A Bioeconomic Model for Managing Harvest Size/Mercury Contamination Tradeoffs in King Mackerel

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Organization of Presentation

- Introduction and Background
- Research Objectives
- Brief Overview of the King Mackerel Fishery
- The Model
  - Population Dynamics of King Mackerel
  - Bioeconomic Model Incorporating Mercury Contamination
- Simulation Results
- Conclusions and Future Work

Fish, Mercury, and Health

- Contaminated fish is growing public health concern
- Methylmercury bioaccumulates in the tissues of fish
- Human nervous system is very sensitive to mercury
- Exposure to high levels of methylmercury can permanently damage the brain, kidneys, and developing fetus.
- Fish consumption is the dominant source of methylmercury exposure for the general population.

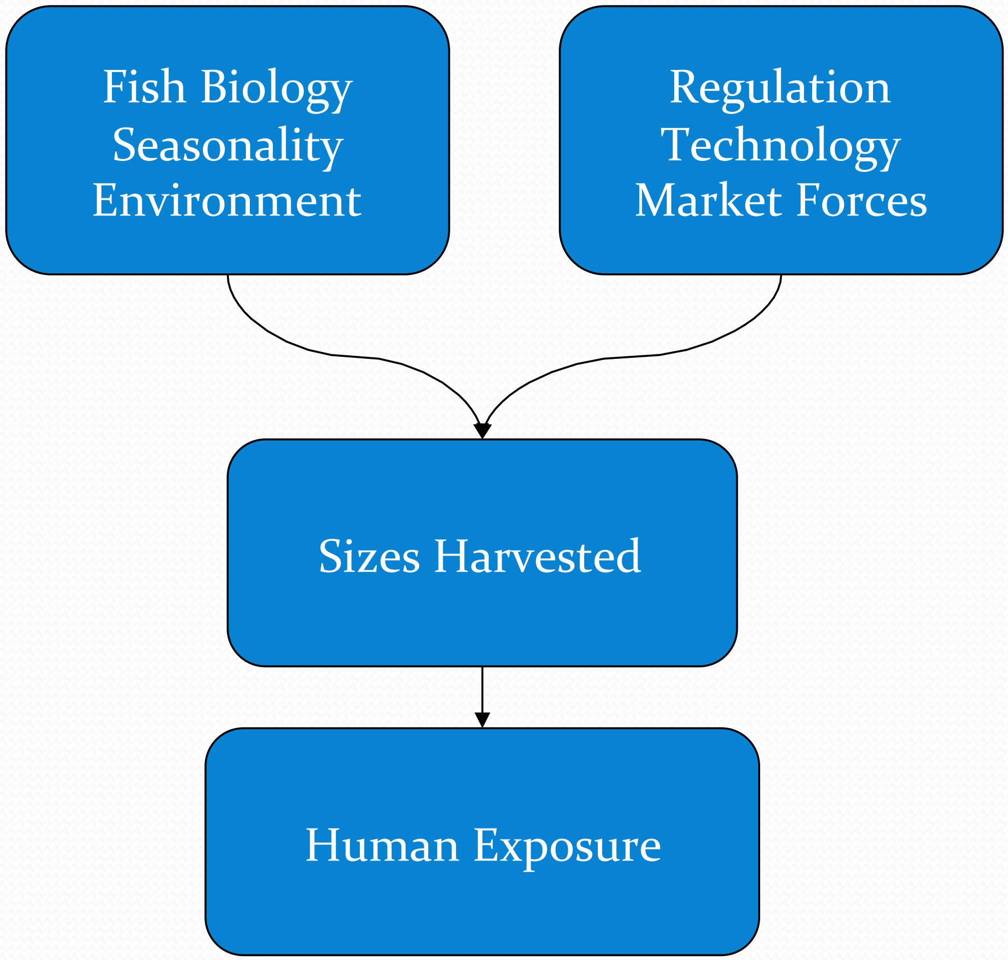
Limiting Consumer Exposure

- Fish consumption advisories
  - Inconsistent or unintended responses
- Long term pollution control
  - Does not necessarily lead to decreases in the contaminant concentrations found in fish, at least in the short-run.

