NAVIGATING THE WATERS: A COMPREHENSIVE APPROACH TO HERRING MANAGEMENT USING ECOLOGICAL MODELING

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OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

PRESENTATION OVERVIEW

INTRODUCTION

Martha's Vineyard, MA (Wampanoag Tribe 2024)

Figure 1. Overview Map of Project Locations

Upper Penobscot River, ME

FISHERIES HISTORY

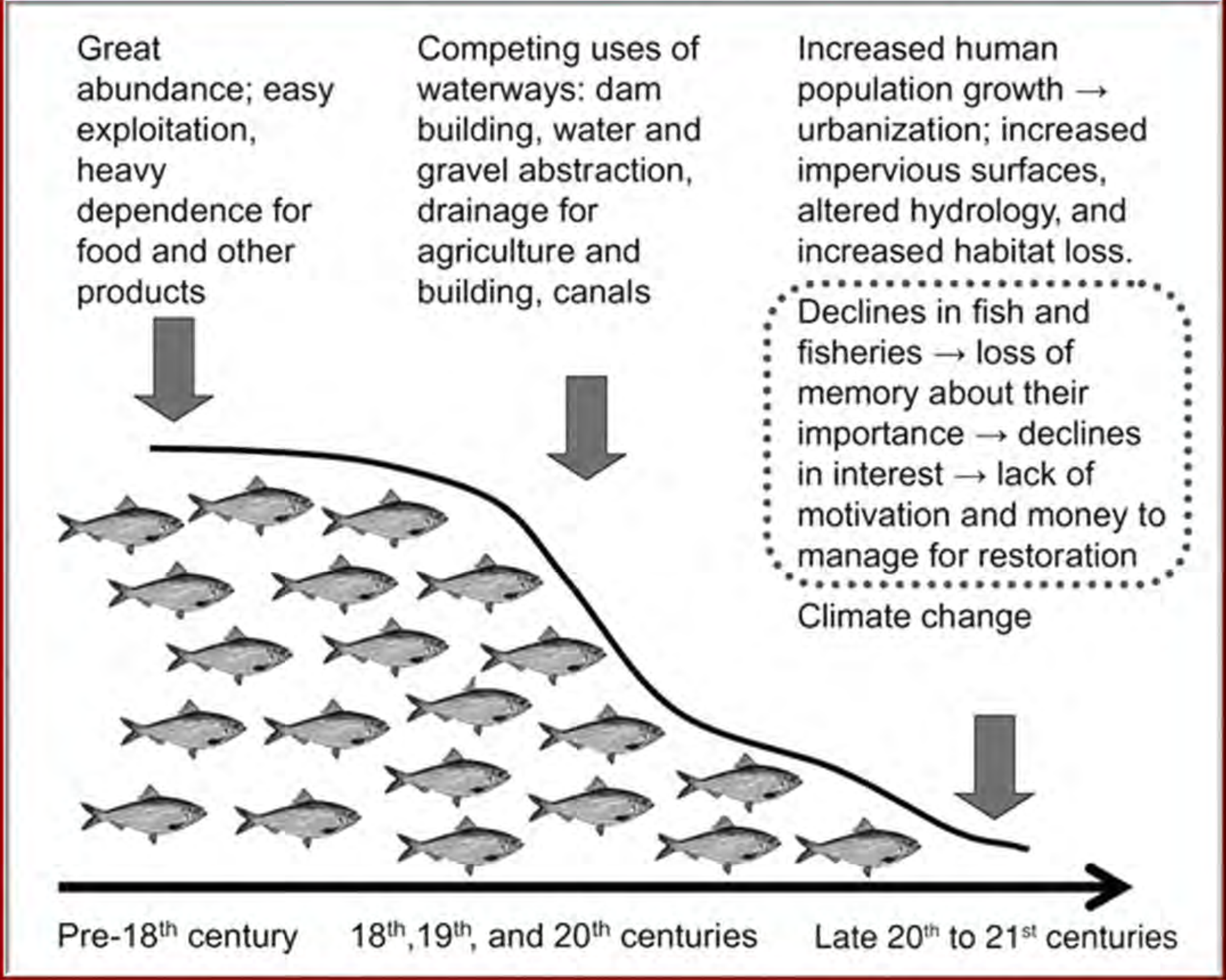
Overview

Historic Abundance: Diadromous fish thrived in Northeast US waterways, supporting robust fisheries and ecosystems.

Human Impacts: Waterway changes, overfishing, pollution, and urban growth disrupted migration and spawning, leading to population declines.

Industrialization and Pollution: Urbanization introduced pollutants, degrading habitat and impeding fish migration further.

Limited Recovery: Despite conservation efforts, diadromous fish populations remain fragmented and diminished compared to historical levels.



Great abundance; easy exploitation, heavy dependence for food and other products

Competing uses of waterways: dam building, water and gravel abstraction, drainage for agriculture and building, canals

Increased human population growth → urbanization; increased impervious surfaces, altered hydrology, and increased habitat loss.

