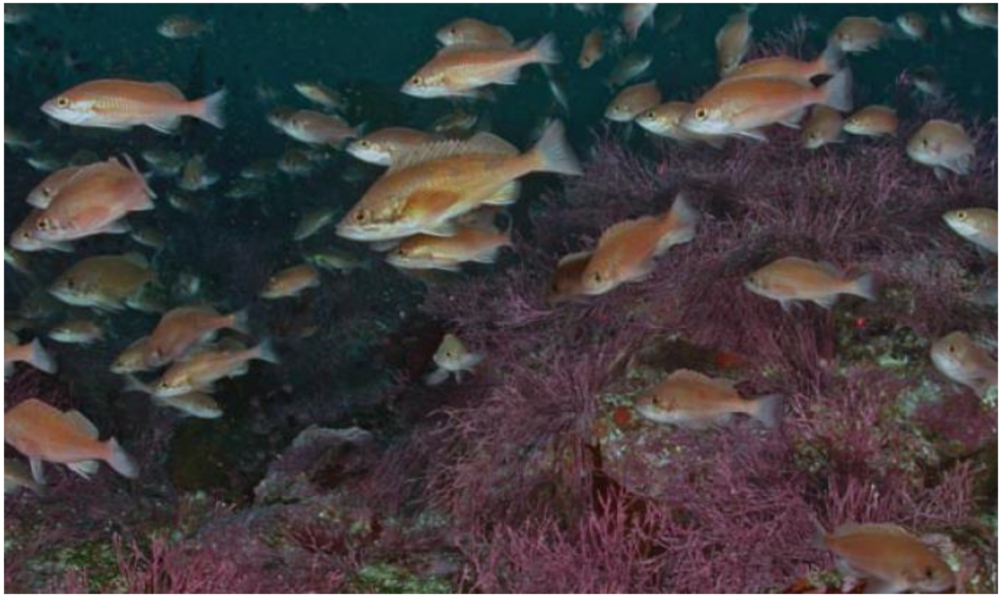
Incorporating Socioeconomic Data into Stock Assessments and its Effect on Status Criteria Determination



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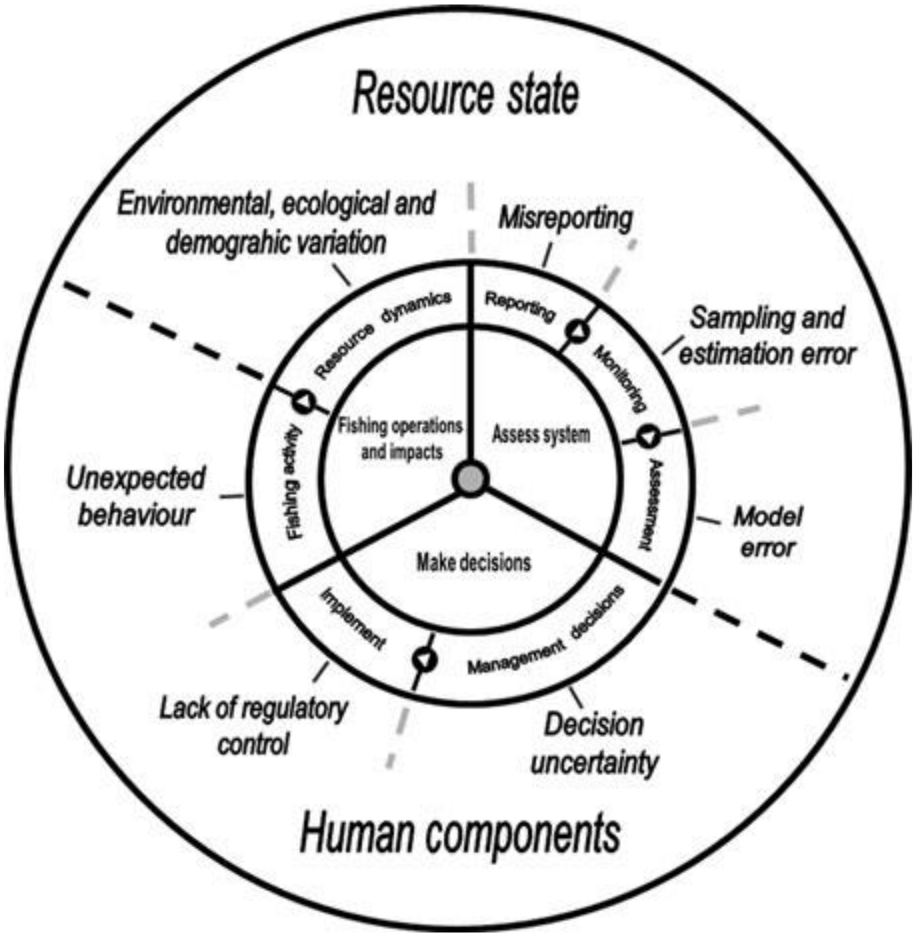
Objectives

- Human behavior and uncertainty in fisheries assessments
- Agent-based modeling to understand interactions and feedbacks in a system
- Gulf of Mexico agent-based simulation model: versions and configuration
- Simulation model results
- Stock assessment of simulation model results and comparison with “known” simulation system dynamics
- Results, discussion, and implications
- Additional applications of models to understand fisher behavior
- Future research

Fisher Behavior: Key Source of Uncertainty in Fisheries

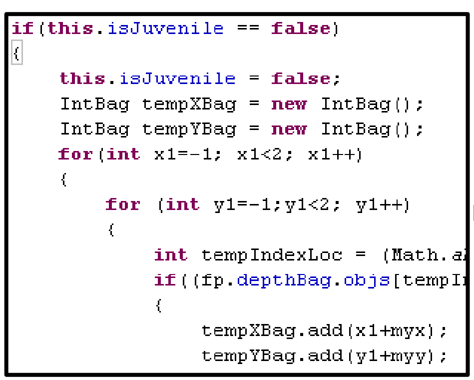
- Resource users sometimes respond to policies in an unintended way.
- Attention mostly focused on model and biological data uncertainty.
- Uncertainty due to human behavior has received much less attention.
- Human behavior dictates the spatial and temporal locations of fishery-dependent observations, often used to infer abundance trends and population demographics in assessment models.

(See *Fulton, et al. 2011* for review)



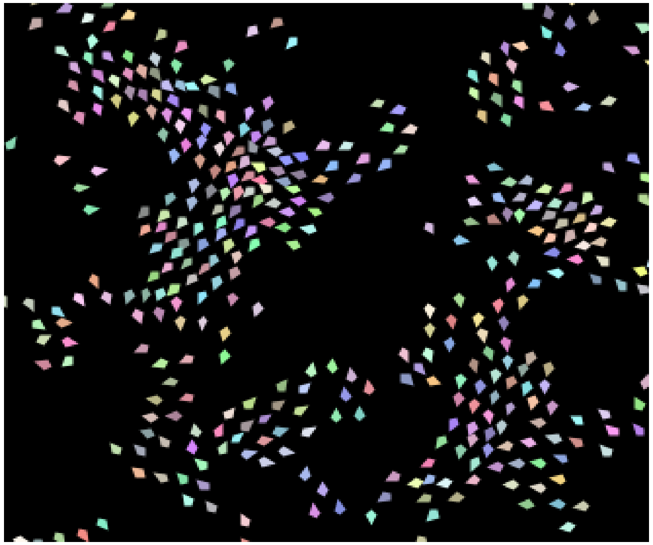
Hypothesis Testing Through Simulation

- Reproduce fish population dynamics and fishing fleet behavioral dynamics – allow them to interact across space and time under realistic state conditions.
- Compare metrics derived from simulated fishing fleet observations, with the biological dynamics simulated in the system.
- Agent-based modeling well suited to simulate complex social and biological dynamics and their interactions.



Agent Based Modeling

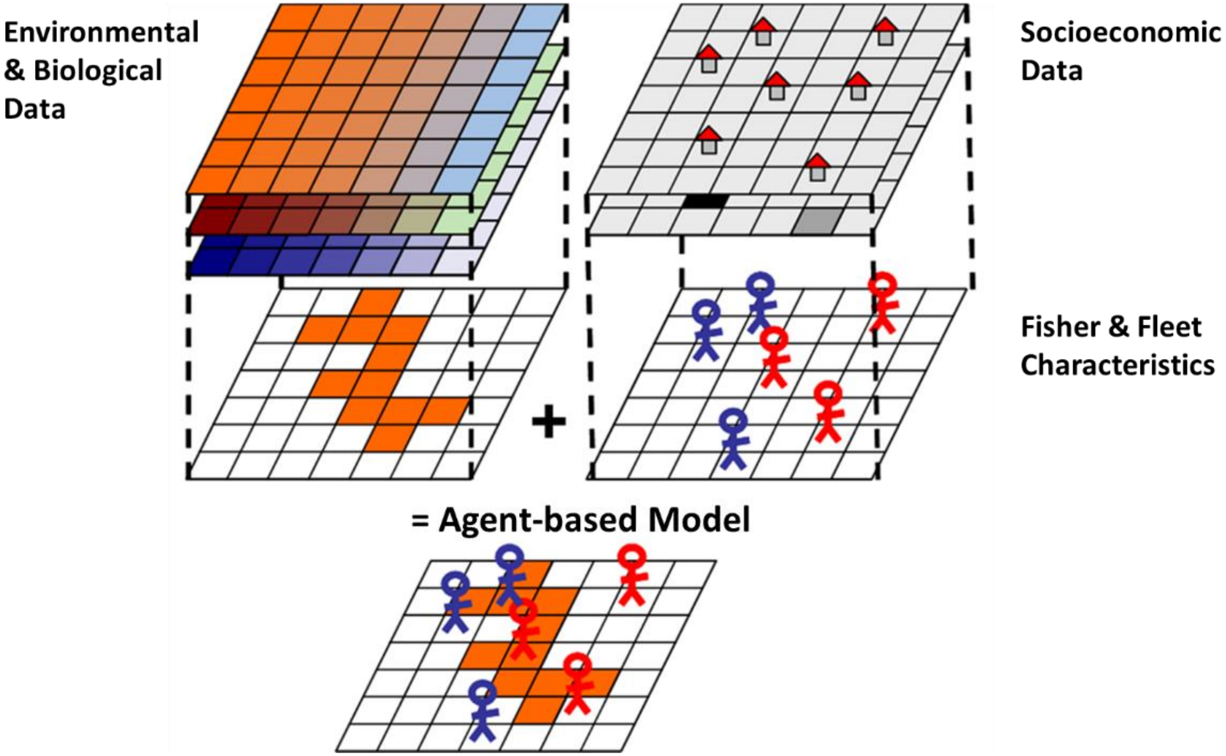
- Bottom-up approach: define behavior of individual
- Formulate theories about their interactions with one another and their environment
- Implement these theories in a computer simulation
- Observe the emergence of system-level patterns



Agent-based Modeling

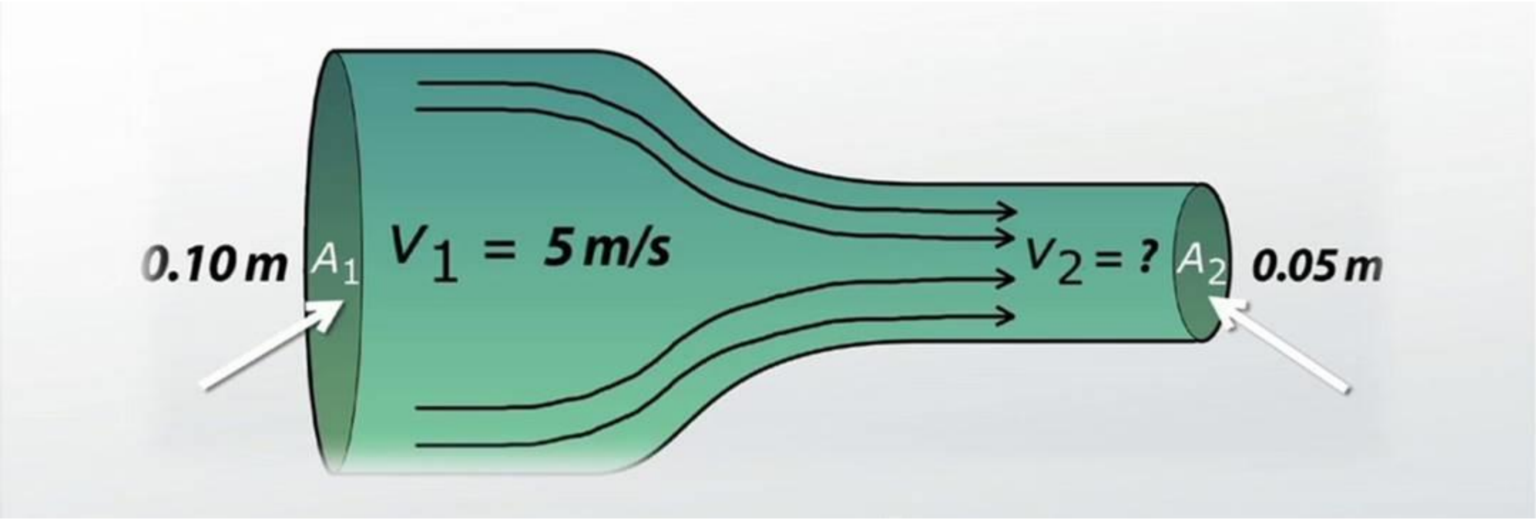
Simulated agents have:

- A clear goal
- Autonomous in decisions about achieving the goal
- Adaptable to changing situations



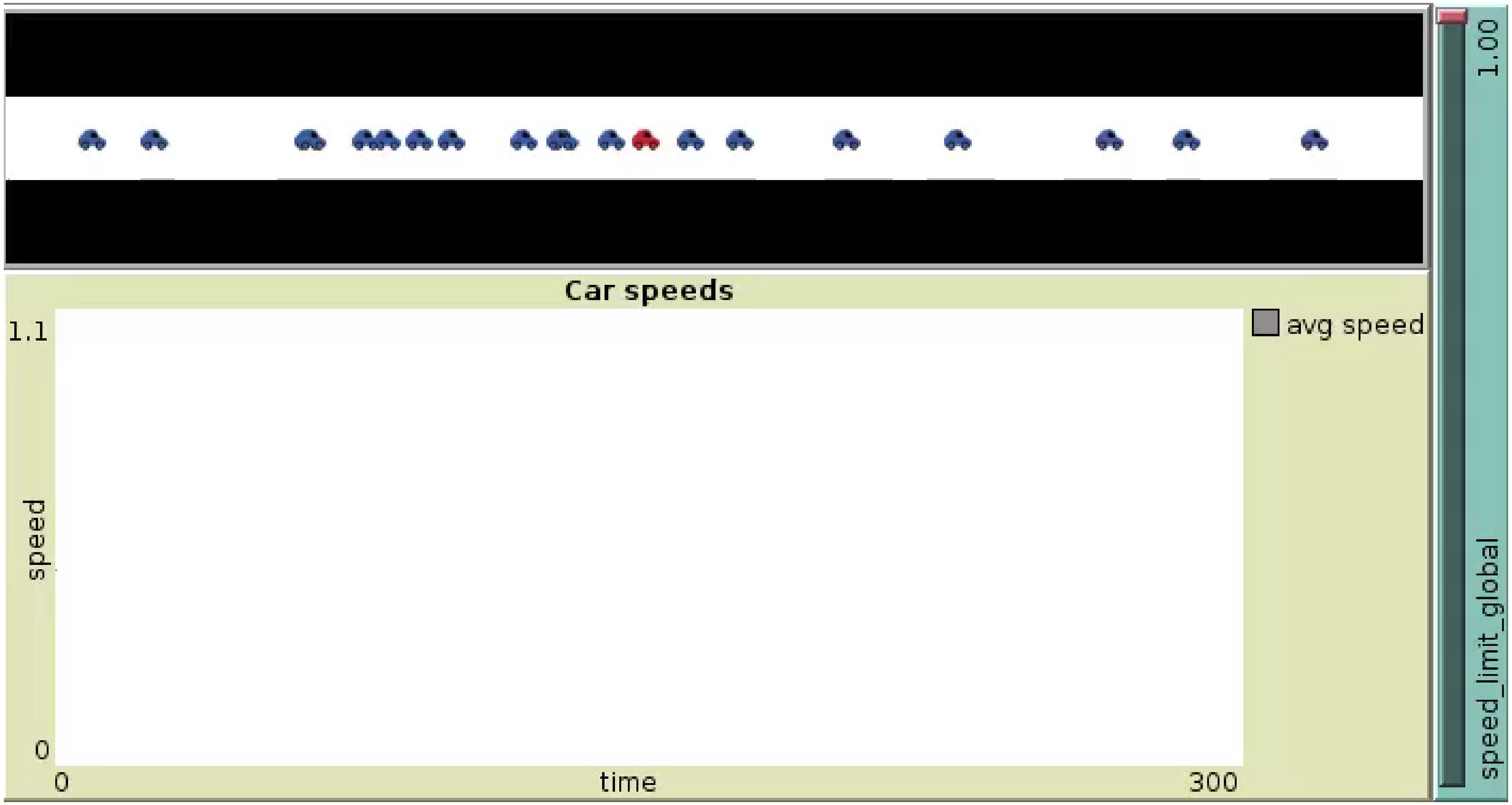
Agent Based Modeling

- Traditional models define aggregate behavior and generate responses to shocks.
  - —Statistically brittle and rigid: hide important components when individual behavior is heterogeneous, or multiple feedback mechanisms in place
- ABM useful when feedback mechanisms in place (i.e. agent ⟶ environment ⟶ regulations ⟶ agent
- Example: modeling traffic as equation (i.e. fluid dynamics)