Exploring An Alternative Method

- Significant positive relationship between fish size and mercury concentration in many species
- Current FMPs may actually increase the levels of contaminant exposure experienced by consumers.
- Currently no pre-harvest methods are being used to limit exposure
- An alternative would be a more directed, size-based management of contaminated marine fisheries that accounts for contamination

Conceptual Model

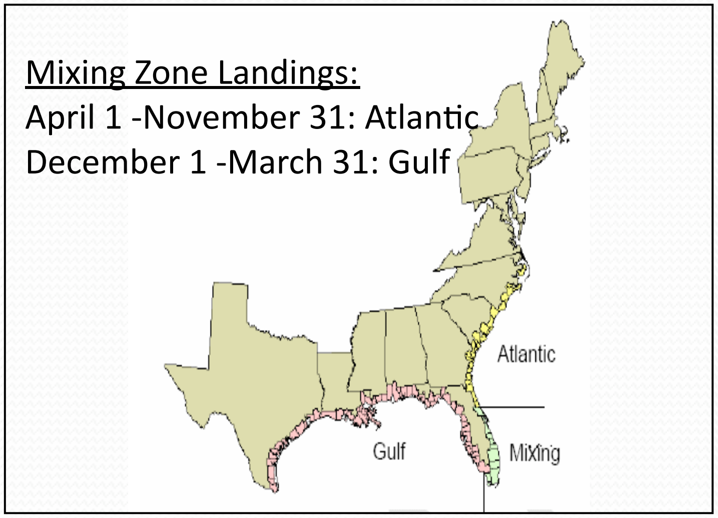


Objectives

- Develop a realistic, multiple-cohort population dynamics model for King Mackerel
- Incorporate the population dynamics model into a bioeconomic model accounting for
  - Commercial King Mackerel harvesting sector
  - Mercury and the potential exposure to human consumers
- Apply the bioeconomic model to the investigation of fishery management scenarios
  - Mitigate the deleterious effects of contamination on humans?
  - Preserve the public and private benefits associated with the fishing industry?

King Mackerel Fishery Overview

- Coastal pelagic
  - W. Atl, GOM, Caribbean
- Substantial catches in U.S. waters
- Managed as two independent migratory groups
  - Gulf Migratory Group
  - Atlantic Migratory Group
- Managed through quotas, possession and trip limits, size limits, and seasonal closures
- Mercury levels are high
- Primarily harvested with hook and line gear



Population Dynamics Model

- Discrete time model that tracks recruitment, growth, and mortality of individual age classes
- Parameterized using stock assessment data from SEDAR 16
- Validated by comparing simulated and actual values of landings and biomass
  - Differences resulting from recruitment specification
- Model is good for use in applied research of king mackerel stocks

Numbers in each age class

$$N_{s,a,t} = \begin{cases} N_{s,a-1,t-1} e^{-Z_{s,a-1,t-1}} & for\ a = 1,2,\ldots,10 \\ N_{s,10,t-1} e^{-Z_{s,10,t-1}} + N_{s,11,t-1} e^{-Z_{s,11,t-1}} & for\ a = 11 \end{cases}$$

$$Z_{s,a,t} = M_{s,a} + F_{s,a,t}$$

Recruitment

$$N_{s,0,t} = \frac{\alpha_s SSF_{s,t-1}}{(\beta_s + SSF_{s,t-1})}$$

Biomass

$$B_{s,t} = \sum_{a=0}^{11} N_{s,a,t} \cdot W_{s,a,t}$$

Catch Numbers

$$CN_{s,a,t} = \frac{F_{s,a,t} \cdot N_{s,a,t}}{Z_{s,a,t}} \left(1 - e^{-Z_{s,a,t}}\right)$$

Catch Weight

$$C_{s,t} = \sum_{a=0}^{11} CN_{s,a,t} \cdot W_{s,a,t}$$

Population Dynamics Model

- Commercial Fishing Mortality not available in SEDAR16
  - Used indices to determine commercial catch proportion by age
- Provides baseline against which alternative harvesting patterns can be compared

Fishing Mortality

$$F_{s,a,t} = FComm_{s,a,t} + FRem_{s,a,t}$$

Commercial Catch

$$CommCN_{s,a,t} = \frac{FComm_{s,a,t} \cdot N_{s,a,t}}{Z_{s,a,t}}\left(1 - e^{-Z_{s,a,t}}\right)$$

$$CommCW_{s,t} = \sum_{a=0}^{A} CommCN_{s,a,t} \cdot W_{s,a,t}$$

Economics Model

- Economics of the harvesting sector
  - Revenue
  - Cost
  - Profit
- Linked to population dynamics model through Cobb Douglas harvest function
  - Allows estimate of effort