Declines in fish and fisheries → loss of memory about their importance → declines in interest → lack of motivation and money to manage for restoration

Climate change

Pre-18th century

18th, 19th, and 20th centuries

Late 20th to 21st centuries

Figure 2. Decline of Diadromous Fish (Limburg & Waldman, 2009)

DIADROMOUS FISH

Habitat Usage by Fish

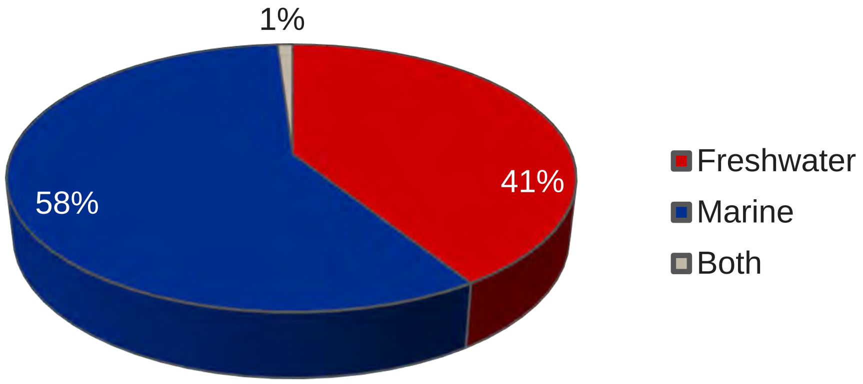


Figure 3. Habitat Usage Across Known Fish Species

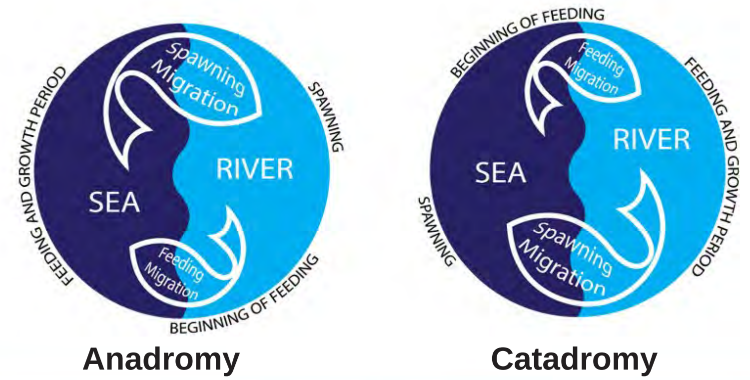


Figure 4. Types of Diadromy in Fish (An@dromos.pt, 2020)

Diadromous Fish Species

DIADROMOUS FISH

Habitat Usage by Fish

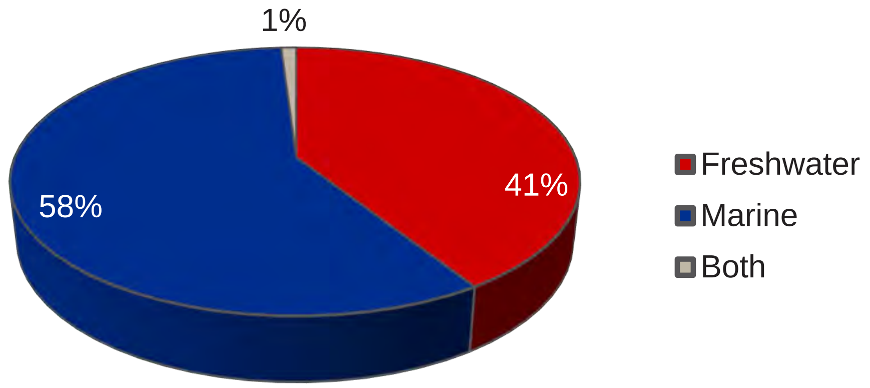
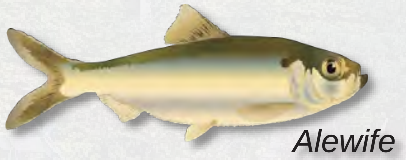


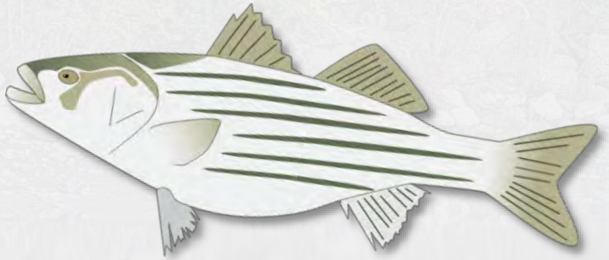
Figure 3. Habitat Usage Across Known Fish Species