Agent Based Modeling

- Example: modeling traffic as a collection of individuals
- Define a car:
  - — accelerates if there is space
  - — Stops if another car is in front

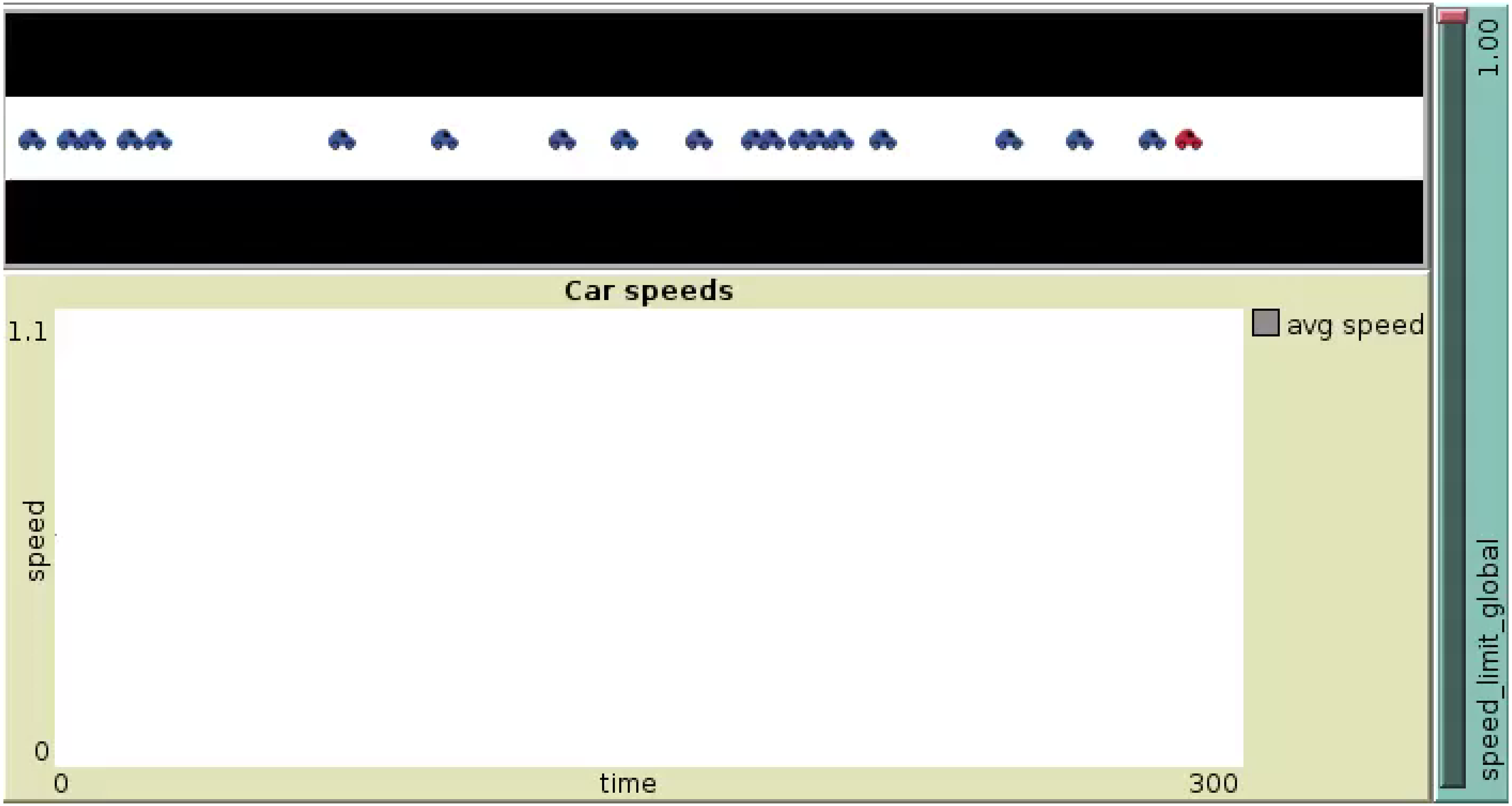


Agent Based Modeling

- Example: modeling traffic as a collection of individuals
- Validation: compare model output to real world behaviors.

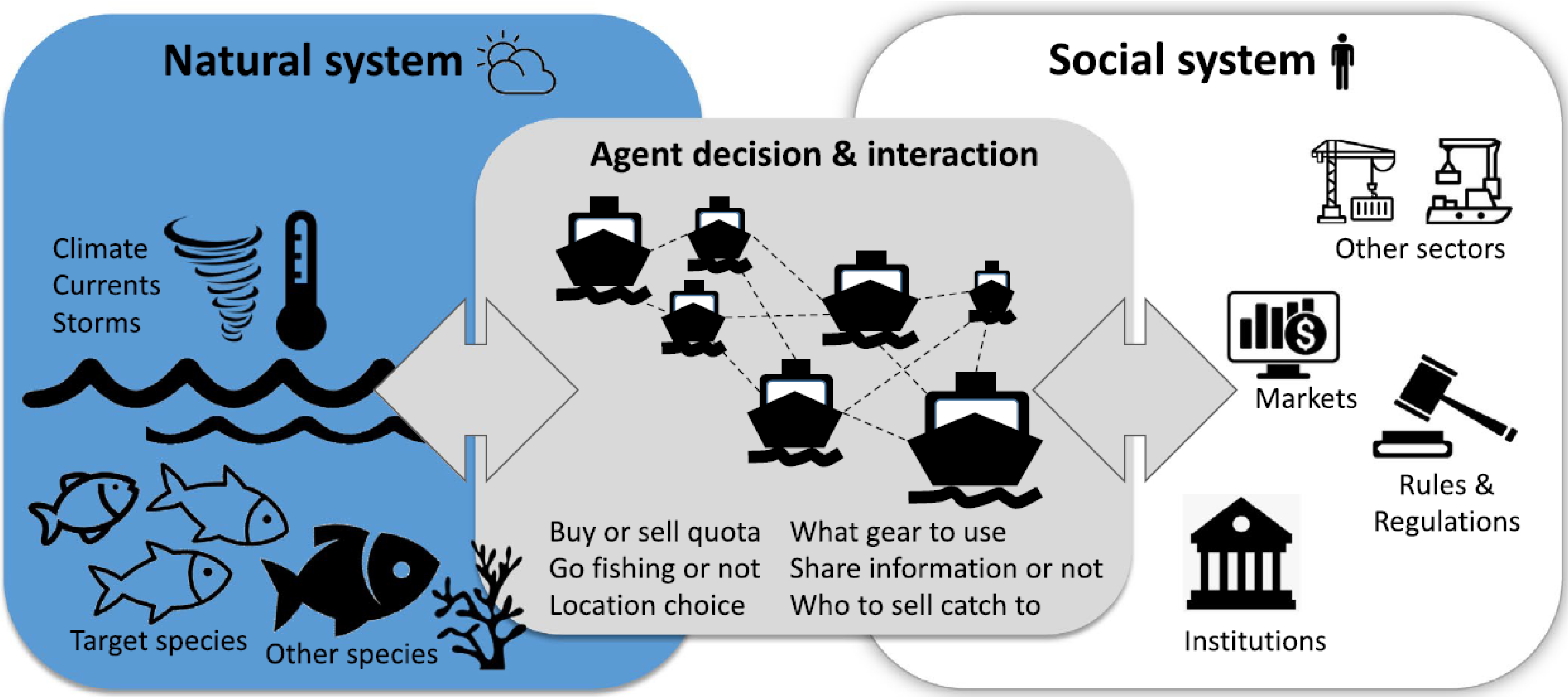
Agent Based Modeling

- Example: modeling traffic as a collection of individuals
- Policy Exploration



Agent Based Models

Human and fish population interacting dynamics and feedback mechanisms

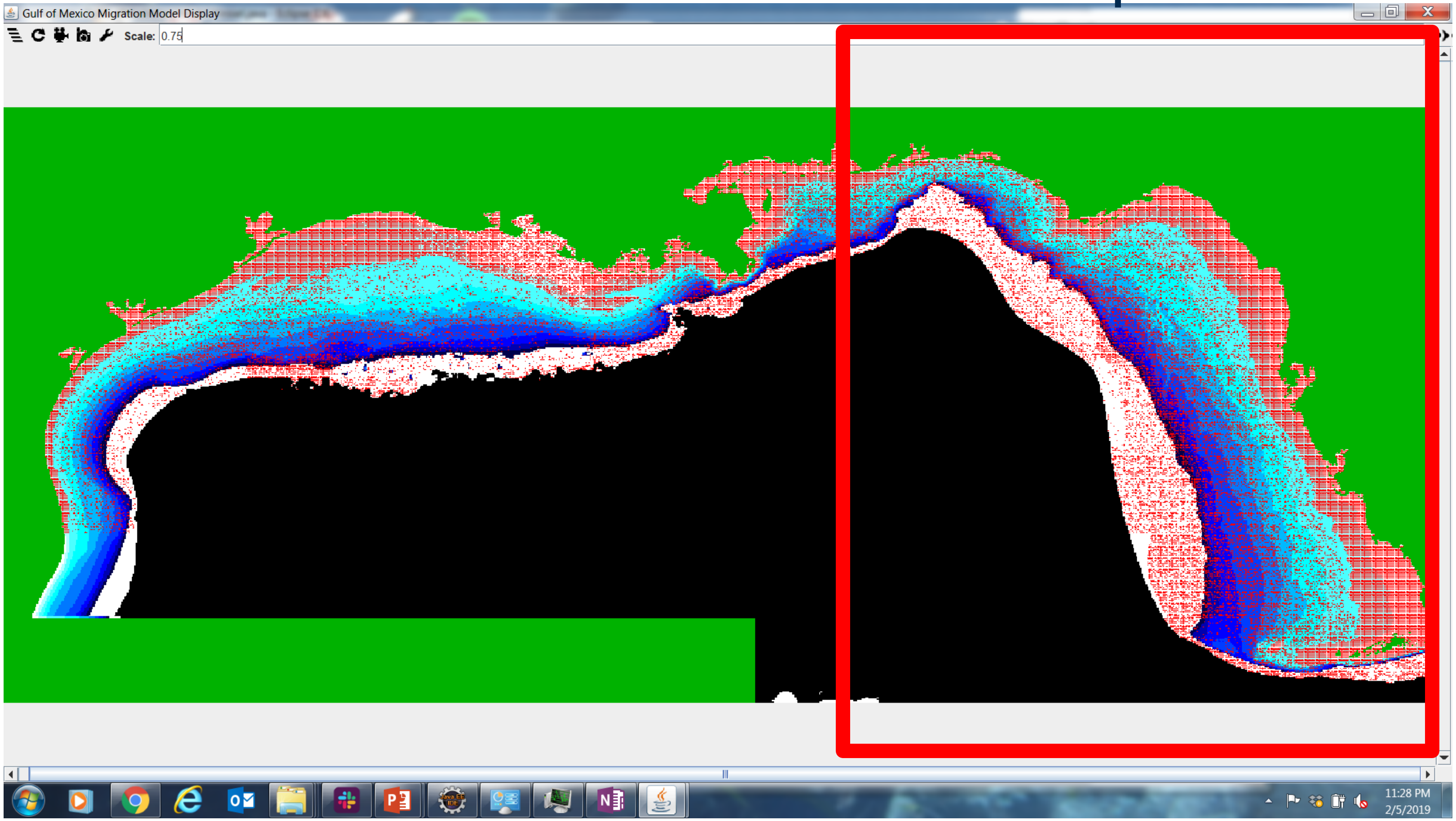


Burgess…**Saul**…et. al.. 2020. Opportunities for agent-based modelling in human dimensions of fisheries. Fish and Fisheries 21: 570-587

Gulf of Mexico Agent Based Model

- Version 1: West Florida Shelf (WFS) only ("Legacy Version") – Pre-IFQ time period
- Version 2: Full Gulf of Mexico pre and post IFQ

WFS Spatial Extent



Gulf of Mexico Agent Based Model

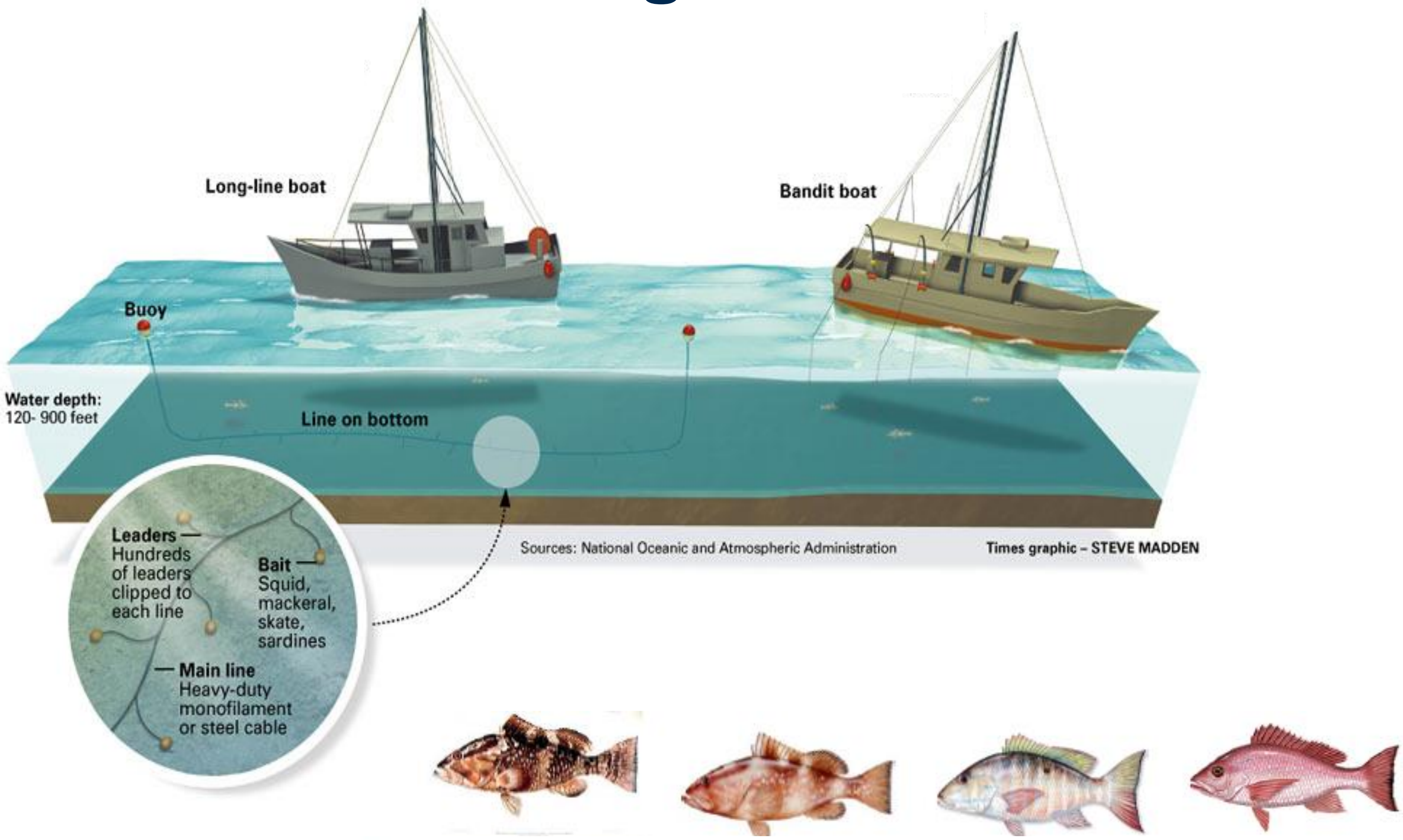
Important Caveat: Real vs. Simulated

- Purpose is <u>**NOT**</u> to develop a model that exactly represents reality. Rather, develop a simulation that represents <u>**some**</u> of the important <u>**processes**</u> that drive fish and fisher dynamics.

- This is particularly important when we look at results of the stock assessments of the simulated fisheries.

Purpose is to develop a tool that simulates fishery-dependent data that is appropriately influenced by aspects of fishery operations we observe in the real world.

Gulf of Mexico Agent Based Model



Full Gulf Model adds:

Gulf of Mexico Agent Based Model (GOM-ABM)

Structural Layer

- Bathymetric data, model grid, sectors
- Calendar, wind speed, etc.