Revenue

$$\mathrm{Rev}_{s,t} = P \cdot CommCW_{s,t}$$

Harvest

$$CommCW_{s,t} = q_s E_{s,t}^{\phi_s} B_{s,t}^{\gamma_s}$$

Cost

$$Cost_{s,t} = cE_{s,t}$$

Profit

$$\pi_{s,t} = \mathrm{Rev}_{s,t} - Cost_{s,t}$$

NPV

$$NPV_s = \sum_{t=1}^{T} \left(\frac{1}{1+r} \right)^t \pi_{s,t}$$

Economics Model Data

- Price
  - NMFS ALS database
  - Single, constant price assumption
- Effort
  - NMFS Coastal Logbook
    - unique trip identifier, landing date, fishing gear deployed,
    - areas fished, number of days at sea, number of crew,
    - species caught, whole weight of the landings, and gear specific fishing effort
    - Hook and line effort measures
      - number of lines fished,
      - number of hooks per line
      - total fishing time.
- Cost
  - NMFS ALS database

Mercury Exposure Model

- Output of the bioeconomic model is linked to exposure through the size/mercury relationship
  - Growth function
  - Size-mercury relationship estimated by Adams and McMichael (2007)
- Calculate average mercury concentration of fish actually harvested
  - Cannot change actual Hg amounts in fish
  - Can influence amounts reaching consumers by harvesting smaller fish