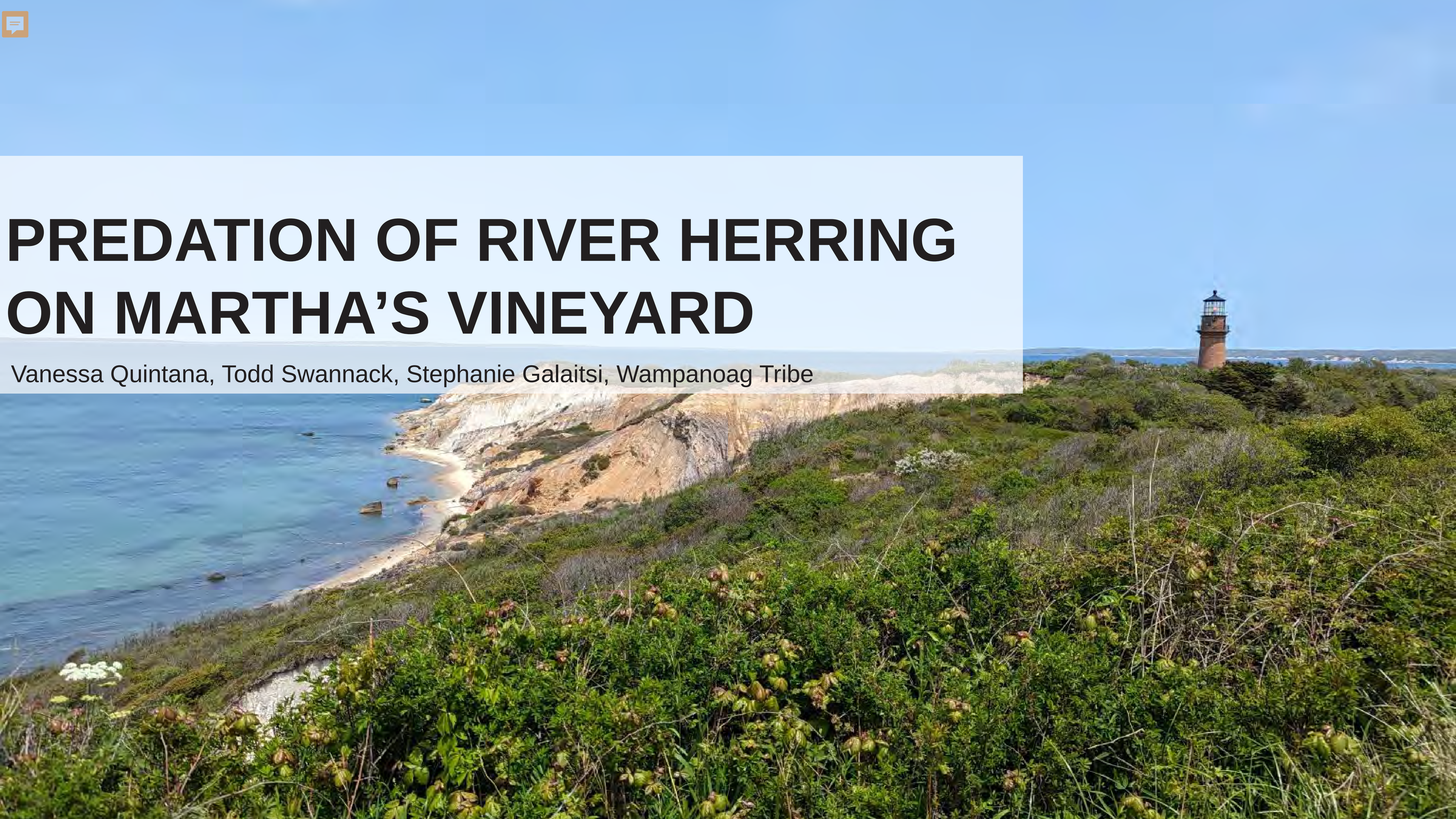
Anadromy **Catadromy**

Figure 4. Types of Diadromy in Fish (An@dromos.pt, 2020)

Diadromous Fish Species


Alewife


Striped Bass



PREDATION OF RIVER HERRING ON MARTHA'S VINEYARD

Vanessa Quintana, Todd Swannack, Stephanie Galaitsi, Wampanoag Tribe

HERRING CREEK

Figure 5. Regional Map of Martha's Vineyard (Oldale, 1992).

Wampanoag Tribe

For over ten thousand years the Wampanoag have inhabited the island of Noepe (**Martha's Vineyard**). The Wampanoag Nation ancestral homelands includes all of Southeastern Massachusetts and Eastern Rhode Island. The Tribe resides in Aquinnah on Martha's Vineyard, upholding a continuous existence in their ancestral territory.

Herring Creek Fishery

A channel historically maintained by the Tribe between Squibnocket and Menemsha Ponds in Aquinnah on Martha's Vineyard.