Ecological Layer

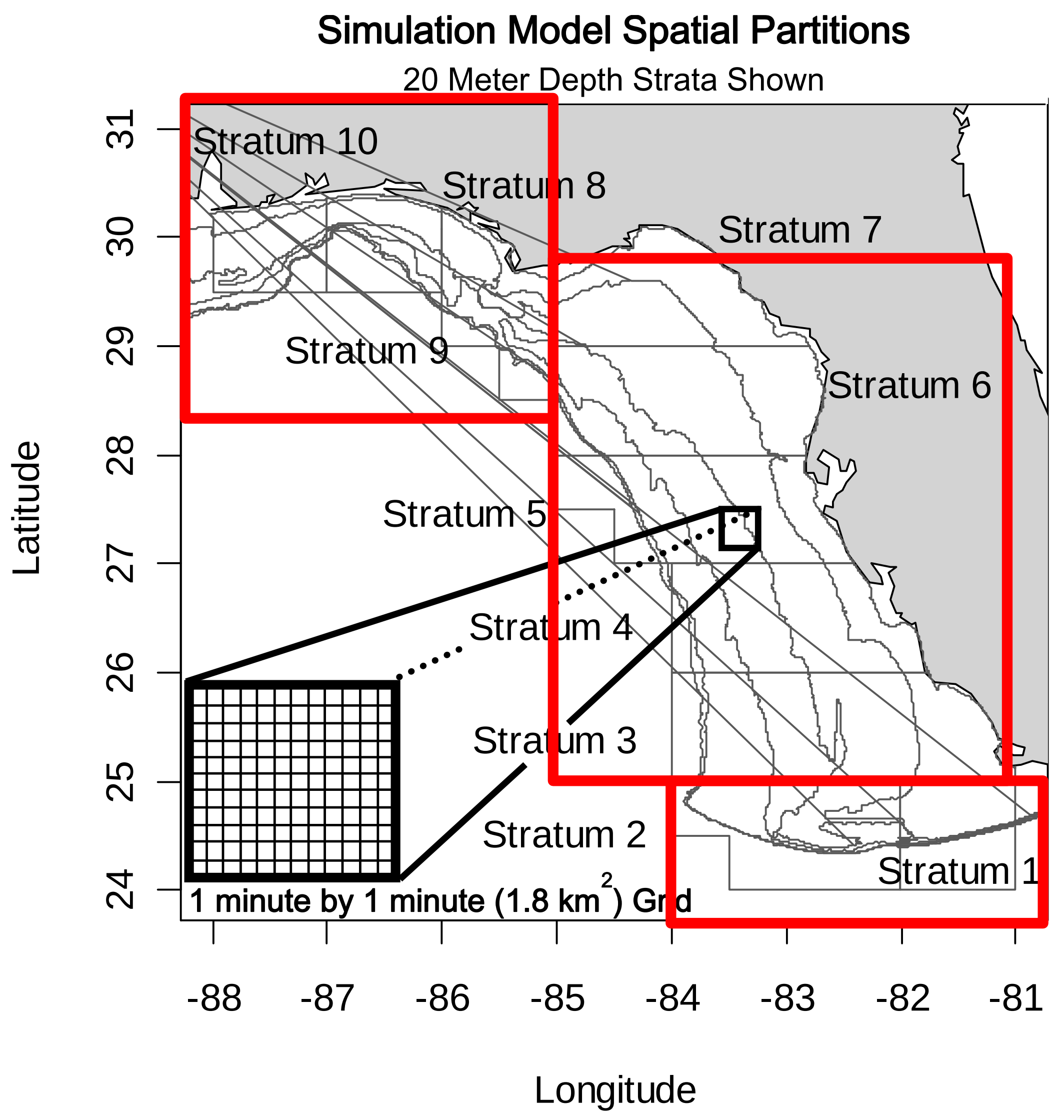
- Species parameters
- Abundance simulation
- Growth, maturity, spawning, migration, death

Human Layer

- Vessel characteristics (physical/economic)
- Cognitive model (when, where, how long to fish)
- Ex-vessel prices
- ITQ market

GOM-ABM: Structural Layer

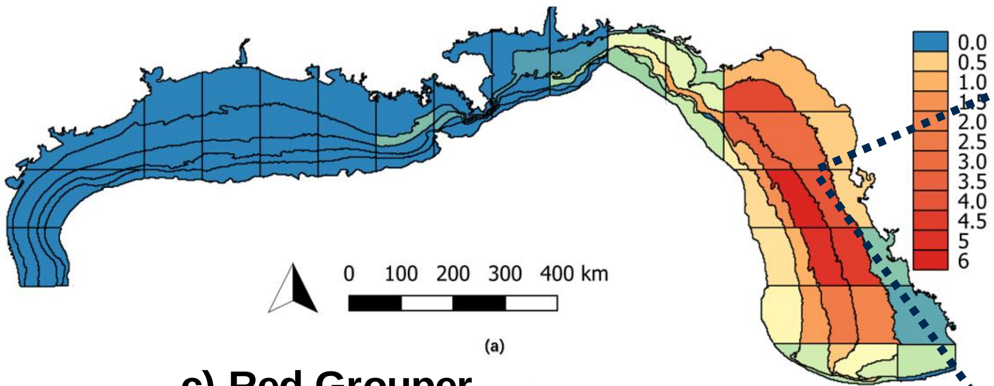
- Strata (φ): areas of equal latitude where Florida's coast runs north-south, areas of equal longitude where the coast runs east-west.
- Depth Sub-strata (δ): 20m isobaths
- Grouped Strata (ω): 3 groupings of Strata
- Grids (τ): cells one minute latitude by one minute longitude



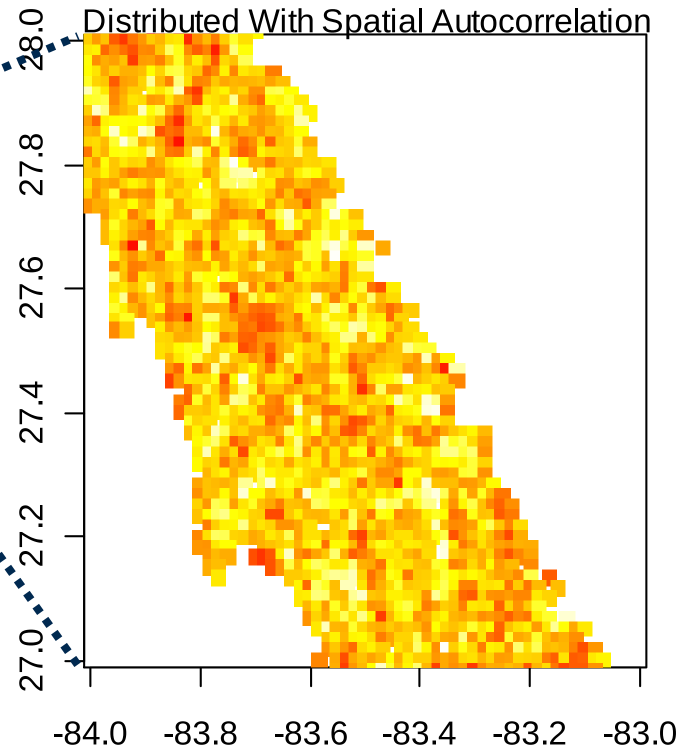
GOM-ABM: Structural Layer

Spatial Distribution of Fish (WFS Legacy Version)
Red Grouper Example. Input data: video survey

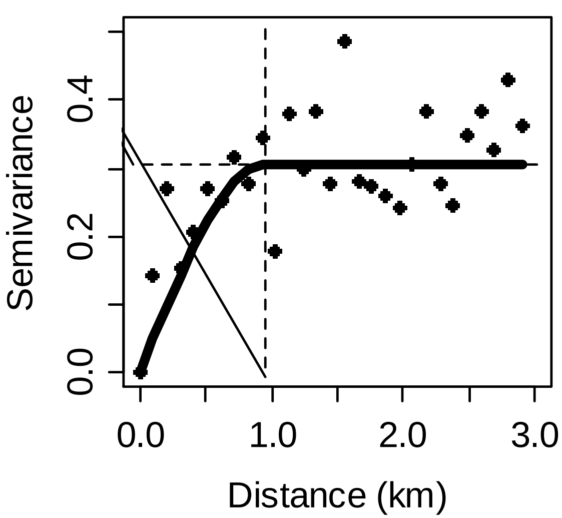
Spatial CPUE: Red Grouper



Red Grouper



c) Red Grouper

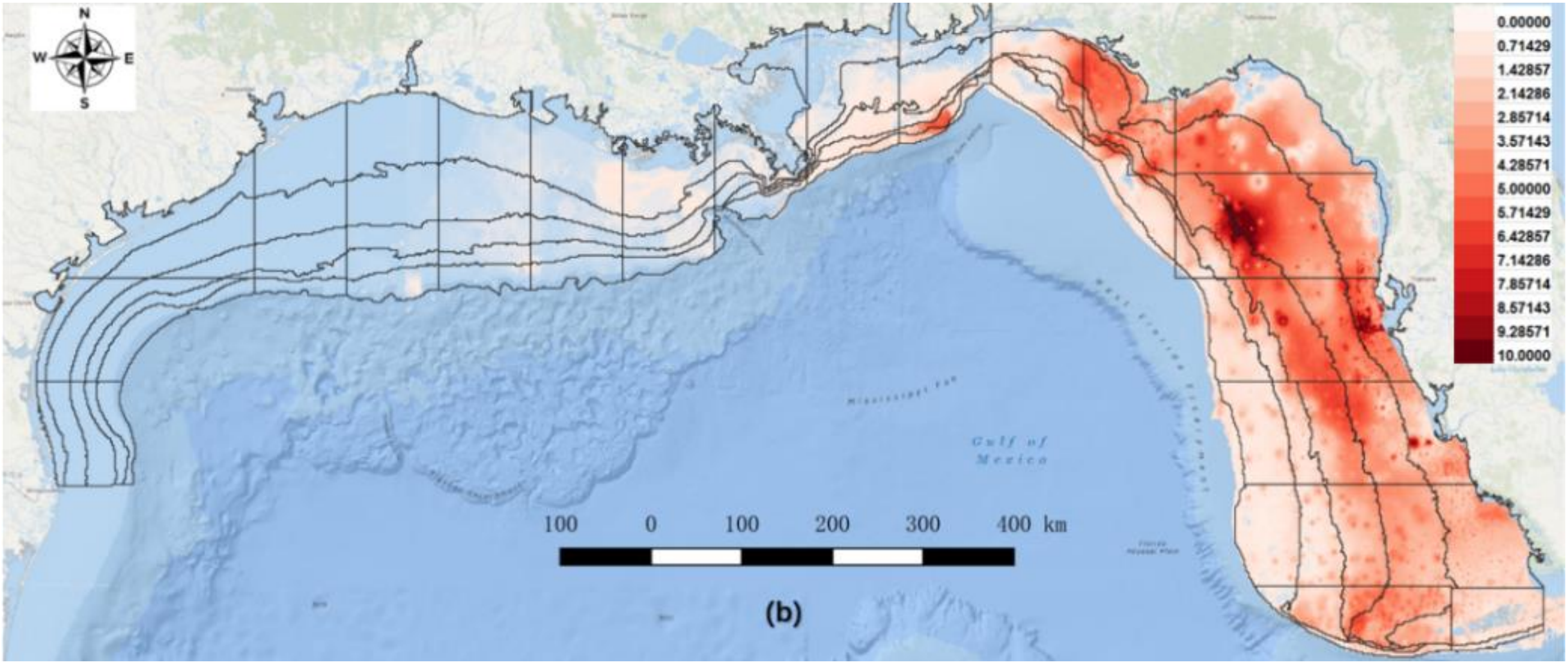


Saul, et al. 2013. Modeling the spatial distribution of commercially important reef fishes on the West Florida Shelf. Fisheries Research 143: 12-20

GOM-ABM: Structural Layer

Spatial Distribution of Fish (Full Gulf Version – Machine Learning model ensemble approach). Input data: video survey and habitat data.

Predicted Red Grouper Spatial Distribution

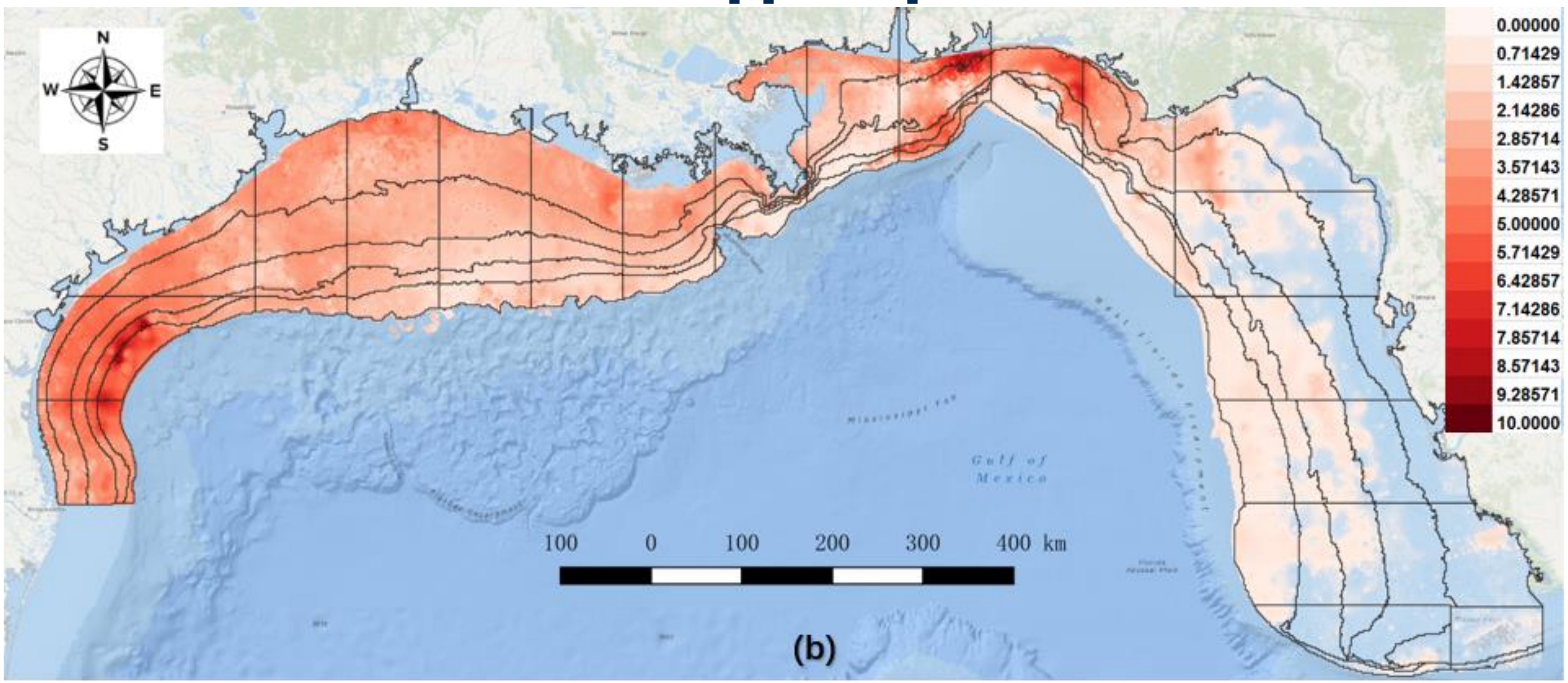


Lu, **Saul,** and Jenkins. 2022. Statistical methods for predicting the spatial abundance of reef fish species. Ecological Informatics 69: 101624.

GOM-ABM: Structural Layer

Spatial Distribution of Fish (Full Gulf Version – Machine Learning model ensemble approach). Input data: video survey and habitat data.

Predicted Red Snapper Spatial Distribution



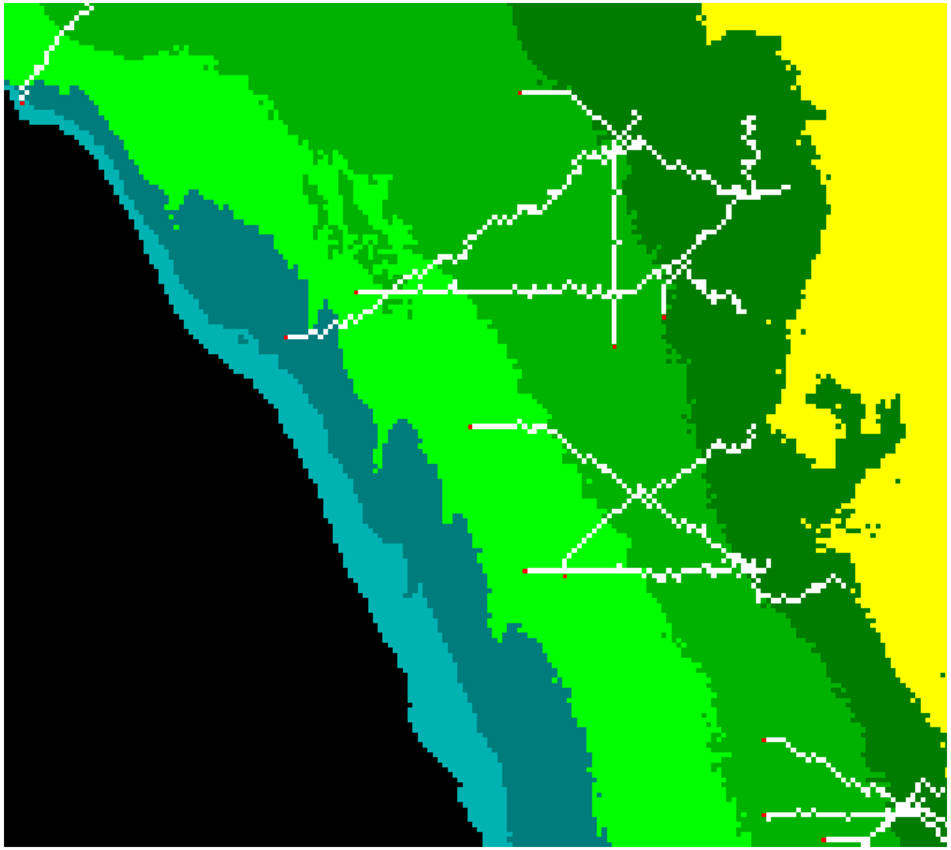
Lu, **Saul,** and Jenkins. 2022. Statistical methods for predicting the spatial abundance of reef fish species. Ecological Informatics 69: 101624.