Growth Function

$$FL_{s,a} = L_{\infty,s}[1 - e^{-K_s(a - a_{0,s})}]$$

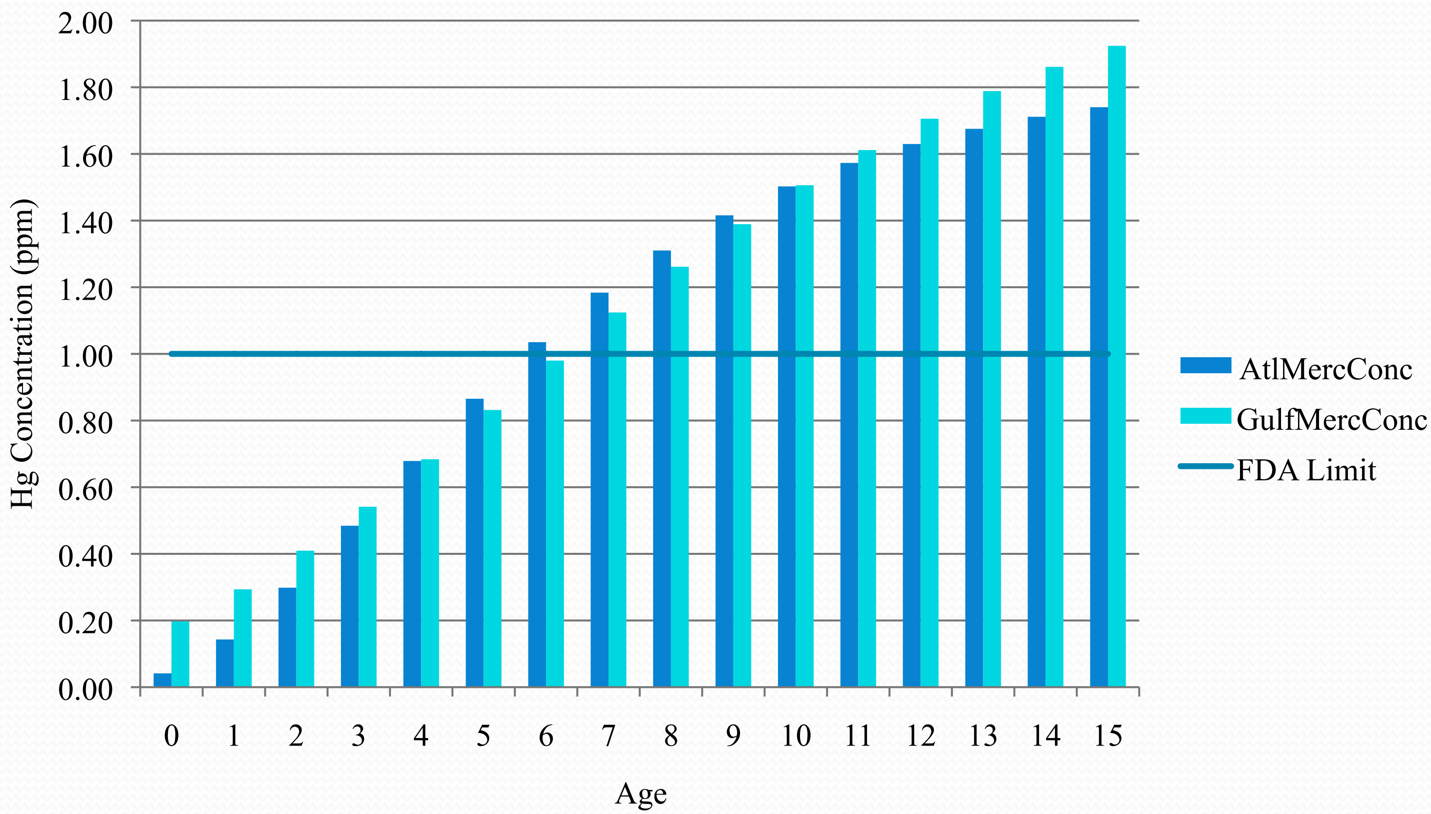
Mercury Concentration

$$Hg_{s,a} = \begin{cases} 1.11 \cdot 10^{-7} FL_{s,a}^{3.51} & for\ s = Atlantic \\ e^{-3.09 + .032 FL_{s,a}} & for\ s = Gulf \end{cases}$$

Mean Hg in Total Catch

$$\overline{Hg}_{s,t} = \frac{\sum_{a=0}^{11} Hg_{s,a} \cdot CommCN_{s,a,t}}{CommCN_{s,t}}$$

Mercury concentration by age class



How much mercury is too much?

- US FDA limit for human consumption:
  - 1 ppm
- US EPA reference dose:
  - 0.1 micrograms/kg bodyweight per day
- WHO recommendation
  - 1.6 micrograms/kg bodyweight per week
- US ATSDR
  - 0.3 micrograms/kg bodyweight per day

Model Implementation

- Examine impact of changing commercial fishing mortality at age
- 6 Simulated Scenarios
  1. Status Quo
  2. Eliminate catch of fish age 6 and older
  3. Establishment a 33" fork length maximum size limit (with no increased catch of smaller fish),
  4. Scenario 3 with an increase in catch of smaller fish
  5. Reduce catch of age 4 fish along an increase in catch of younger fish
  6. Scenario 5 with consideration for incidental catch