HERRING CREEK

Figure 6. Herring Creek Opening 1900s (Provided by Tribe)

Figure 7. Herring Creek Opening 2023

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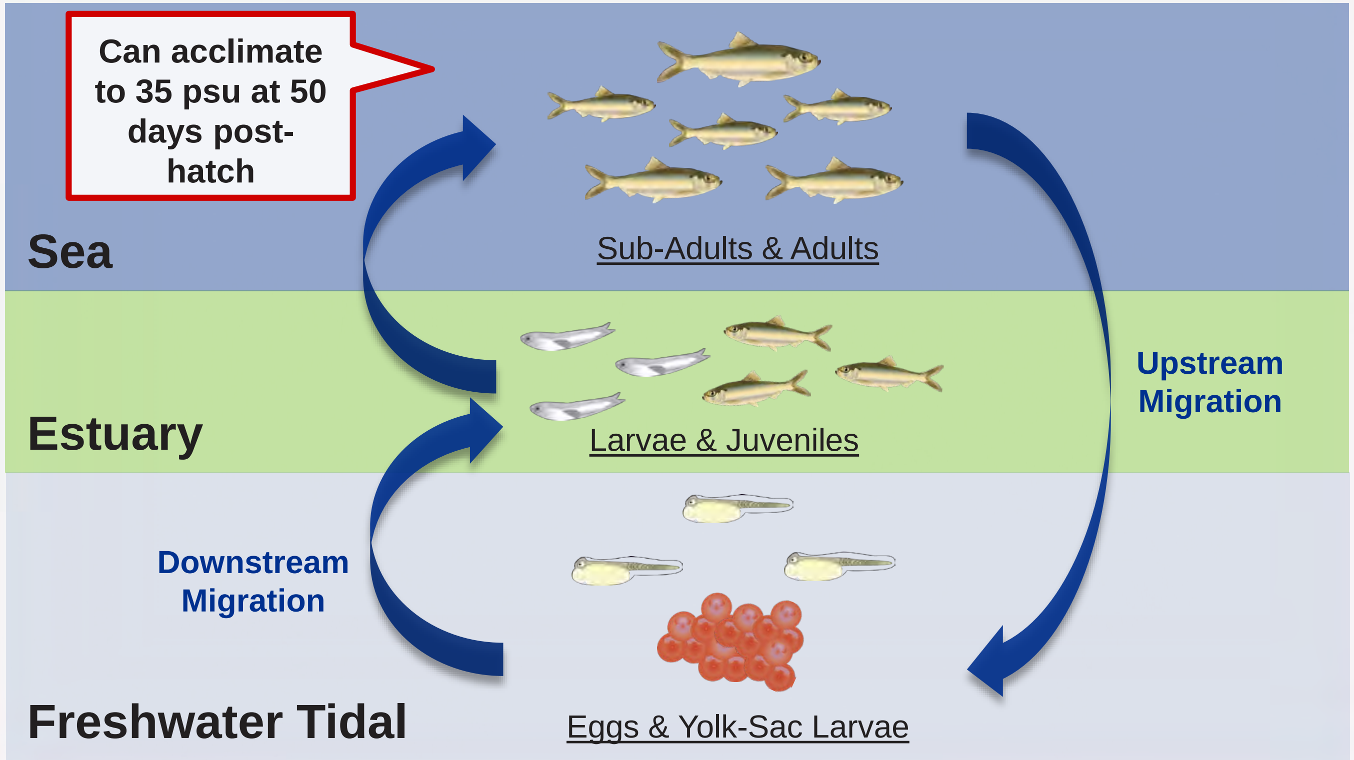
Herring Creek Fishery

A channel historically maintained by the Tribe between Squibnocket and Menemsha Ponds in Aquinnah on Martha's Vineyard.

CHALLENGES IN HERRING MANAGEMENT

Diadromous River Herring Life Cycle



Can acclimate to 35 psu at 50 days post-hatch

Sea

Sub-Adults & Adults

Estuary

Larvae & Juveniles

Upstream Migration

Downstream Migration

Freshwater Tidal

Eggs & Yolk-Sac Larvae

Local Behavior?

Striped Bass in Aquinnah sit in a Culvert to Consume Migrating River Herring.

Figure 8. Map of Squibnocket and Menemsha Ponds (MEP 2017)

CHALLENGES IN HERRING MANAGEMENT

Site Characteristics

- **Species-Specific Challenges:** Overfishing, migration impediments, offshore fishing, and habitat degradation has led to the overall decline of river herring stock.
- **Local Recovery and Setbacks:** Local stock showed a brief recovery, but migration survival dropped from ~ 3% in 2016 to ~1% in 2023, coinciding with increased salinity and the presence of residential striped bass.
- **Management Impediments:** Lack of understanding of estuary habitat utilization by herring life stages and site-specific challenges at the Herring Creek Fishery hinder effective population management.

Local Behavior?

Striped Bass in Aquinnah sit in a Culvert to Consume Migrating River Herring.