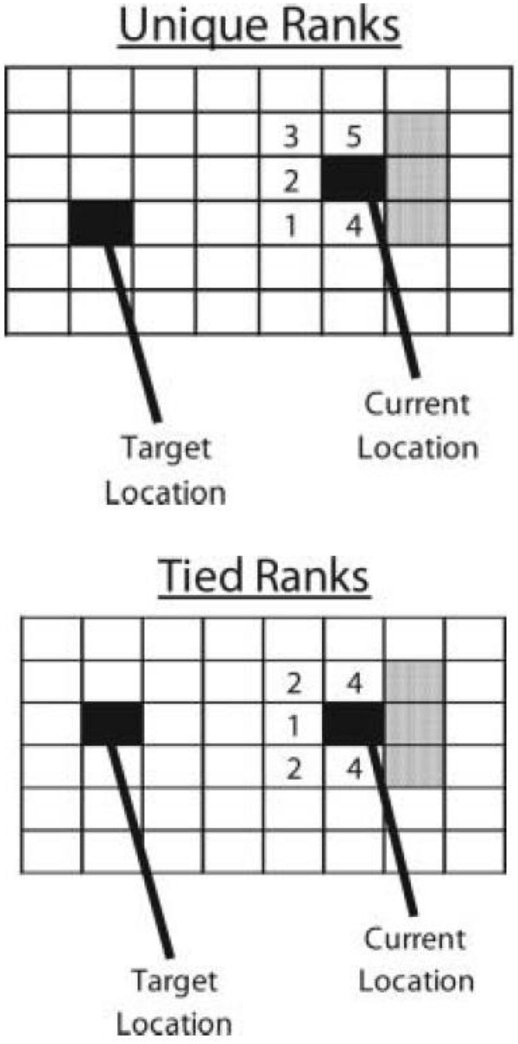
GOM-ABM: Ecological Layer

- Abundance, population demographics (number at age), recruitment function, M, and life history parameters used from most recent stock assessment for each species.
- Recreational fishing mortality and that from other commercial gears modeled as F uniformly applied across space and time.
- Time step of simulation is daily.
- Recruitment occurs at the start of each year. Spawning stock biomass reflects the sum of mature individuals across space and time at the end of each simulation year.
- Newly recruited age zero individuals placed in “nursery habitat” defined as within 0 and 20 meters of water.
- Ontogenetic migration modeled at age of maturity.
- Recruits provided a pre-destined adult habitat location based on species distribution maps.

GOM-ABM: Ecological Layer

Ontogenetic migration – WFS Legacy Version: biased random walk.

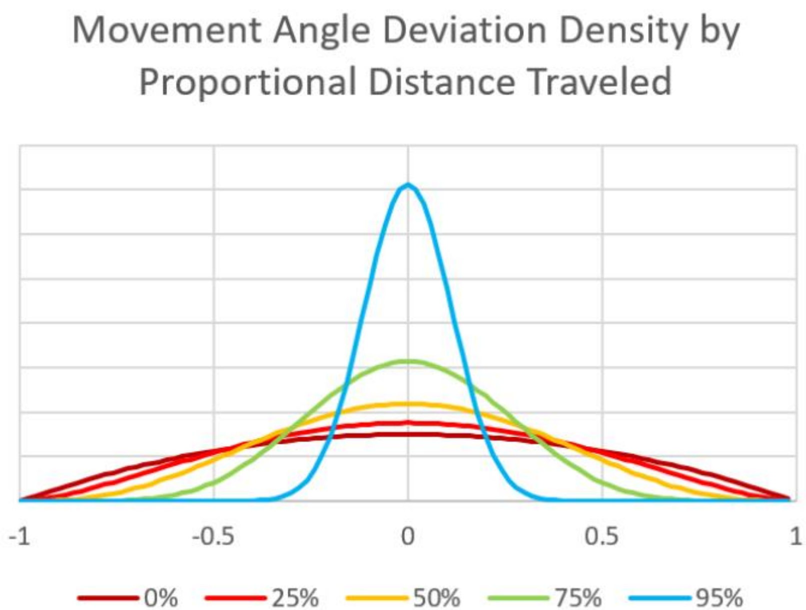


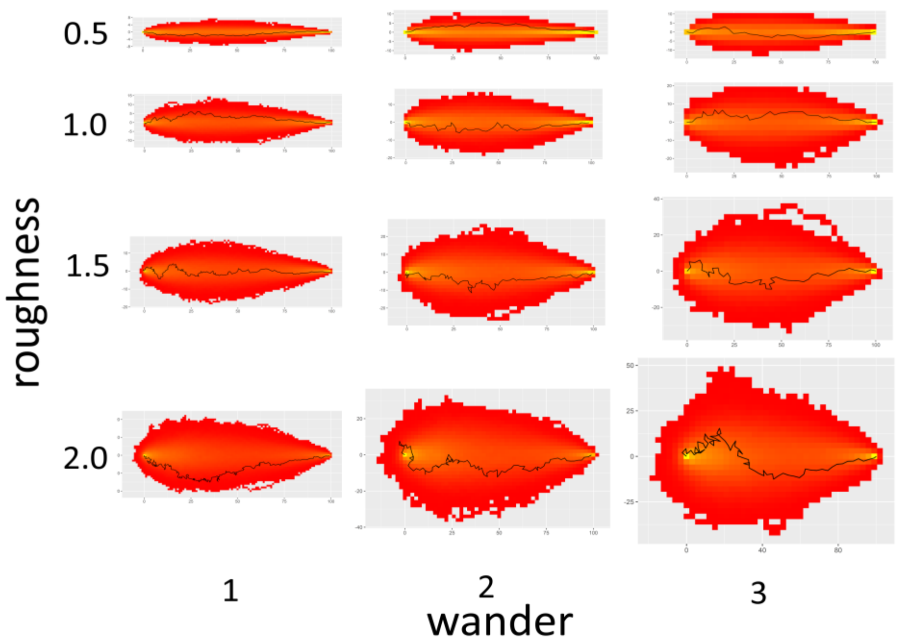


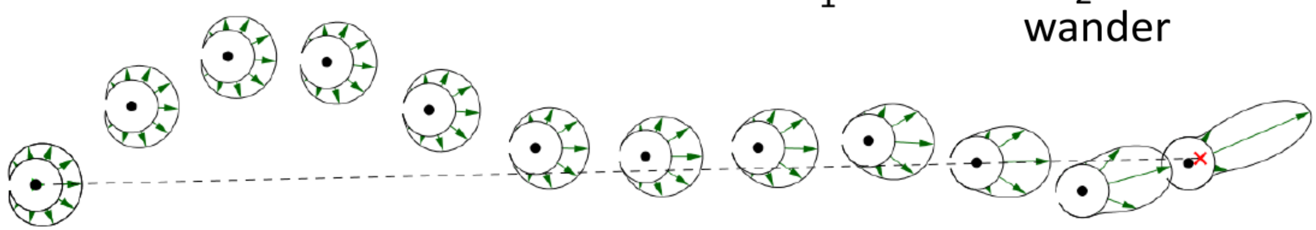
Saul, et al. 2012. An Individual-Based Model of Ontogenetic Migration in Reef Fish Using a Biased Random Walk, Transactions of the American Fisheries Society, 141: 1439-1452

GOM-ABM: Ecological Layer

Ontogenetic migration – Full Gulf Version: biased random walk using turning angles.





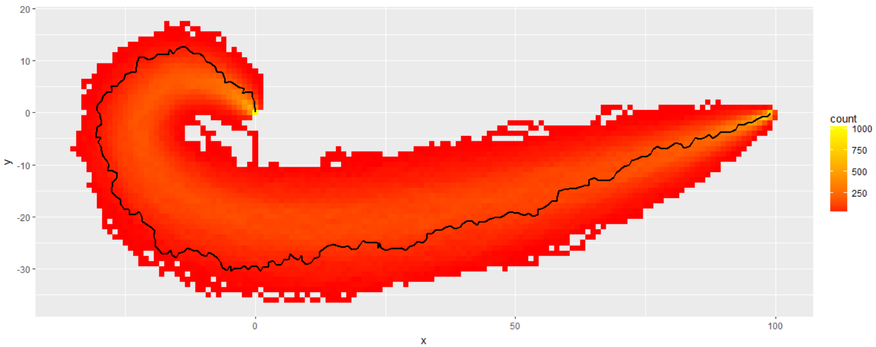


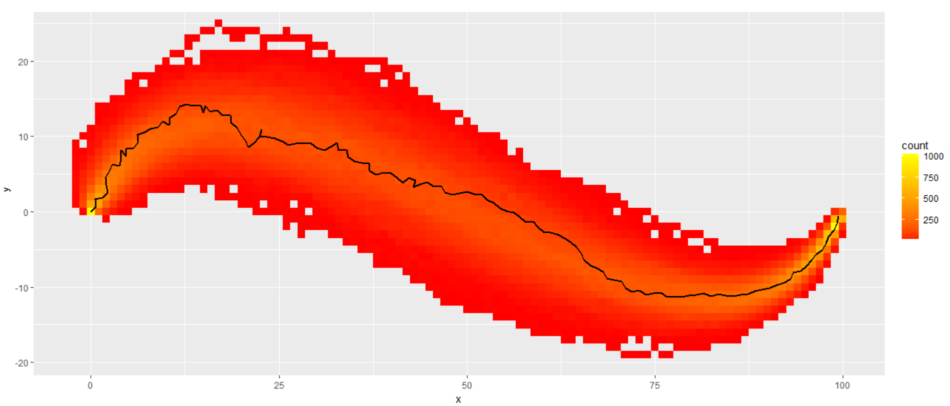
Powers, B. and **S. Saul**. *In Prep*. Modelling the ontogenetic migration behavior of reef fish in the Gulf of Mexico. Target journal: Ecological Modelling.

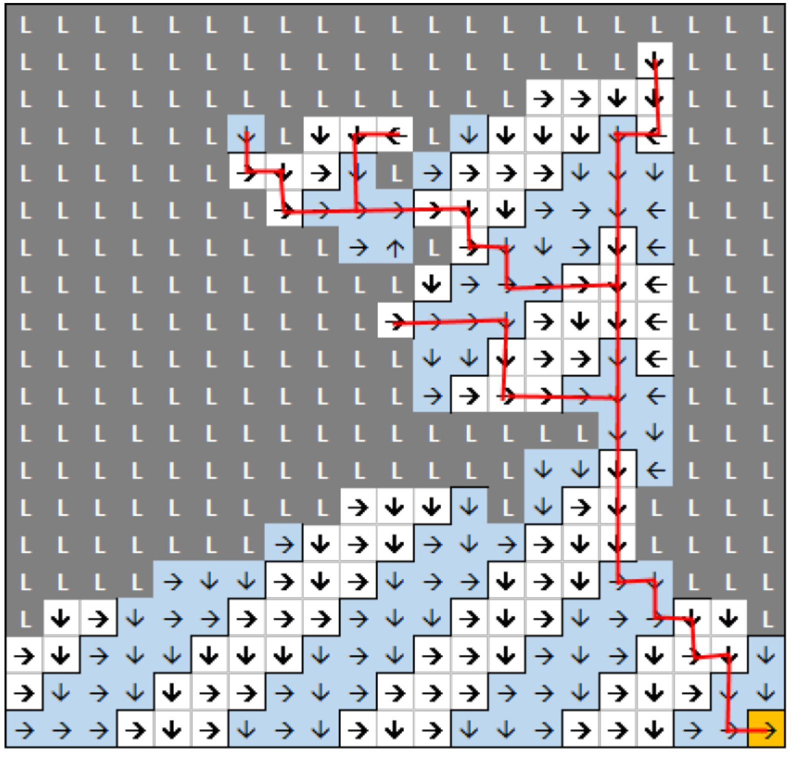
GOM-ABM: Ecological Layer

Ontogenetic migration – Full Gulf Version: biased random walk using turning angles.

Migration algorithm along a parametrically defined curve.





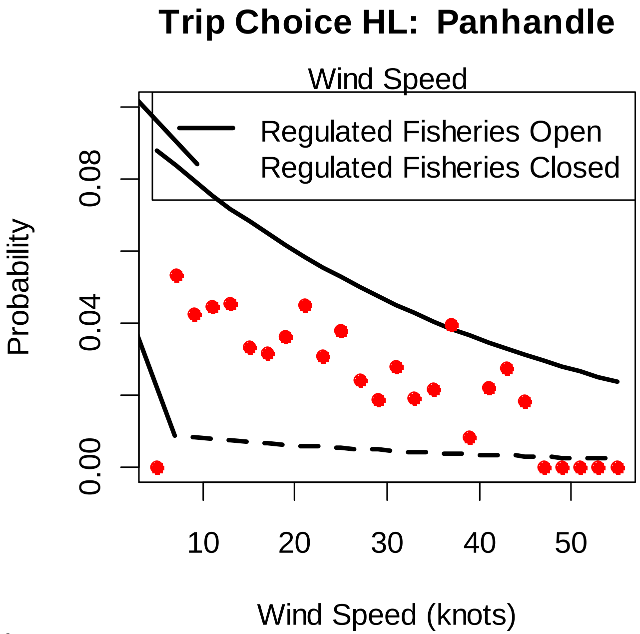


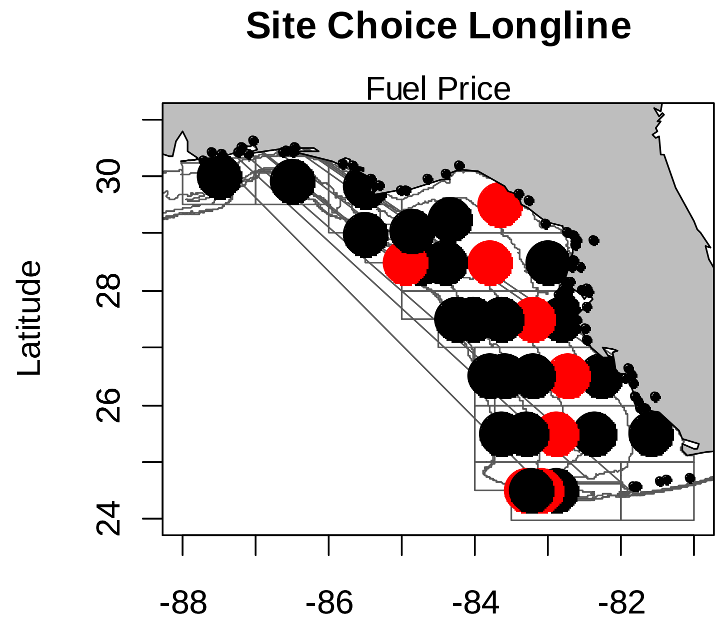
Powers, B. and **S. Saul**. *In Prep*. Modelling the ontogenetic migration behavior of reef fish in the Gulf of Mexico. Target journal: Ecological Modelling.

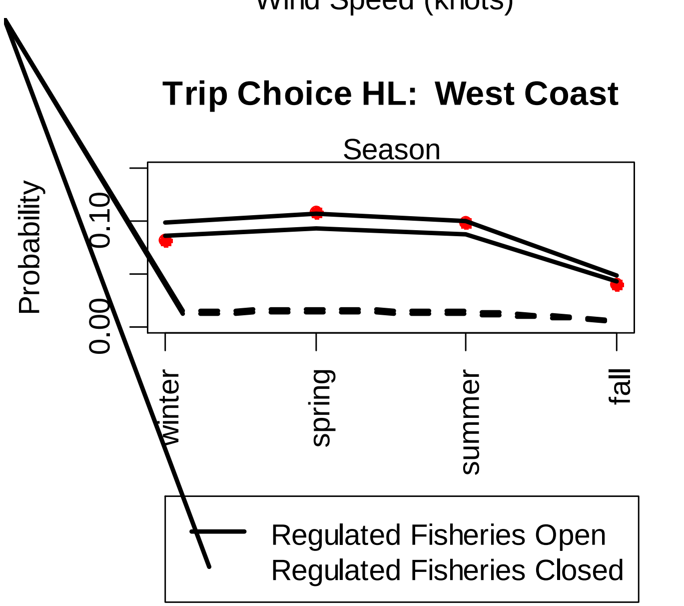
GOM-ABM: Human Layer

- Logbook, state variable data and vessel characteristics combined to create panel dataset.
- Discrete choice models (binomial and multinomial logistic regressions) fit to panel dataset; parameters guide decision-making in agent-based model.
- Survey of commercial captains informed variable selection:
  - **Participation decision variables:** wind speed, vessel length, season, fuel price, fish price, and quota allocation
  - **Site choice decision variables:** distance between port and fishing locations, windspeed, habitat composition, fuel price, fish price, expected catch, and habit
  - **Return to port decision variables:** catch to fish hold ratio, regulations, season, vessel length, allocation, windspeed, and fish price

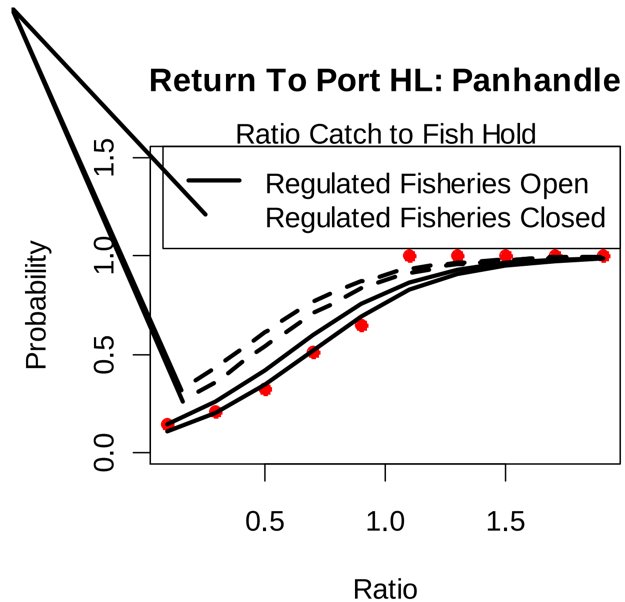
Saul, S. and D. Die. 2016. Modeling the decision making behavior of fishers in the reef fish fishery on the West Coast of Florida. Human Dimensions of Wildlife 21(6): 567-586