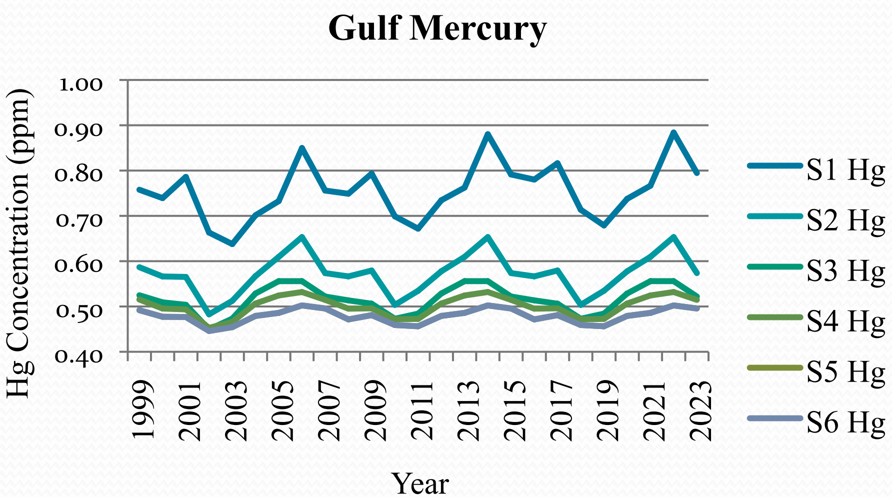
Model Implementation

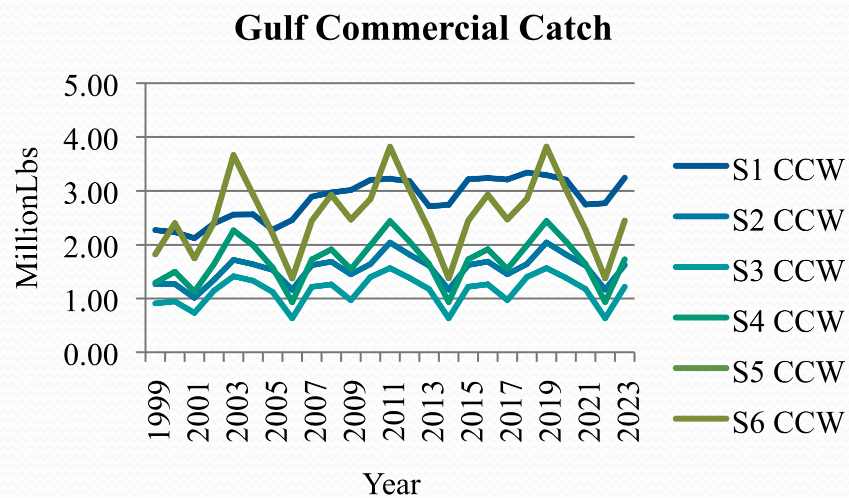
- 25 year simulation time frame
- Focusing on:
  - annual mean mercury concentration in the harvest
  - annual commercial catch in pounds
  - annual stock biomass, annual profits in the fishing industry
  - NPV of the fishery