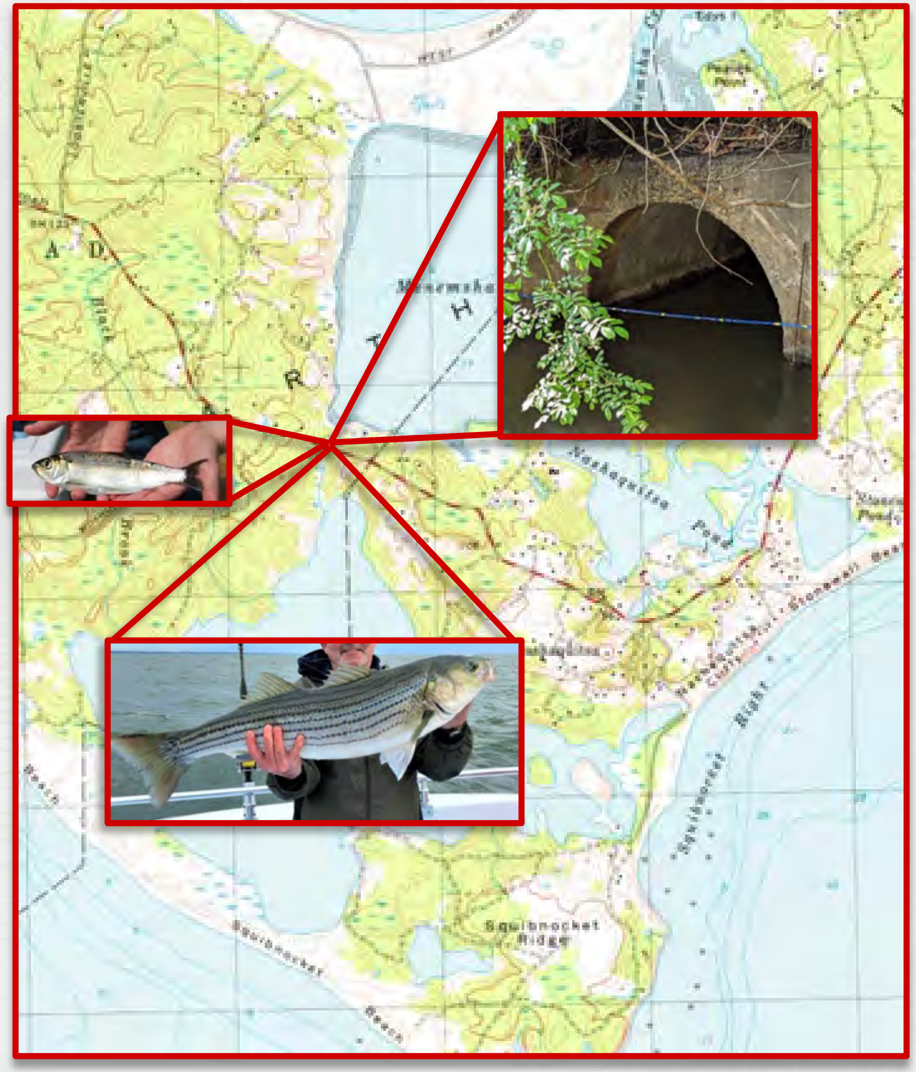
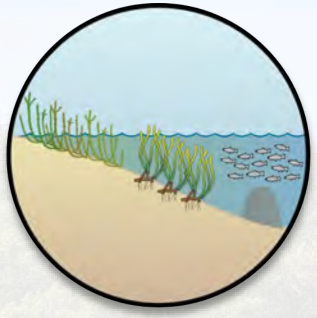


Figure 8. Map of Squibnocket and Menemsha Ponds (MEP 2017)

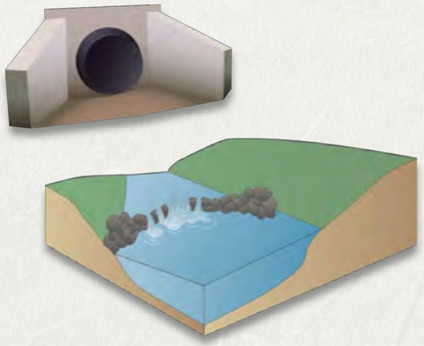
NAVIGATING HURDLES USING ECOLOGICAL MODELS

Challenges in Herring Management



- ❖ Unknown habitat utilization in estuaries by different life stages

- ❖ Increased predation from species like striped bass population



- ❖ Migration obstructions like culverts, dams, and sedimentation

Ecological Modeling Approaches

<u>Habitat Suitability Models</u> use species preferences and environmental data to identify potential habitats efficiently.

<u>Agent Based Models</u> simulate individual interactions, and demonstrate spatial capabilities, replicating long migration routes, migration barriers, and narrow channels.

