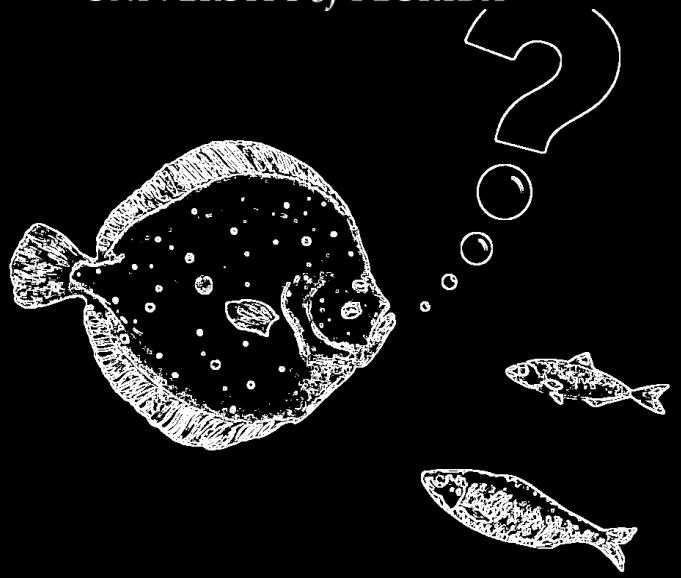
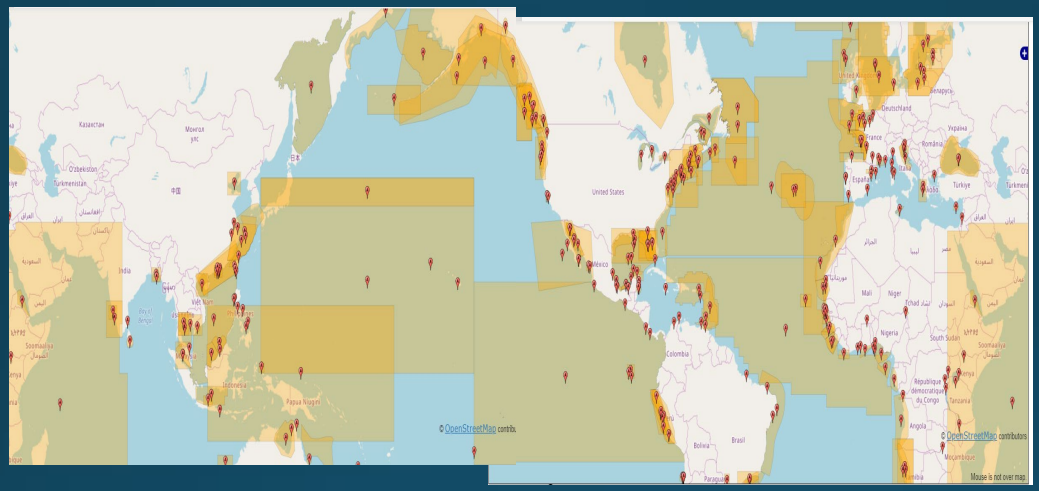


Appendix

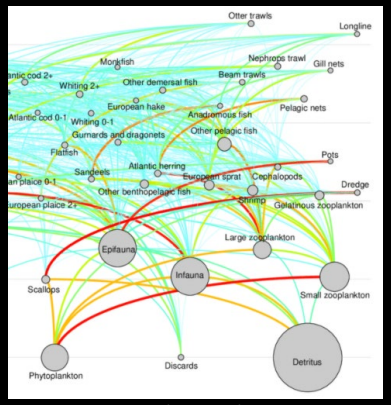
Ecopath with Ecosim and Ecospace (EwE)