Multiple lines represent weekend and weekday



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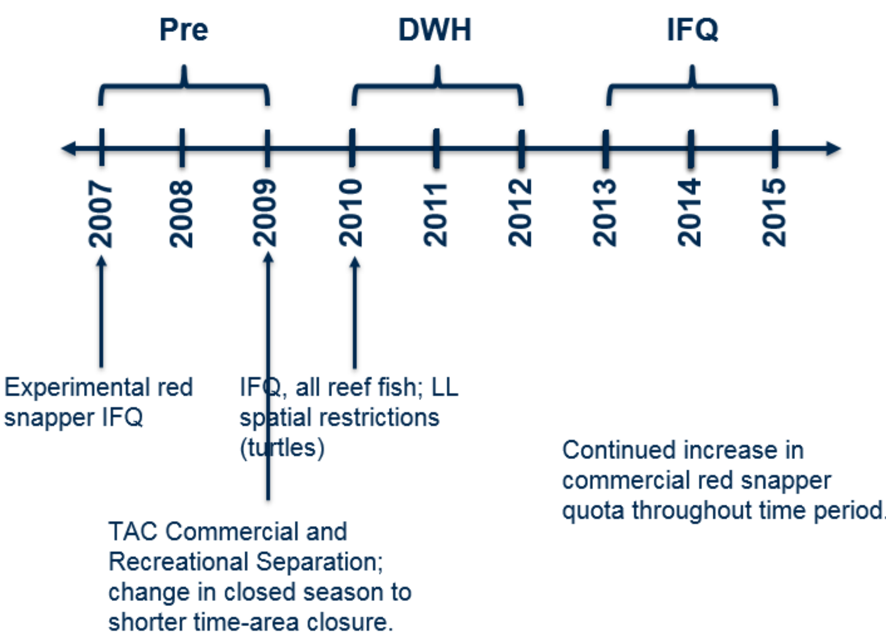
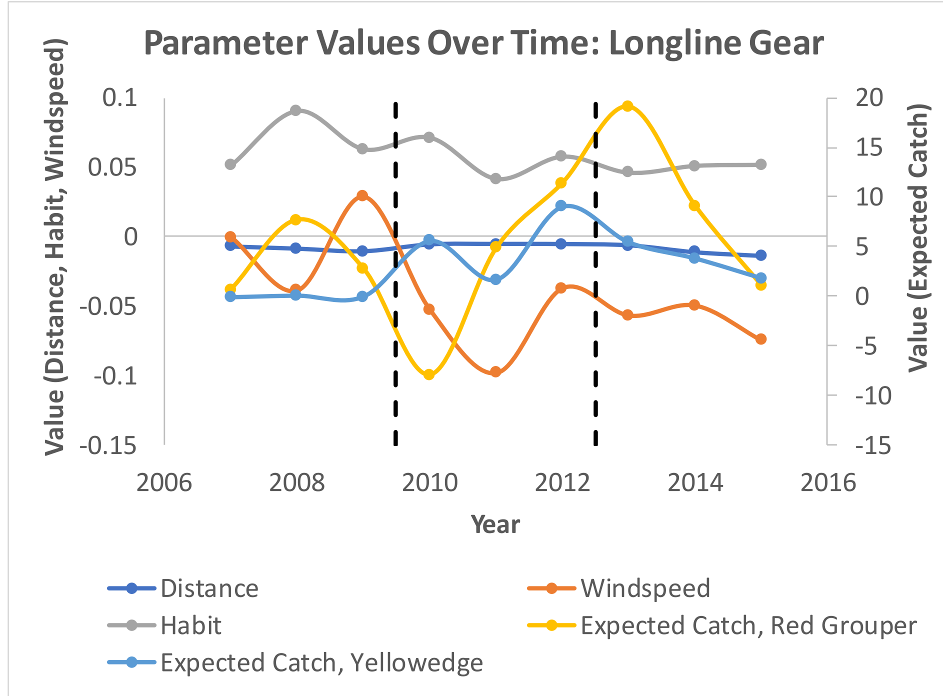
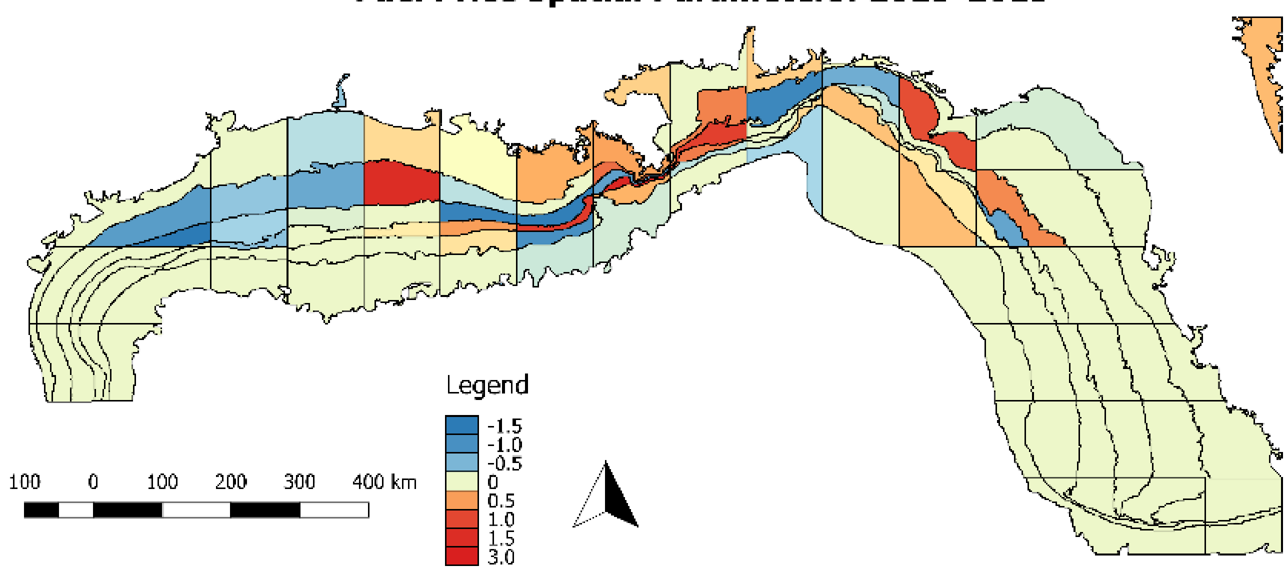
GOM-ABM: Human Layer
Full Gulf Model





Fuel Price Spatial Parameters: 2013-2015



Saul, S. In Prep. Quantifying and comparing fisher decision-making strategies in the Gulf of Mexico before and after the Deepwater Horizon Oil Spill and ITQ implementation. Target Journal: Marine Resource Economics.

GOM-ABM: Human Layer

ITQ Model

ITQ model implemented based on Little et al., 2009

$$P_{v,s} = p_s - c_v \frac{U_{v,s}}{\sum_s U_{v,s}}$$

P_v, s is expected marginal profit
p_s is ex-vessel price
c_v is daily operating cost based on vessel characteristics, distance to site and fuel price
$U_{v,s}$ is expected catch, continually updated per region based on past catches
Vessels with high marginal profit buy/lease quota from vessels with low marginal profit

GOM-ABM

- Limited learning: vessel agents keep a record of their personal CPUE and use it to help make site choice decisions.
  - —Inclusion of a variable indicating the frequency that individuals fished in a location.
- Fisher behavior was also “statistically fixed” in the agent-based model, meaning that all fisher agents within the same fleet used the same set of discrete choice model-fitted parameters to make decisions.

GOM-ABM

Return to port

When to fish

Where to fish

20 Year Projection

From 2005/2006 State of Fishery (pre-IFQ)

Simulated Logbook Data

	Species Name	Code	Gutted-lbs	Whole-lbs	Gear	Area	Depth
	Amberjack-Great	1812	#	#			'
	Amberjack-Lesser	1815	#	#			'
	Almaco	1810	#	#			'
	Banded Rudder	1817	#	#			'
	Crevalle	0870	#	#			'
	Cobia	0570	#	#			'
	Dolphin Fish	1050	#	#			'
GROUPER	Black	1422	#	#			'
GROUPER	Gag	1423	#	#			'
GROUPER	Warsaw	4740	#	#			'
GROUPER	Red	1416	#	#			'
GROUPER	Scamp	1424	#	#			'
GROUPER	Snowy	1414	#	#			'
GROUPER	Yellowedge	1415	#	#			'
GROUPER	Yellowfin	1426	#	#			'

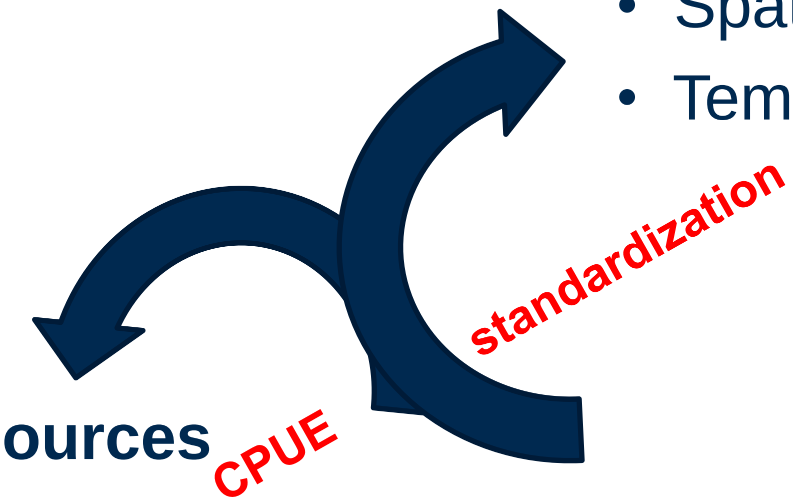
GOM-ABM: Simulation Model Results

Where can human behavior enter stock assessments?

- CPUE index of abundance from fishing operations
- Length data from fishing operations

Relative abundance

- Spatially
- Temporally



Other sources of variation

(including aspects of human dimension)

CPUE Observations

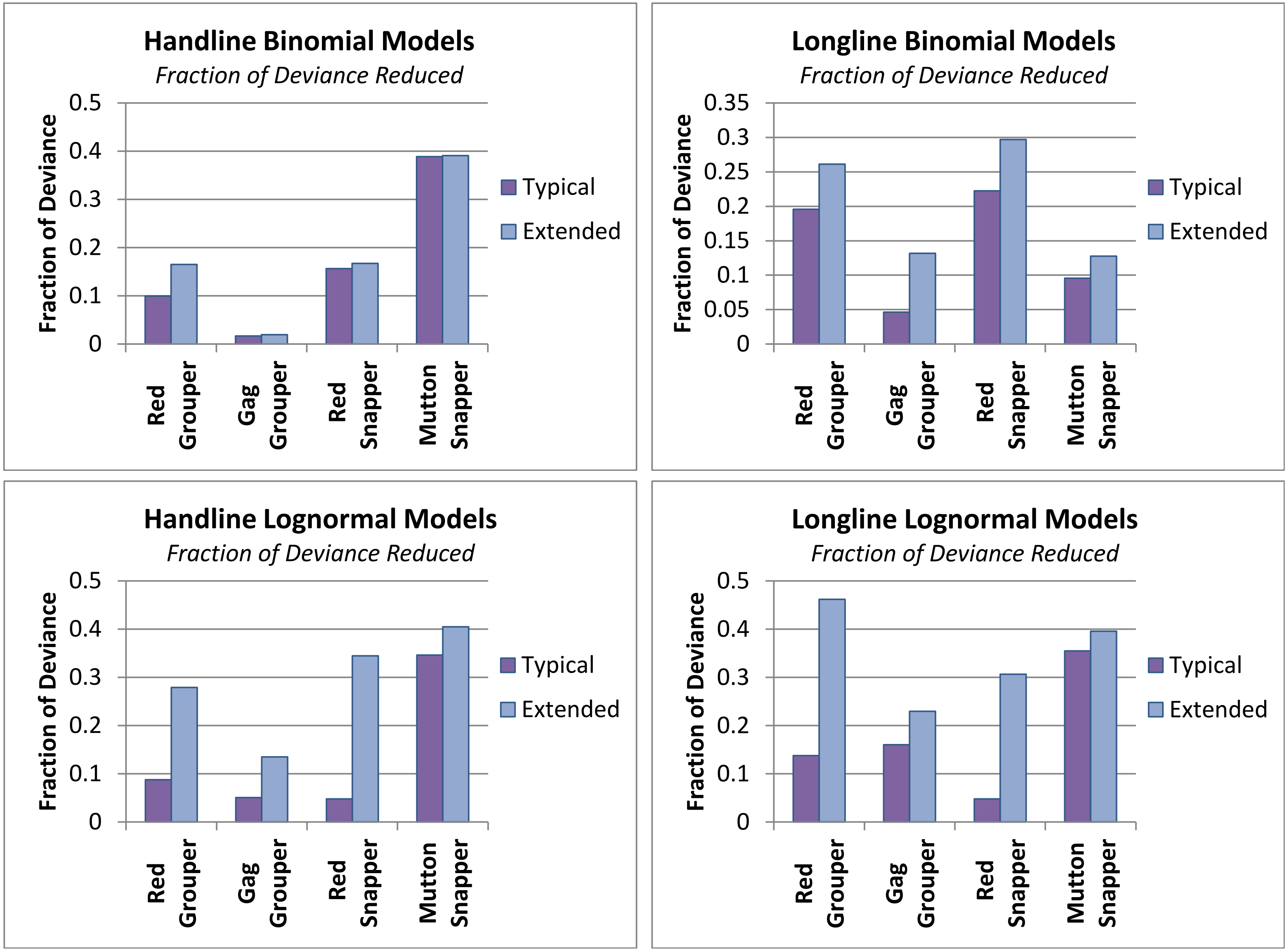
Typical CPUE Standardization

Factor Tested	Factor Description
year	the simulation year
Area	NMFS statistical area (blocks of latitude/longitude)
Month	calendar month
DaysAway (binomial only)	the number of days that the fishing vessel fished on that particular trip - only included in the binomial model because it is used to measure effort in the calculation of CPUE

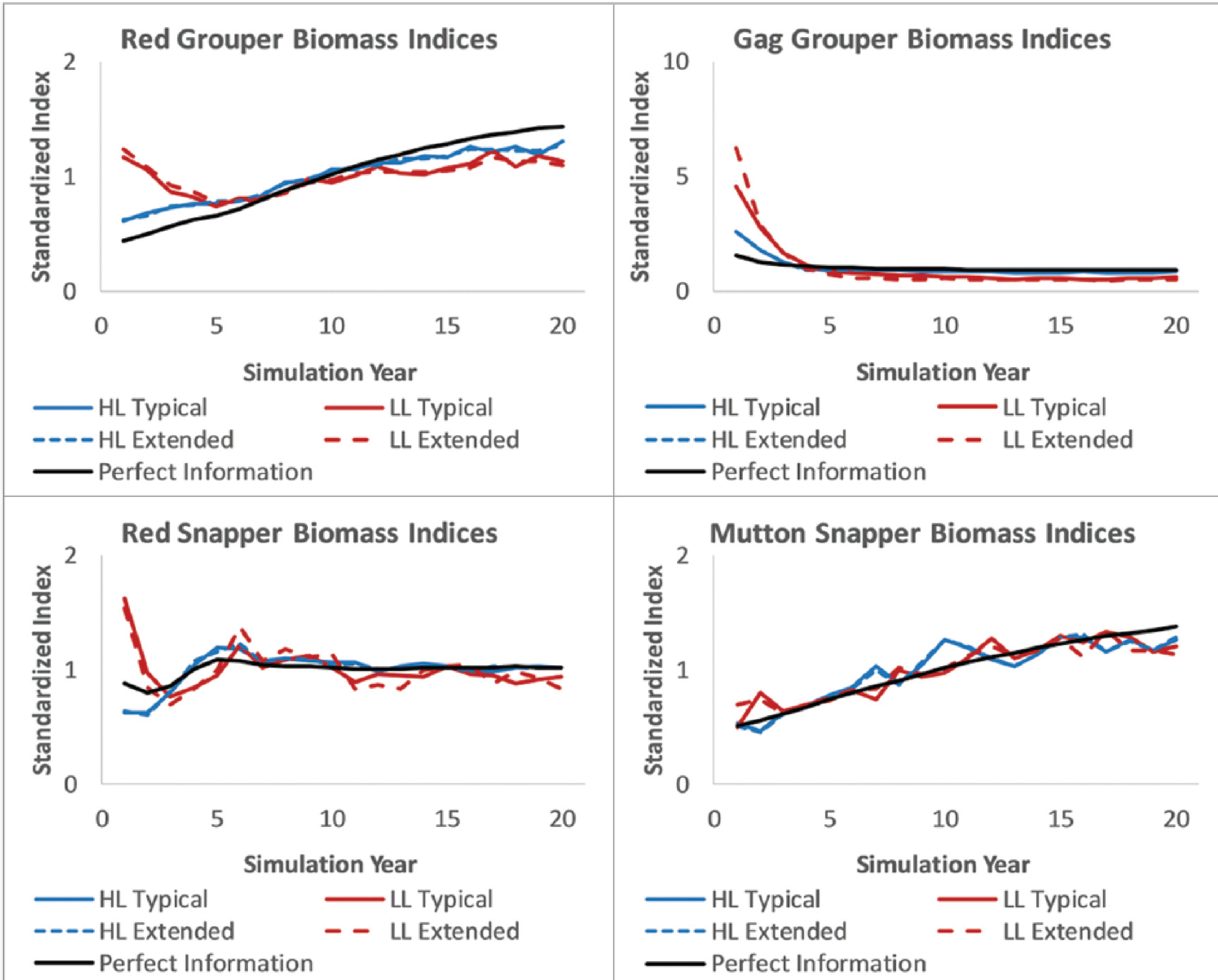
Extended CPUE Standardization

Factor Tested	Factor Description
year	the simulation year
NewArea	the interaction of NMFS statistical area and 20 meter depth strata
Month	calendar month
NumLocationsFished	the number of locations that the vessel fished on that trip
TravelTime_hrs	the hours in transit to/from fishing port
priceGG	average market price of gag grouper across the Gulf of Mexico on each simulation day (consumer price index adjusted)
priceRG	average market price of red grouper across the Gulf of Mexico on each simulation day (consumer price index adjusted)
priceMS	average market price of mutton snapper across the Gulf of Mexico on each simulation day (consumer price index adjusted)
priceRS	average market price of red snapper across the Gulf of Mexico on each simulation day (consumer price index adjusted)
cruseSpeed	the cruise speed that the fishing vessel uses to travel between their port and the fishing grounds
VesselLength	the length of the fishing vessel in feet
redSnapperAllocation	a dummy variable indicating whether a particular fishing vessel has a 2000 pound, 200 pound, or zero pound per trip allocation of red snapper
fishHoldCapacity	The size of the vessel’s fish hold in pounds
DaysAway (binomial only)	the number of days that the fishing vessel fished on that particular trip - only included in the binomial model because it is used to measure effort in the calculation of CPUE

Typical vs. Extended Standardization



Saul, Brooks and Die. 2020. How fisher behavior can bias stock assessment: insights from an agent-based modeling approach. CJFAS 77: 1794-1809.