HABITAT MODELING APPROACH

Habitat Suitability Model: Spawning Alewife Habitat

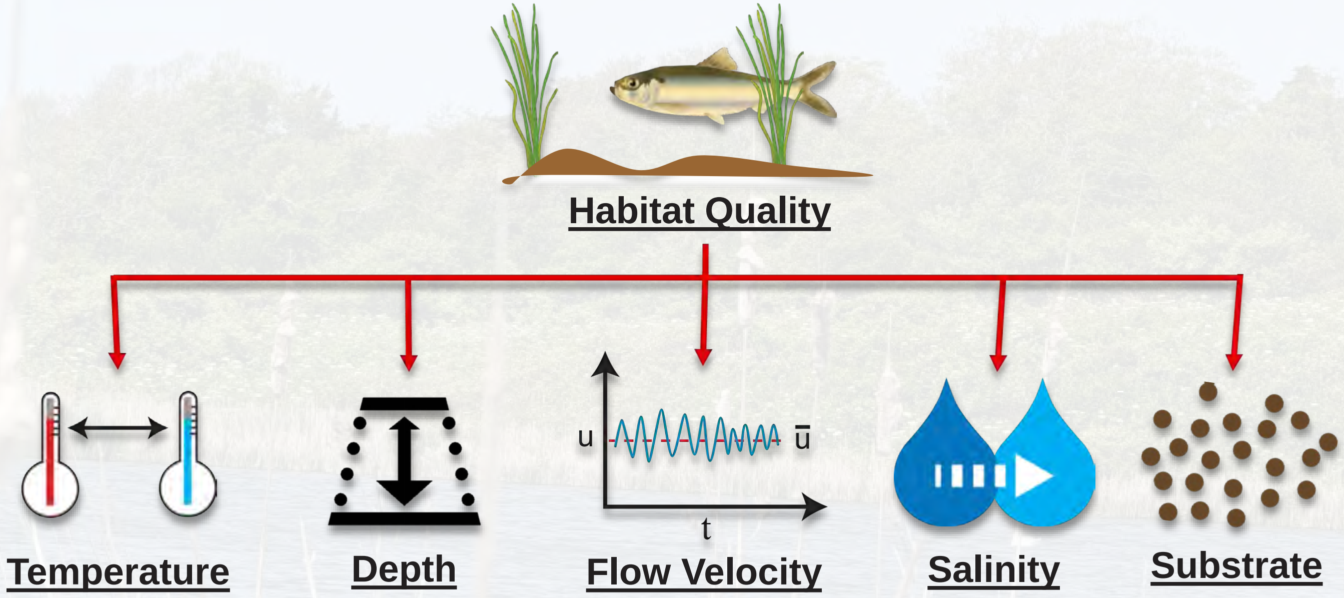
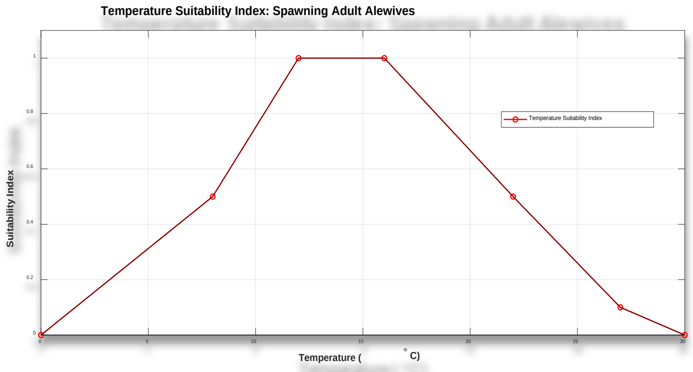


Figure 9. Conceptual Model for Habitat Suitability of River Herring

Habitat Suitability Index: quantifies the suitability of a habitat for a specific species on a scale of 0 to 1, where 0 represents poor-quality habitat and 1 represents optimal conditions.



Types of Questions Addressed:

- ❖ How suitable is the habitat for herring populations?
- ❖ What areas should be targeted for conservation to enhance herring populations?
- ❖ How might herring populations respond to habitat modifications or restoration efforts?
- ❖ How will climate change affect the suitability of herring habitats?

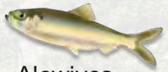
AGENT-BASED MODELING APPROACH

What is Agent-Based Modeling?

Modeling technique to simulate complex systems by representing individual agents and their interactions within a specified environment.

What are Agents?


Striped Bass


Alewives

- ❖ **Agents** are individual entities with the ability to make decisions based on predefined rules or behaviors.
- ❖ Interact with other agents and the environment through “**Patch Attributes**”.

Patches and Patch Attributes?


Patch Example

- ❖ A "**patch**" refers to a specific location within the modeled environment, which can represent distinct spatial units.
- ❖ “**Patch Attributes**” are specific characteristics or features associated with individual spatial units, representing environmental conditions or resources within a modeled area.

Figure 10. Conceptual Diagram for Coupled Modeling Framework

Types of Questions Addressed:

- ❖ What factors influence the reproductive success of river herring?
- ❖ What factors influence the selection of habitats by river herring for feeding and spawning?
- ❖ How might changes in habitat availability influence river herring survival?
- ❖ How do barriers, such as dams or culverts, impact river herring movement?