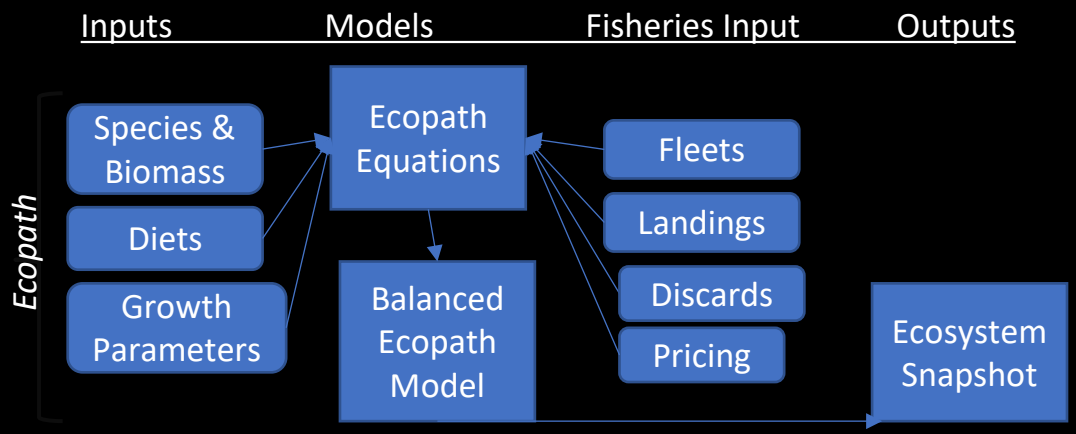
Ecopath
Mass-balance
Snapshot

Ecosim
Time
Dynamics

Ecospace
Space-Time
Dynamics



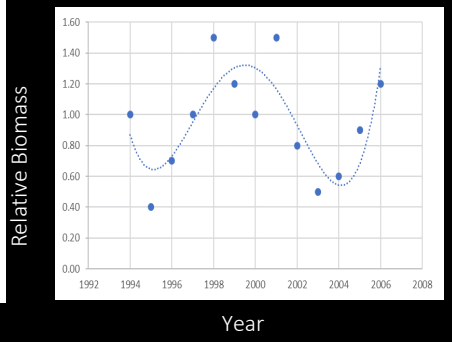
Bentley et al. 2019



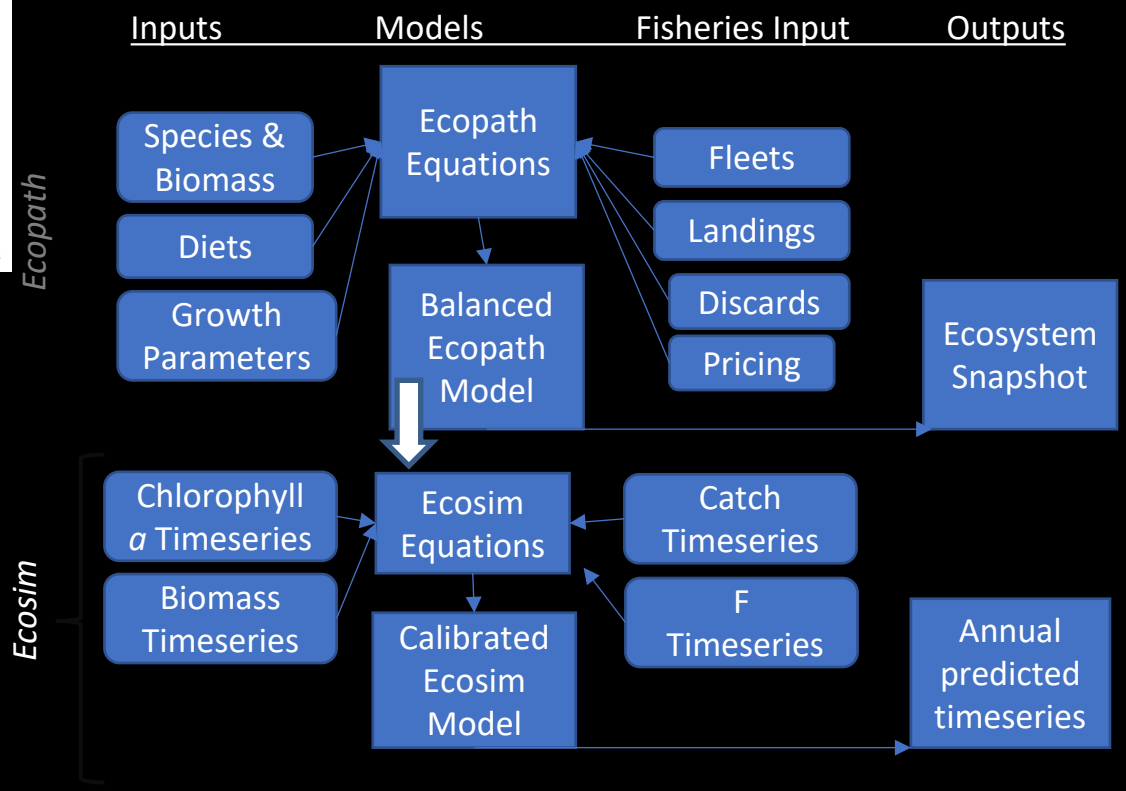
- Ecopath
  - Mass-Balance Snapshot
    - Prey mortality is predator consumption
    - Groups are linked via diet
  - Key groups, system size, flows
  - Best Practices (Link et al. 2010)
    - E.g., most biomass should be found at lower trophic levels
  - Builds the foundation for Ecosim and Ecospace

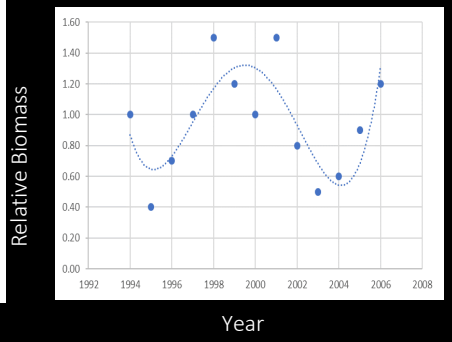
Table 1. Ecological and fisheries related indicators used in this comparison.

Acronym	Indicators	Units	Definition
Ecological indicators			
TST	Total System Throughput	$t \cdot km^{-2} \cdot y^{-1}$	The sum of all the flows through the ecosystem
PP/TST	Primary production/TST		Primary production over the sum of all the flows through the ecosystem
FD/TST	Flows to Detritus/TST		Flows to detritus over the sum of all the flows through the ecosystem
Q/TST	Total consumption/TST		Total consumption over the sum of all the flows through the ecosystem
R/TST	Total respiration/TST		Total respiration over the sum of all the flows through the ecosystem
Ex/TST	Total exports/TST		Total exports of the system over the sum of all the flows through the ecosystem
PP/P	PP/Total Production		Primary production over total production
MeanPz (MaxPz)	Mean (Max) proportion of total mortality due to predation		The mean (or Maximum) proportion of each group's total mortality that was accounted for by each predator
meanEE	Mean Ecotrophic Efficiency	%	Ecotrophic efficiency of a group is that proportion of the production that is utilized in the system.



- Ecopath
- Ecosim
  - Estimate time dynamics
  - Predator-prey interactions are not random and occur in ‘arenas’
  - Only a fraction of prey is available for consumption (i.e., vulnerable)





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