Saul, Brooks and Die. 2020. How fisher behavior can bias stock assesment: insights from an agent-based modeling approach. CJFAS 77: 1794-1809.

Typical vs. Extended Standardization

Table 3. Euclidean distance between the perfect information index and either the typical or extended indices.

Species	Distance (perfect, typical)	Distance (perfect, extended)
Handline		
Red grouper	0.52	0.52
Gag grouper	1.20	1.21
Red snapper	0.38	0.39
Mutton snapper	0.47	0.46
Longline		
Red grouper	1.21	1.30
Gag grouper	3.61	5.21
Red snapper	0.85	0.89
Mutton snapper	0.43	0.49

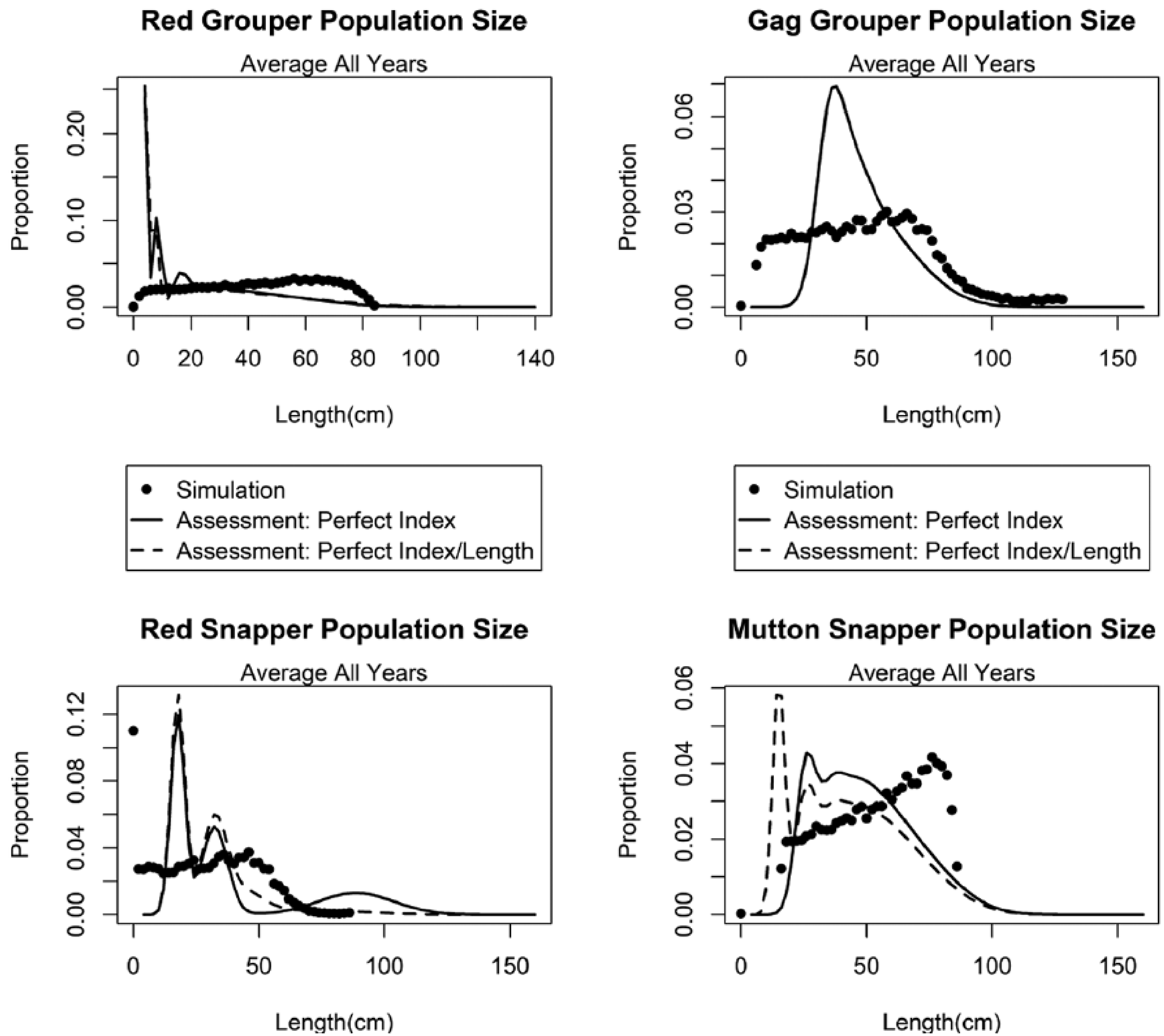
Note: Smaller values indicate closer agreement between indices.

Saul, Brooks and Die. 2020. How fisher behavior can bias stock assessment: insights from an agent-based modeling approach. CJFAS 77: 1794-1809.

Stock Synthesis Configuration

- Three fleets: HL, LL, and Recreational/Other commercial
- Two CPUE indices: handline and longline:
  - Each assessment model configuration tested a different CPUE index scenario (using the typical, extended, and perfect information), where the fourth model tested the inclusion of perfect catch at size information by using the population size structure adjusted for selectivity and retention.
- Catch at size from the simulated handline and longline commercial fleets
- Life history parameters assumed to be known from empirical studies and fixed to those used in the simulation model.

Population Demographics



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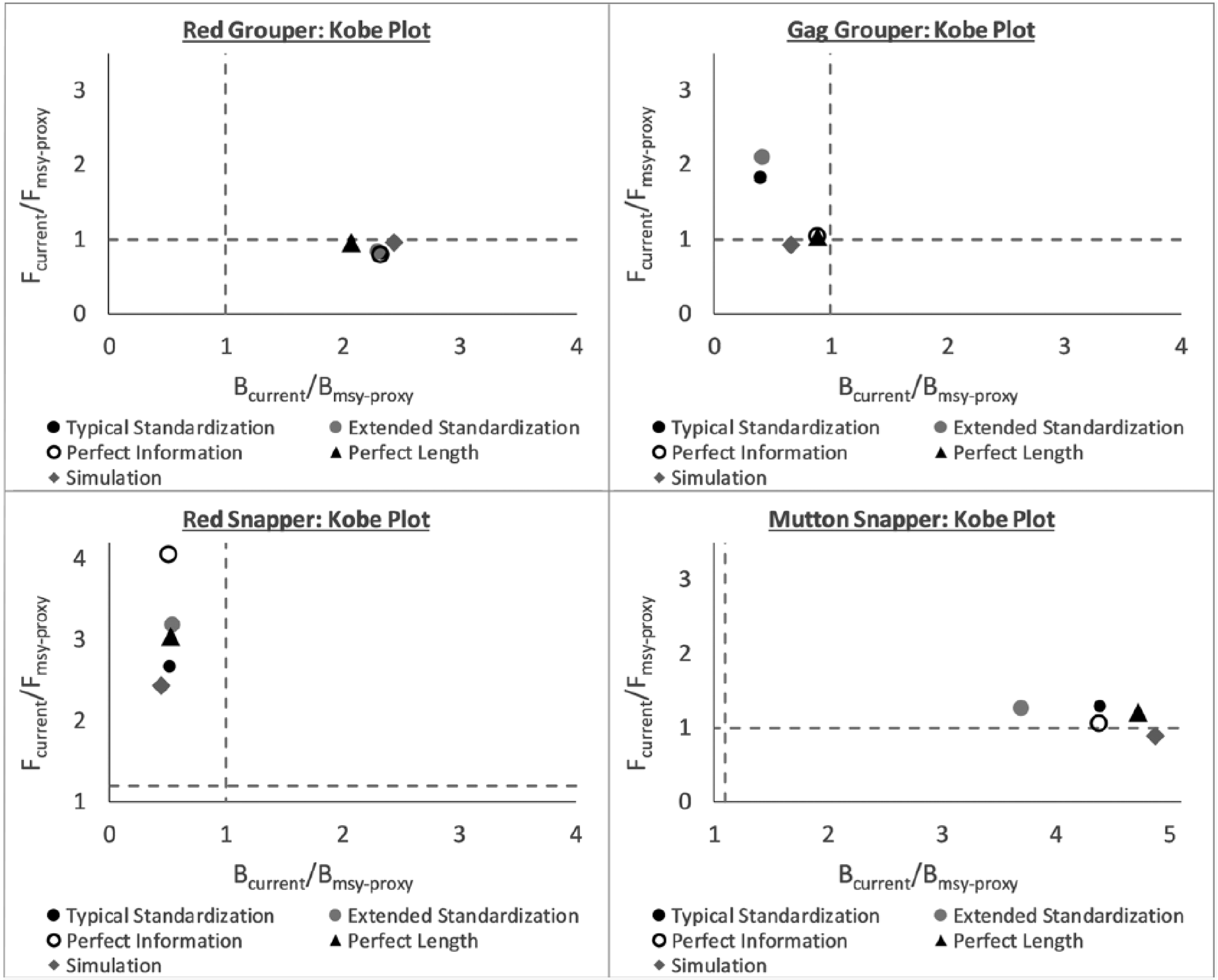
Kobe Plots



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Stock Assessment Model

Table 2. The percentage of partial log-likelihood for the stock assessment model fits to catch per unit effort and catch at length.

Species	CPUE scenario	Log-like. from CPUE (%)	Log-like. from catch at length (%)
Red grouper	Typical index	1.08	69.58
	Extended index	0.52	97.61
	Perfect information	3.30	68.17
	Perfect info. and length	1.72	65.52
Gag grouper	Typical index	7.52	34.80
	Extended index	11.07	68.43
	Perfect information	2.89	73.12
	Perfect info. and length	2.86	73.52
Red snapper	Typical index	3.68	0.37
	Extended index	16.84	3.54
	Perfect information	21.83	1.91
	Perfect info. and length	21.41	0.18
Mutton snapper	Typical index	7.02	0.04
	Extended index	6.50	0.05
	Perfect information	0.22	0.05
	Perfect info. and length	0.33	0.07

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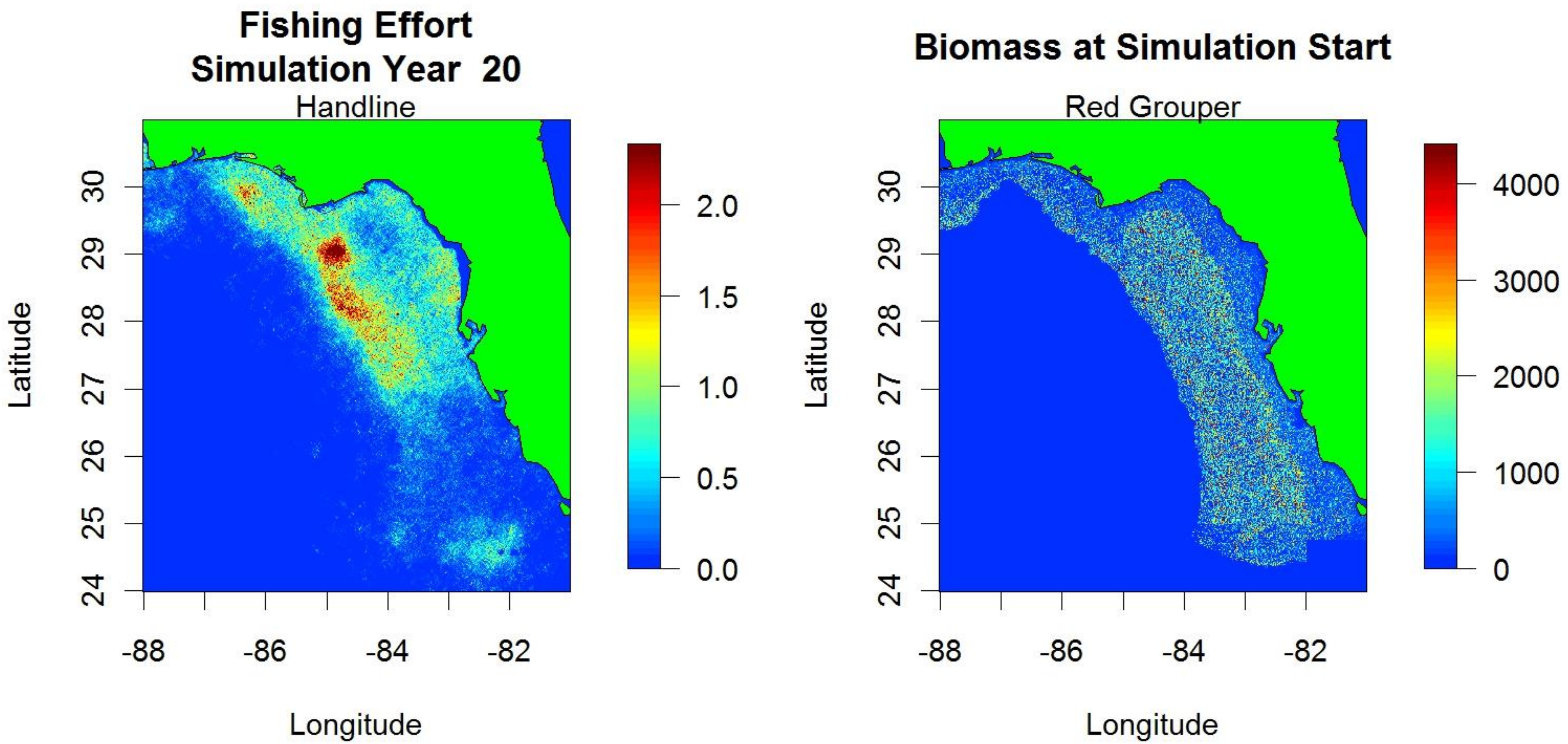
Spatial Distributions of Fishing Effort and Biomass



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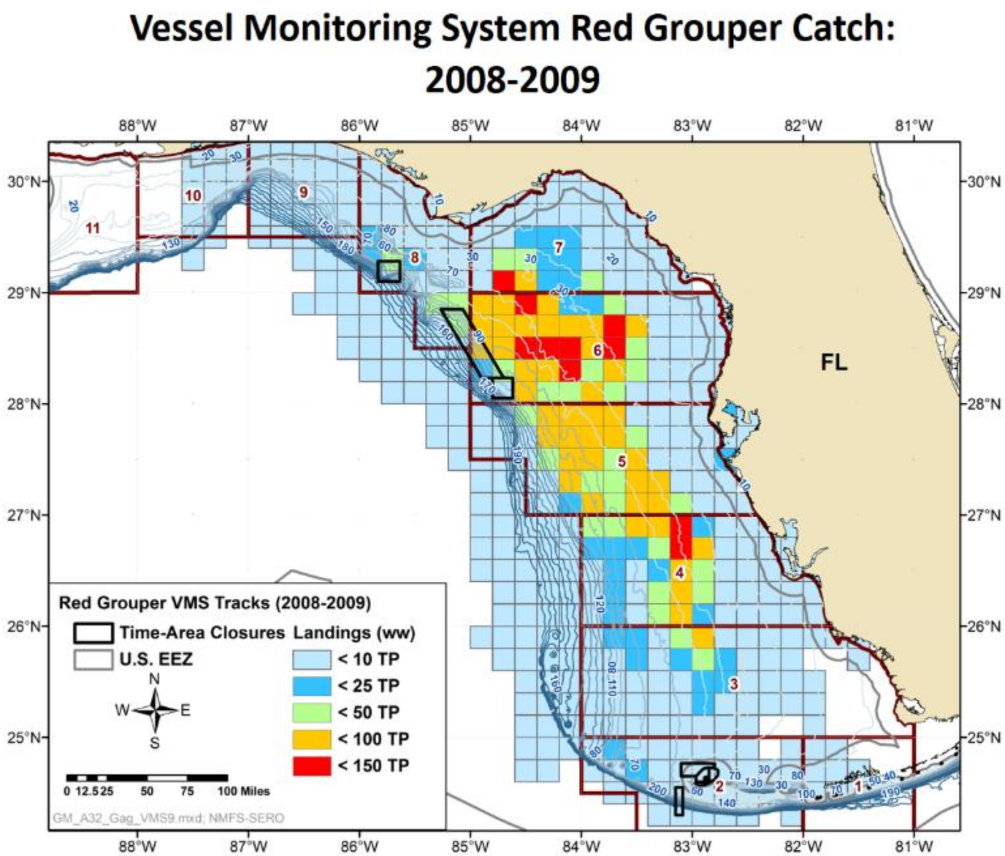
Summary