AGENT-BASED MODELING APPROACH

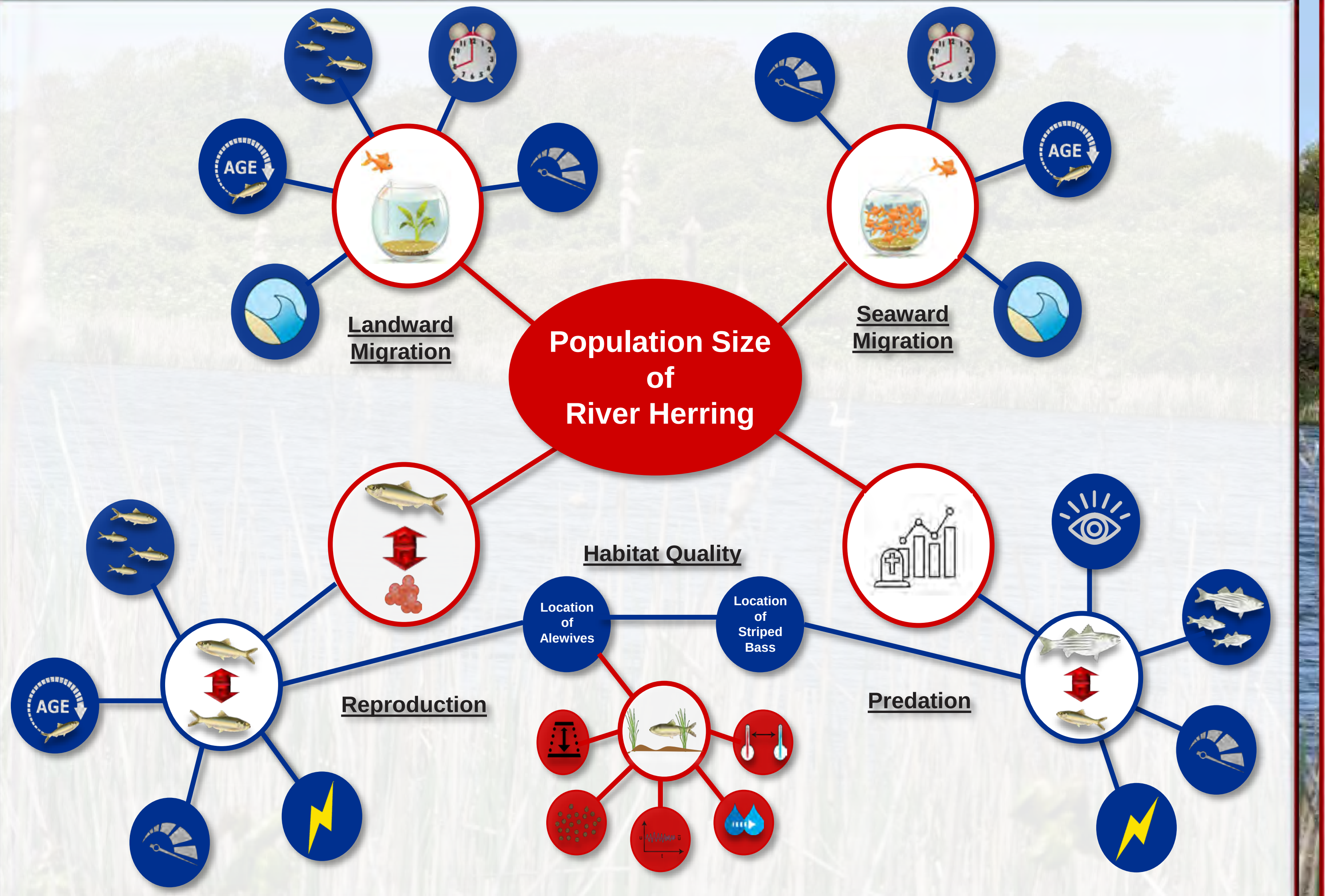


Figure 10. Conceptual Diagram for Coupled Modeling Framework

Project Objectives Addressed:

- How suitable is the habitat for spawning alewives?
- What areas experience the most predation by striped bass?
- Where is spawning occurring within the environment?
- Is predation limiting alewife spawning?