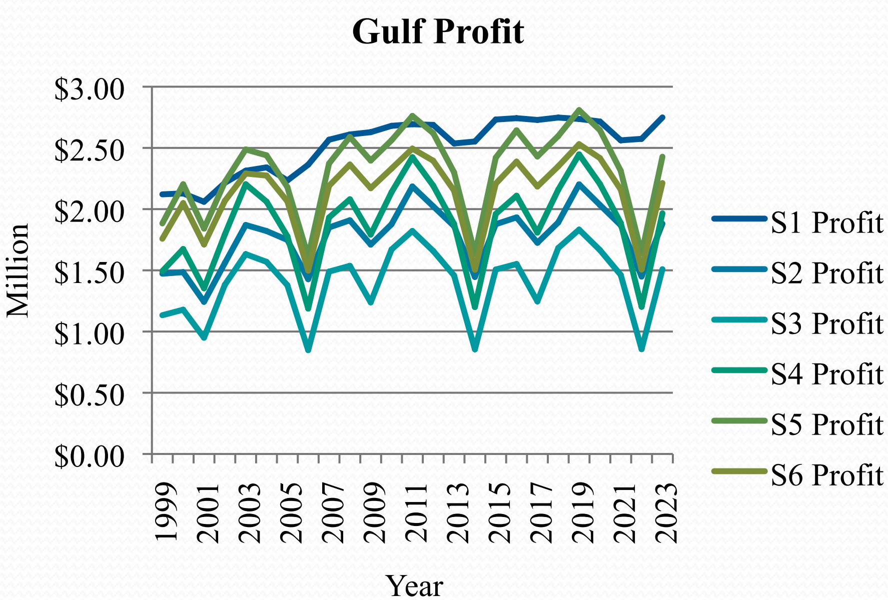
Simulation Results-Gulf

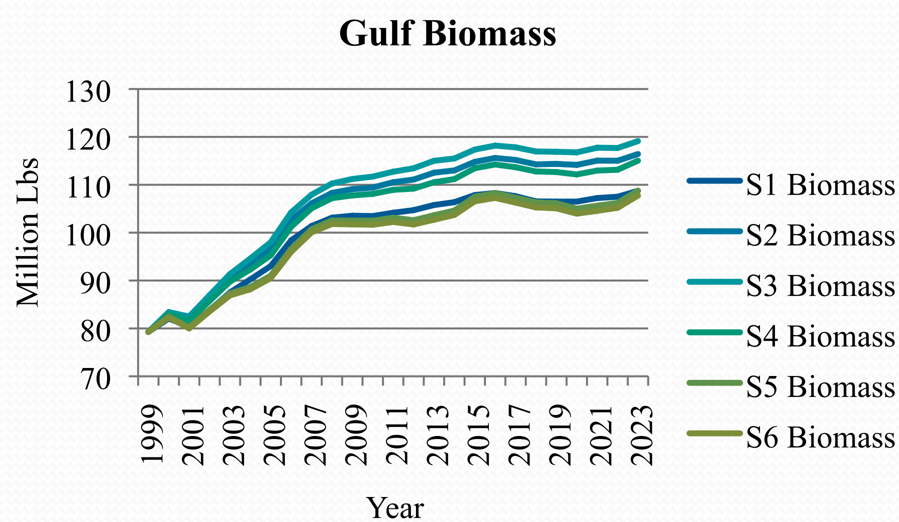
Scenario	NPV	% Change	Min Hg	Max Hg	Mean Hg
1	$34,561,343		0.64	0.88	0.76
2	$24,403,130	-29.39%	0.48	0.65	0.57
3	$19,406,615	-43.85%	0.45	0.56	0.52
4	$25,985,333	-24.81%	0.45	0.53	0.50
5	$32,192,745	-6.85%	0.45	0.50	0.48
6	$29,635,679	-14.25%	0.45	0.50	0.48