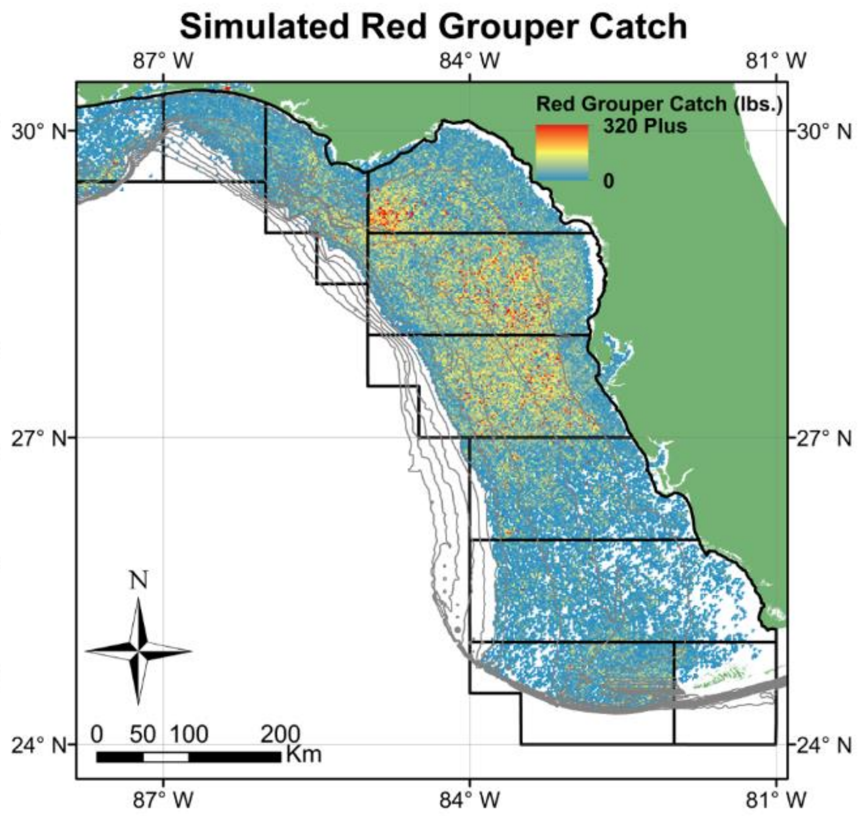
- Biased spatial sampling across the range of the stock and a changing size distribution in heavily fished areas were potential challenges for the stock assessment.
- Local depletion - spatial distribution of fishing effort and fish populations not uniform.
  - —People tend to have their fishing sites that they know work and only exploratory fish a fraction of the time if at all (survey responses suggest 25%).
- Fishing effort spatially and temporally affected by weather and fuel price (for smaller vessels)
- Trip duration sometimes limited by hold size which suggests effort saturation effect on CPUE
- Incorporating additional variables into CPUE standardization does not guarantee an improved index.

Summary

- Improved spatial resolution is needed in the commercial logbook data to determine more precise locations of catch and effort.
- Fishery independent surveys can be strategically placed in areas with low fishing effort to fill in spatial gaps, with some effort overlapping with fished regions to calibrate the survey with fishery dependent data.
- Ensure Trip Interview Program (TIP) sample landings in a way representative of spatial and temporal fishing effort distributions.

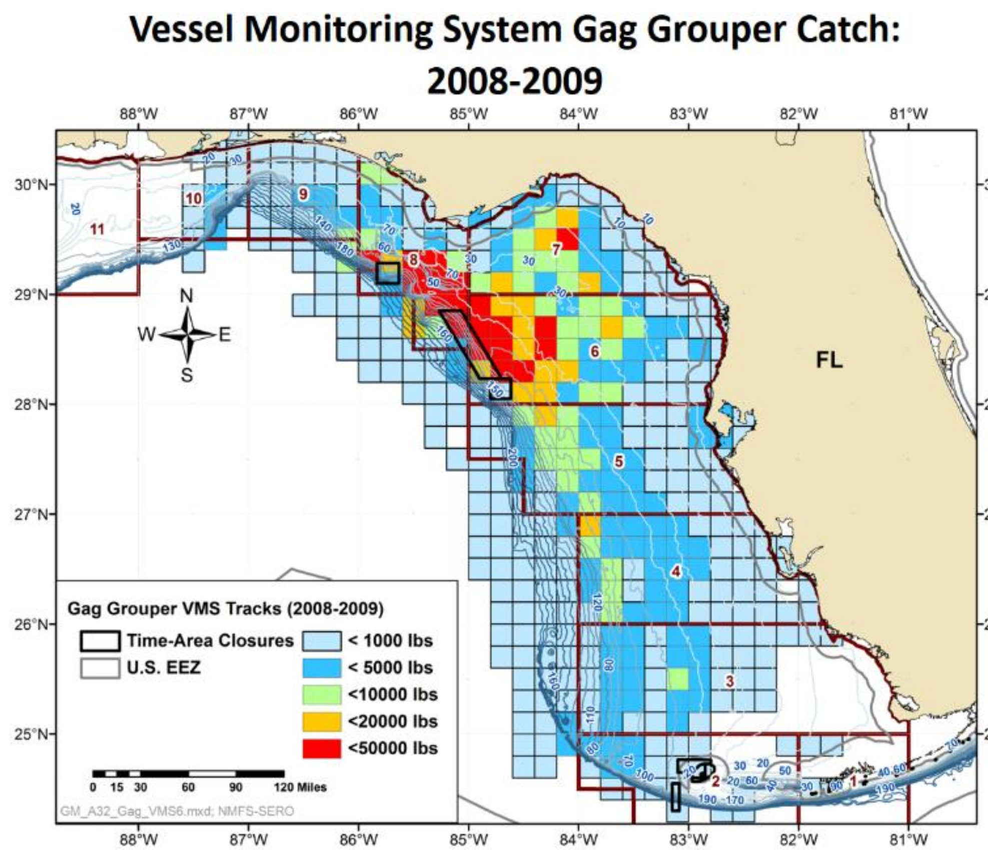
Comparison to Reality

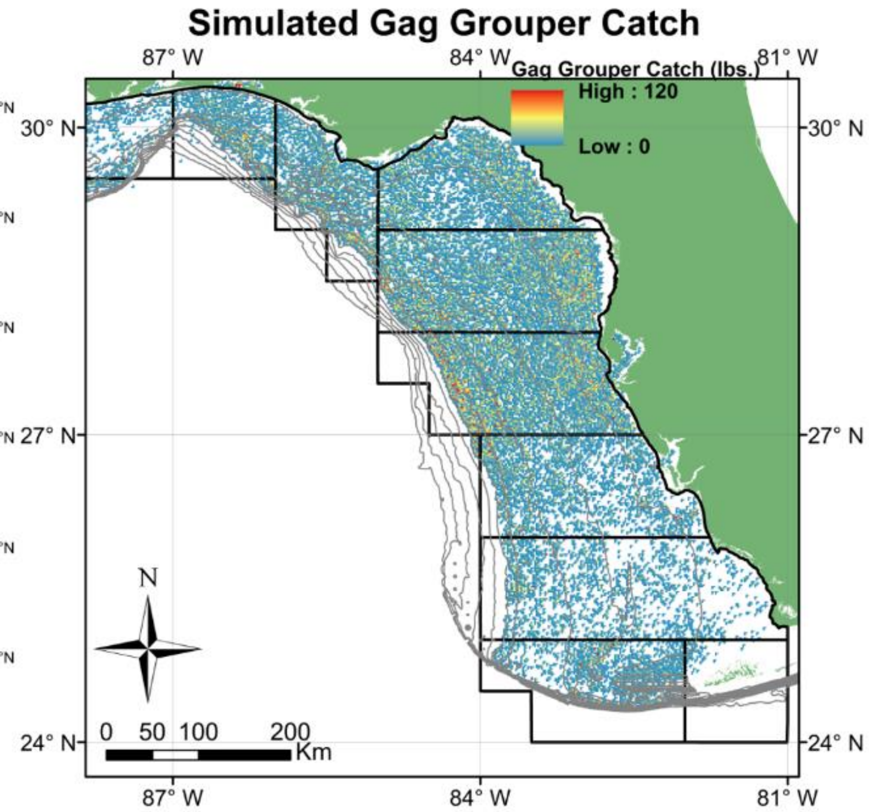




Saul, Brooks and Die. 2020. How fisher behavior can bias stock assessment: insights from an agent-based modeling approach. CJFAS 77: 1794-1809.

Comparison to Reality





Saul, Brooks and Die. 2020. How fisher behavior can bias stock assessment: insights from an agent-based modeling approach. CJFAS 77: 1794-1809.

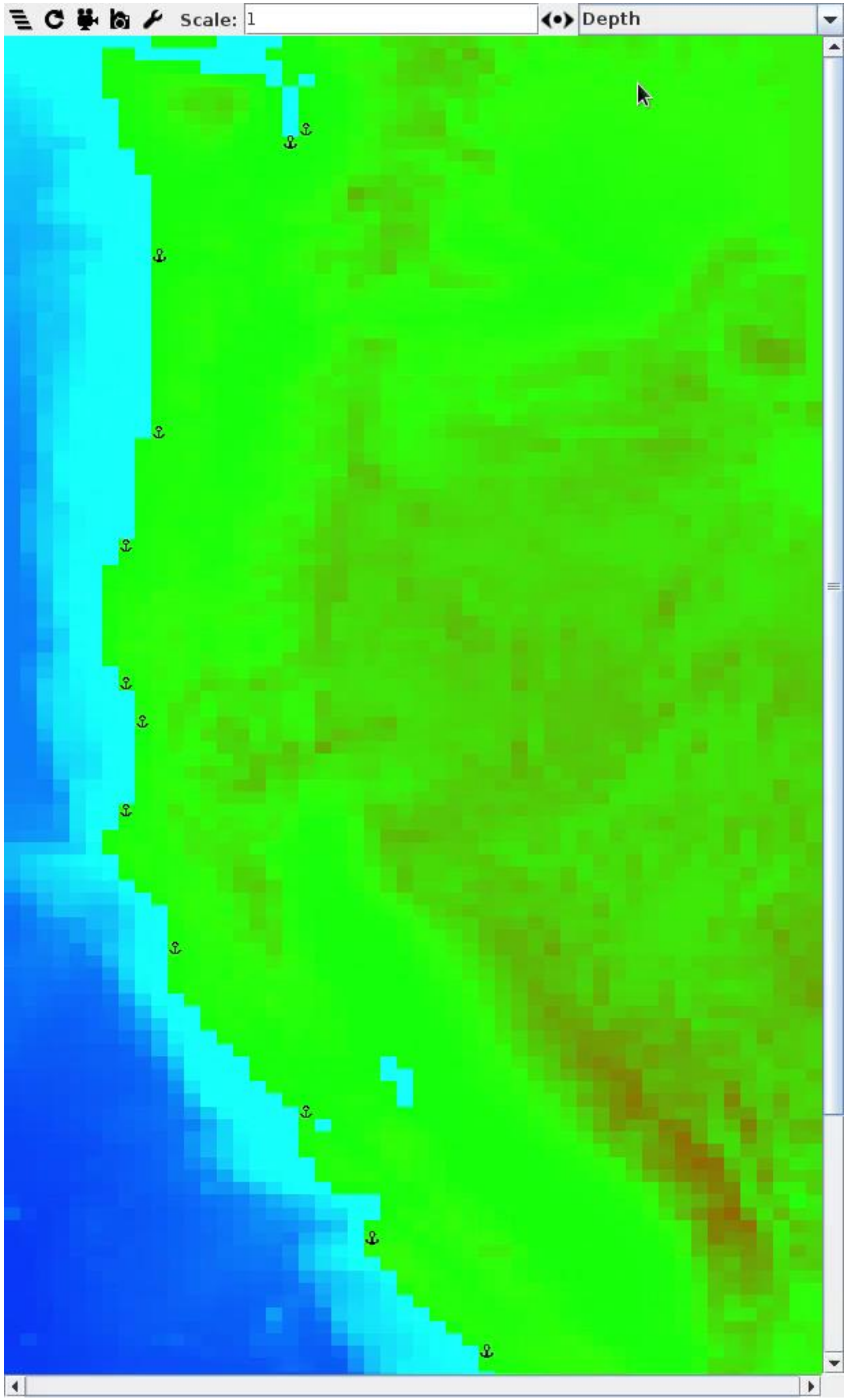
Other Fishery ABMs

- POSEIDON is an agent-based fleet and population dynamics model
- Simulates vessel behavior and fishery outcomes
- Uses machine learning and analytical tools to determine the "best" policies, indicators, and management levers
- Emphasizes the human and spatial dimension with simple biology

Bailey…**Saul**…, et al. 2019. Sustainability Science, 14, 259-275.

POSEIDON: U.S. West Coast Groundfish

- Biological age-structured model used, parameterized from recent stock assessments
- Five species incorporated: dover sole, sablefish, yelloweye rockfish, shortspine thornyhead and longspine thornyhead.

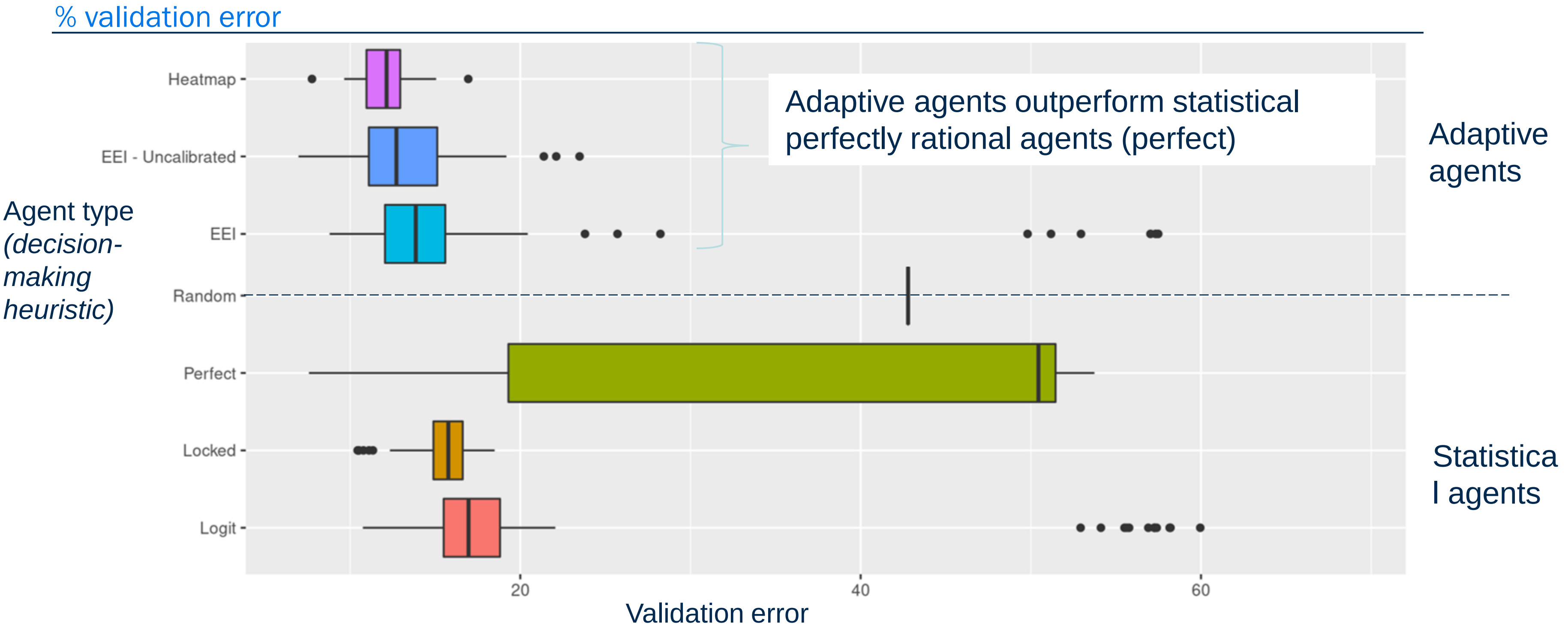


Carrella, **Saul**, et al. 2020. Ecological Economics 169: 106449

POSEIDON Learning: U.S. West Coast Groundfish

In our West Coast Groundfish analysis – we show that simple adaptive agents work as well or better than statistical agents

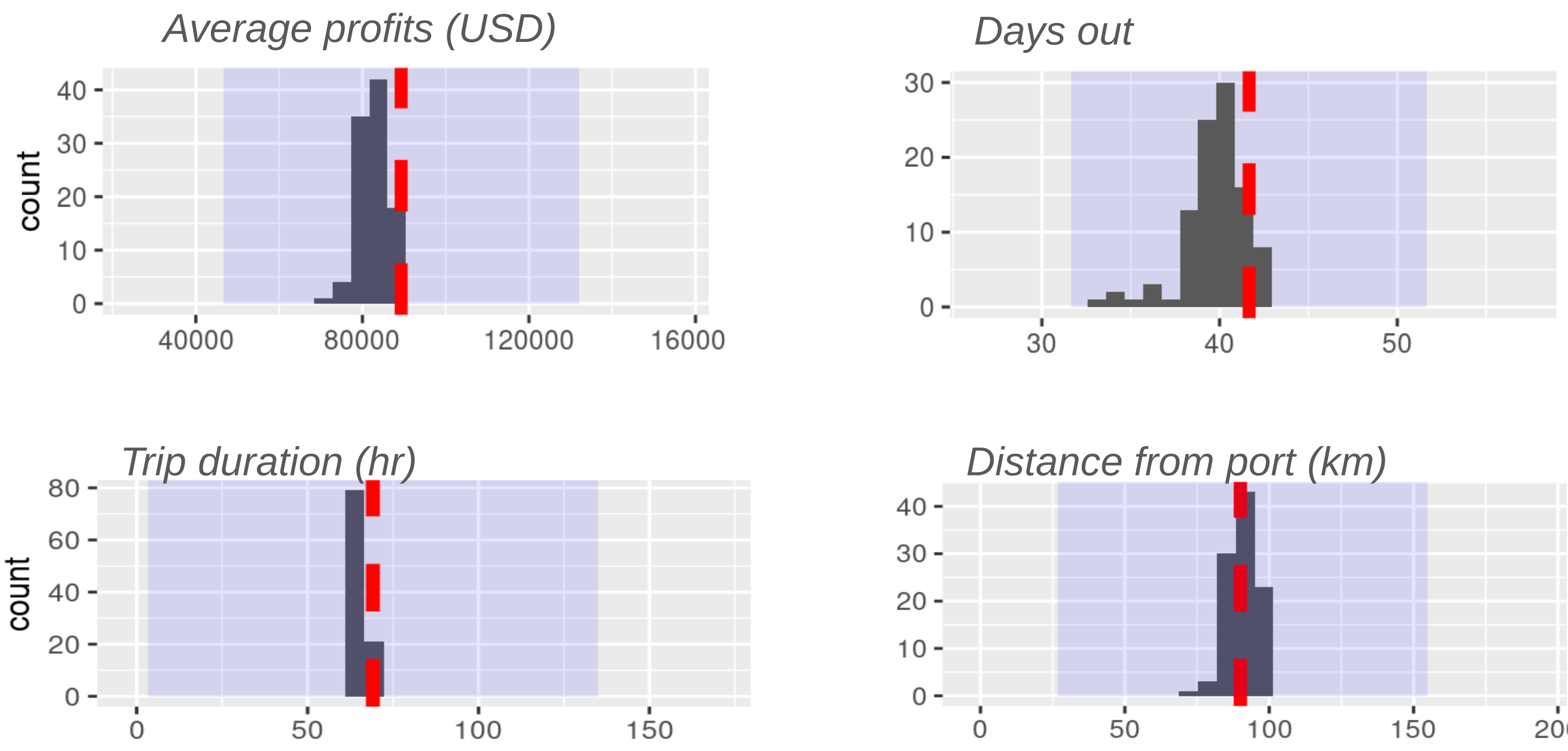
Validation error based on model predictions of fishing patterns for 2015



Carrella, **Saul**, et al. 2020. Ecological Economics 169: 106449

POSEIDON: U.S. West Coast Groundfish

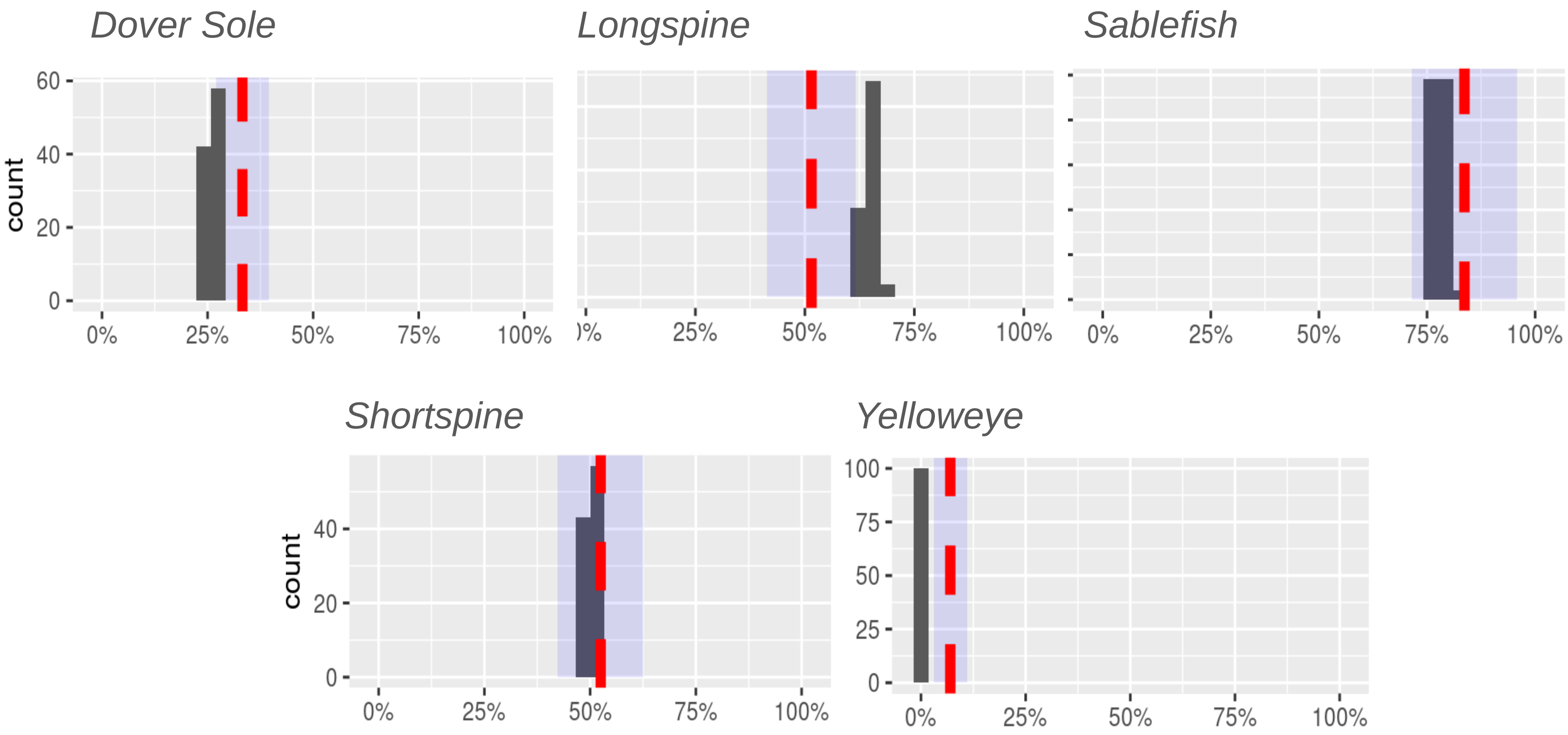
Simulated vs. real vessel activity and profits



Carrella, **Saul**, et al. 2020. Ecological Economics 169: 106449

POSEIDON: U.S. West Coast Groundfish

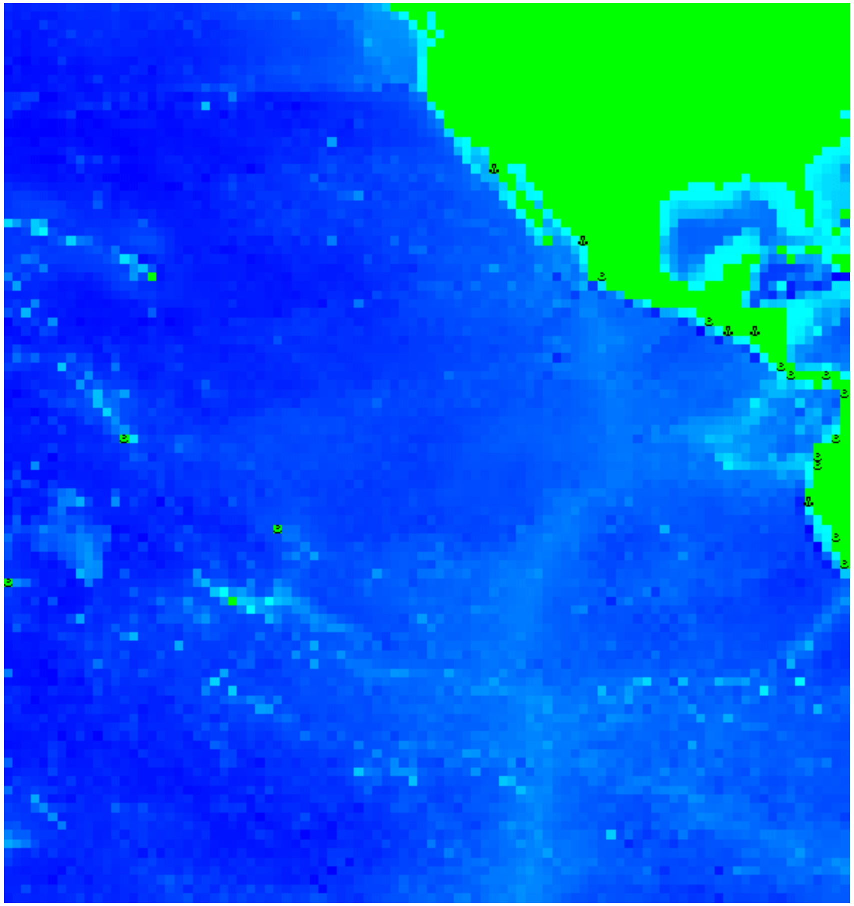
Simulated vs. real quota attainment, by species



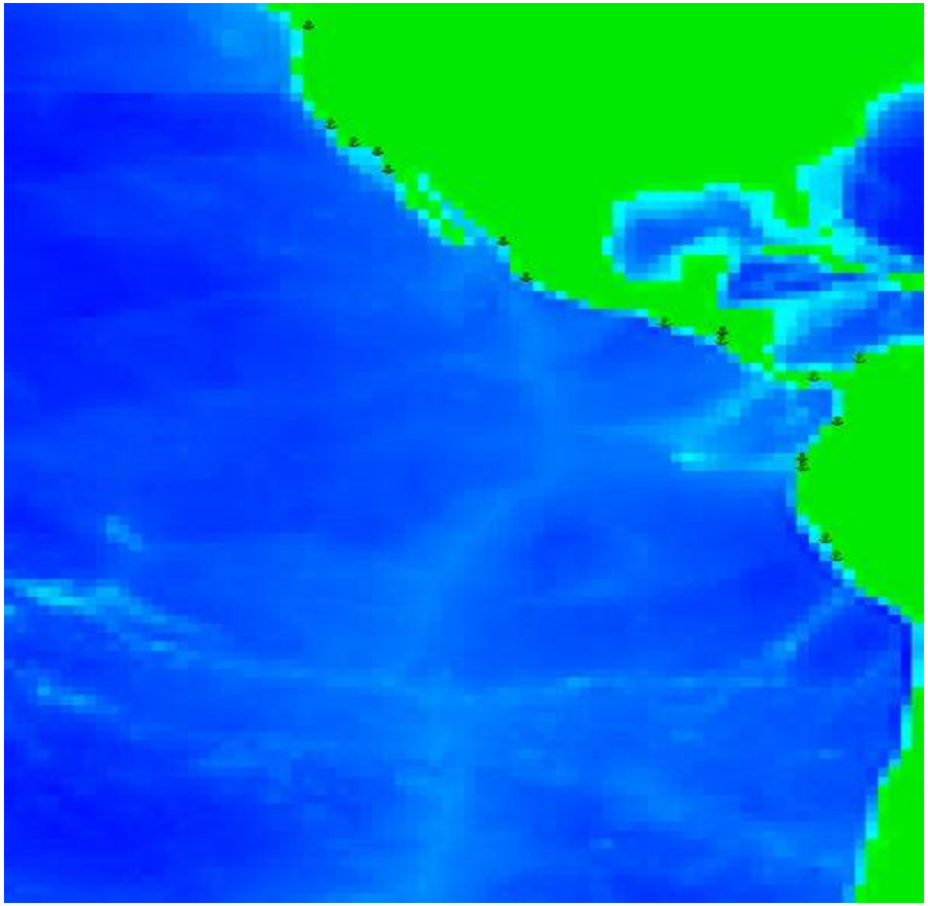
Carrella, **Saul**, et al. 2020. Ecological Economics 169: 106449

POSEIDON: Eastern Pacific Ocean Tuna and FADs

FAD Movement



Boat Movement



Summary

- Agent-based models have many places in fisheries science and stock assessment.
- There are multiple methods for collecting data on fisher behavior, and multiple modeling tools that can represent fisher decision-making.
- Different types of information can be solicited from logbook data, questionnaires, experiments, VMS, and other sampling initiatives.
- Models used to represent fisher behavior should be identified, and best practices developed to define when and how to apply each tool.
- Work is needed to better incorporate information on fisher behavior into stock assessment and fisheries management.

Future Gulf of Mexico Research

- Find ways to combine or embed discrete choice models into stock assessments (challenge: more parameters for optimization).
- Merge CPUE data with environmental, state, and economic variables together with vessel characteristics and use all variables in CPUE standardization.
- Agent-based models could be used to develop enhanced projections that directly account for fisher behavior.
- Agent-based models can be used to trial different management scenarios and to perform MSE.
- Agent-based models could serve as stock assessment infrastructure, but with a “wrapper” of sorts to fit to empirical data.

"Managing fish is managing people"

-Ray Hilborn, 2007

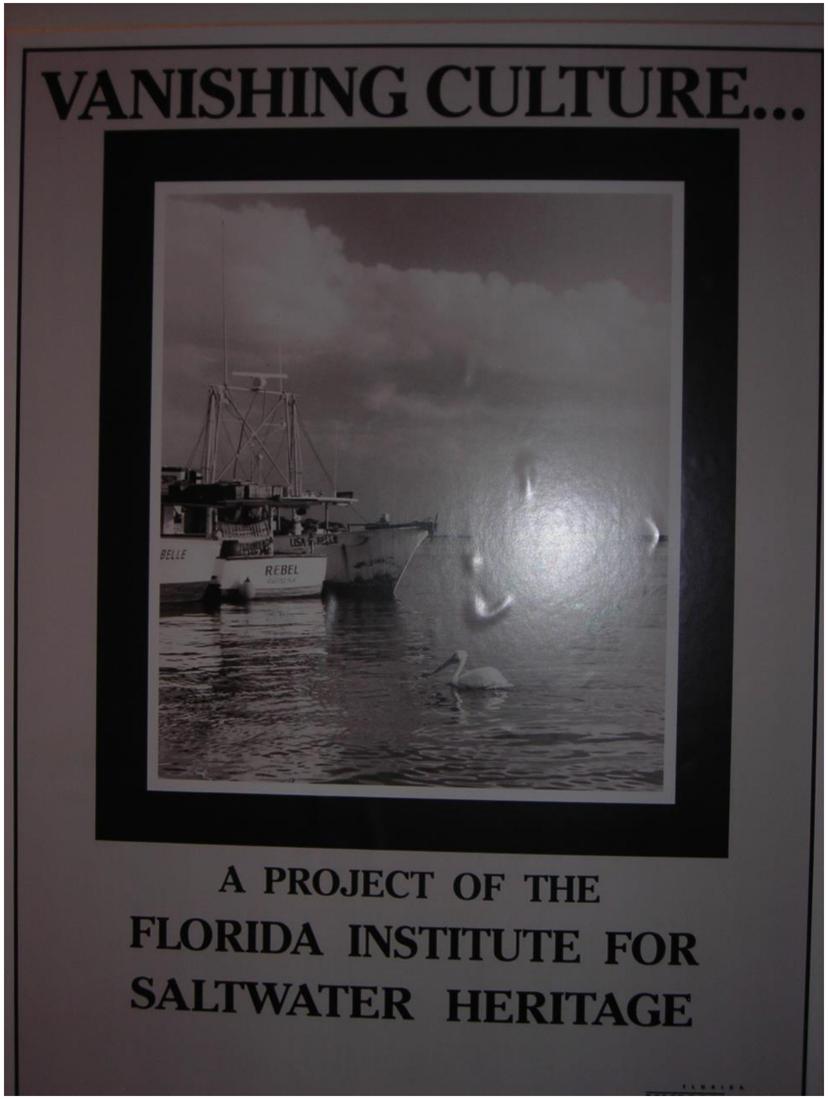
Gulf Fisherman's Association
Southern Offshore Fishing Assn.
Reef Fish Shareholder's Alliance

A.P. Bell and Starfish Market
Abrahm's Seafood
Ariel Seafood
Buddy Gandy Seafood
Cox Seafood
Fish Busterz (Madeira Beach)
Holiday Seafood
Jenson Tuna
Little Manatee Fish House
Madeira Beach Seafood
Sammy's Seafood
Save On Seafood
Water Street Seafood

Glen Brooks
David Krebs
Jason de la Cruz
Bobby Spathe

Funding

Questions?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