Simulation Results-Gulf





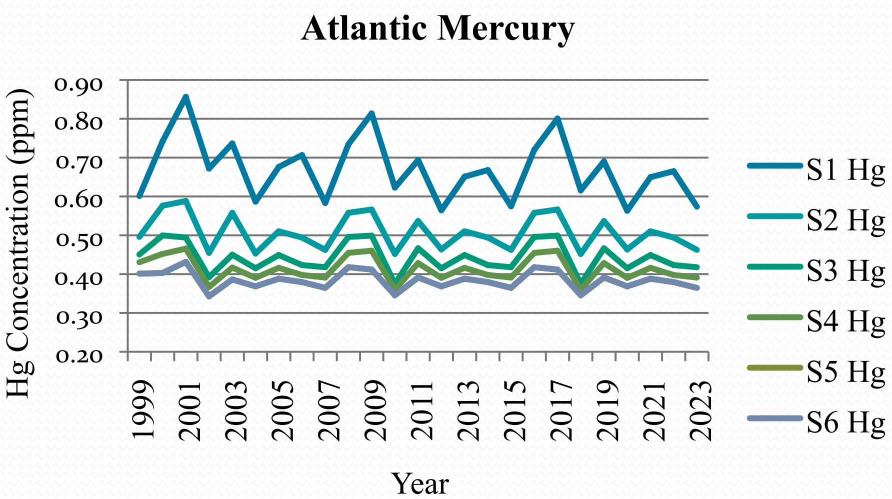


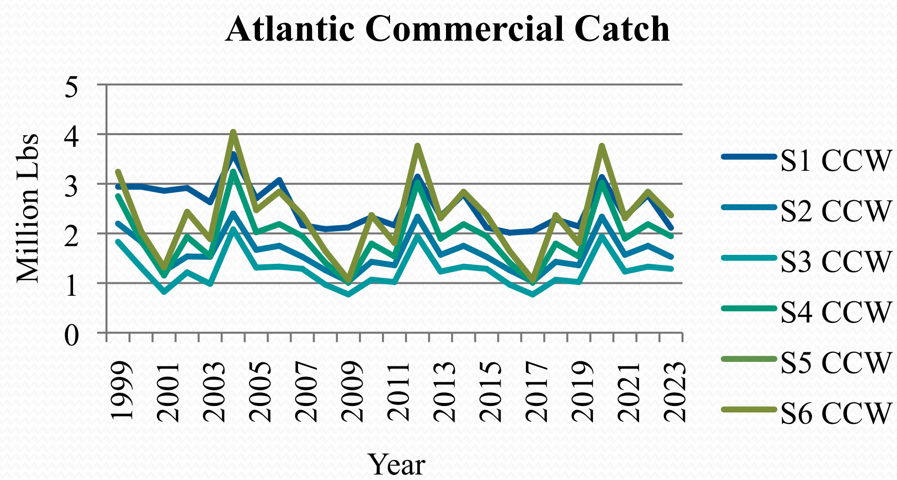


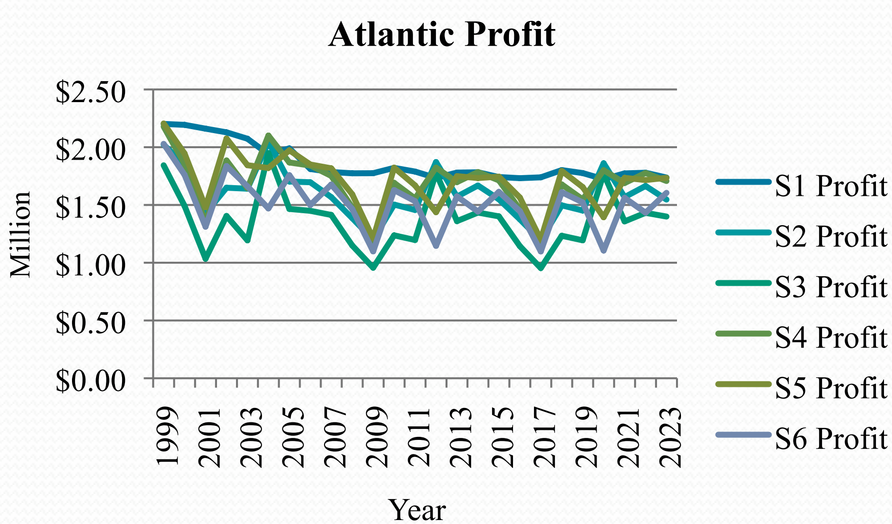
Simulation Results- Atlantic

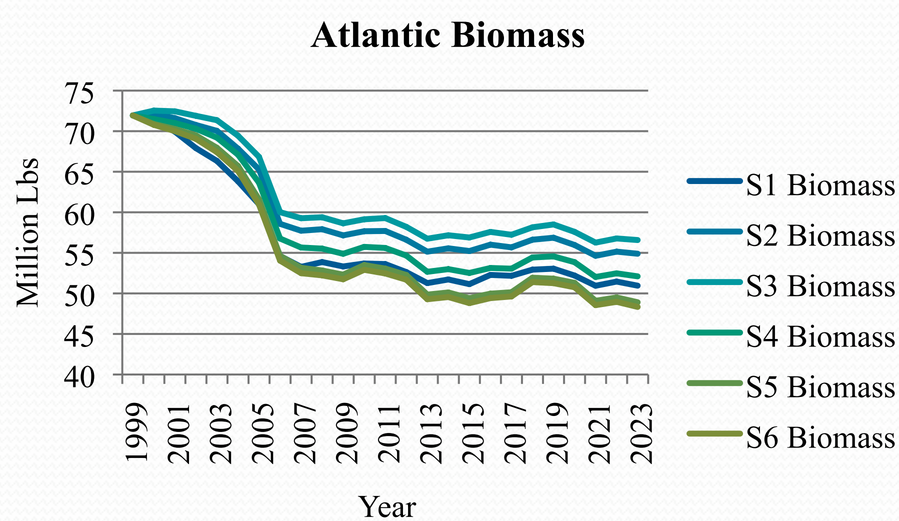
Scenario	NPV	% Change	Min Hg	Max Hg	Mean Hg
1	$26, 920,041		0.56	0.86	0.67
2	$22, 923,928	-14.84%	0.45	0.59	0.51
3	$19,540,856	-27.41%	0.37	0.50	0.44
4	$24,170,976	-10.21%	0.36	0.47	0.41
5	$24,669,159	-8.36%	0.34	0.43	0.38
6	$21,873,321	-18.75%	0.34	0.43	0.38

Simulation Results-Atlantic









Conclusions

- Possible to reduce the amount of mercury that reaches consumers
- Possibly with low impact on commercial catch or biomass
- Gulf and Atlantic mercury reductions came at the price of reduced profits and losses in NPV.
- Some tradeoffs appear necessary, but further research into a win-win management scheme is warranted.

Discussion

- How to transfer model findings to real-world management?
  - Focus on policies that will change age selectivity of the catch
  - Area and seasonal closures
    - Only effective if stock exhibits unique temporal or spatial distribution
    - More research needed
  - Harvesting slot limit
    - Effective at reducing mercury
    - Incidental catch issues
    - How to apply/enforce in large scale commercial fishery?

Future Research

- Improvement of population dynamics model
- Dynamic optimization of the model under various objectives
  - Profit maximization
  - Minimization of average mercury
  - Profit maximization constrained by mercury limits and biomass limits
- Apply framework to another species

Acknowledgments

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