APPLICATION OF COUPLED MODEL

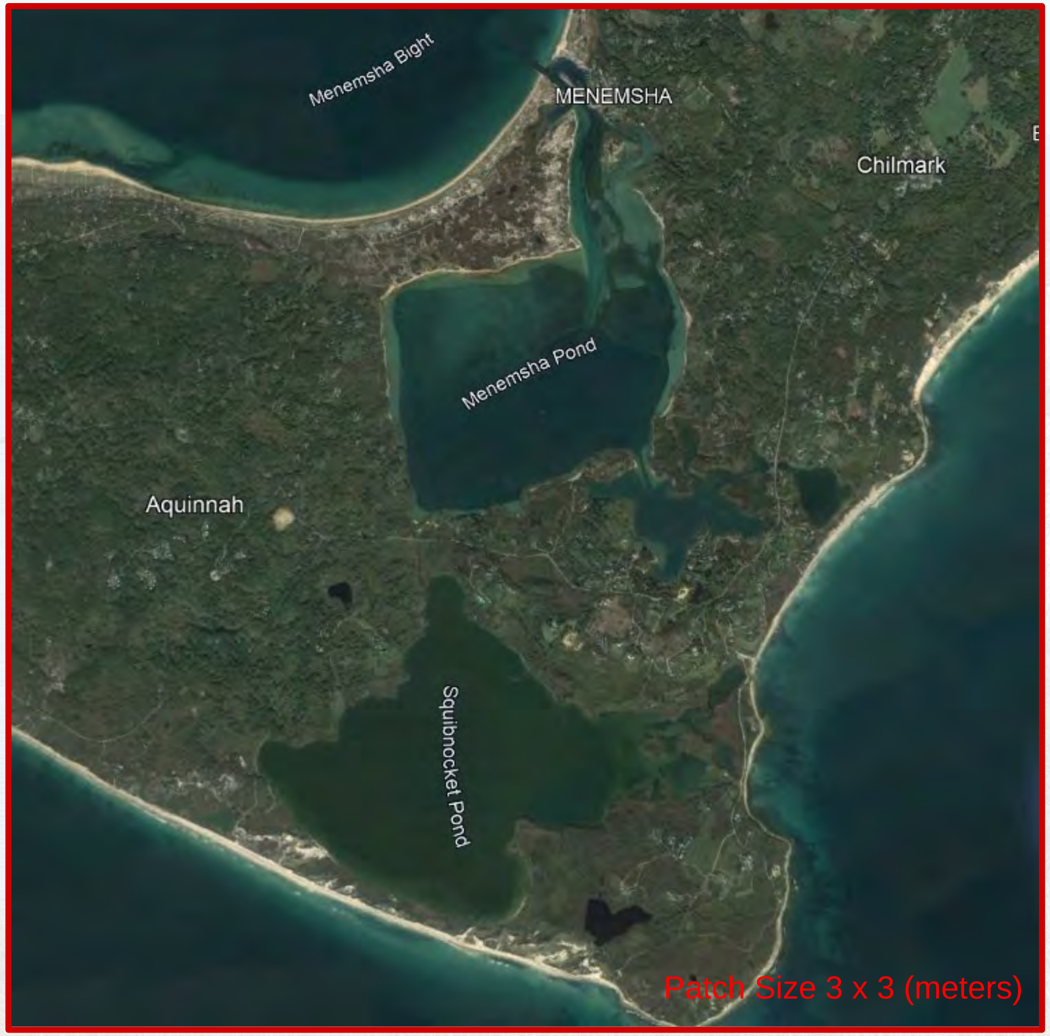
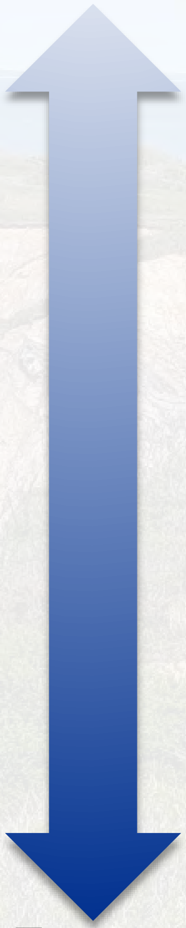
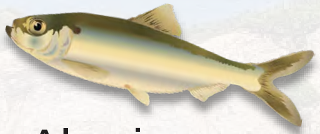


Figure 11. Map of Menemsha and Squibnocket Ponds



Design Concepts

Agents:



Behaviors:

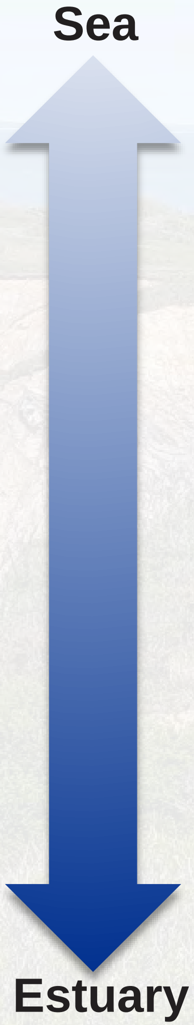
- Migration
- Spawning
- Predation
- Schooling

Patch Attributes:

- Habitat Quality
- # of Spawning Events
- # of Prey Consumed

APPLICATION OF COUPLED MODEL

Figure 12. Landward Migration Movement of Herring (Model Demo)



Landward Migration

Agents:

Behaviors:

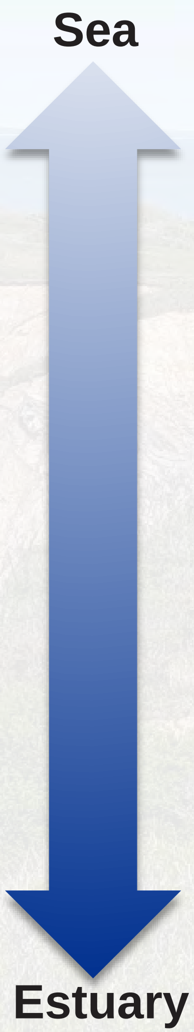
- ❖ Migration
- ❖ Spawning
- ❖ Predation
- ❖ Schooling

Patch Attributes:

- ❖ Habitat Quality
- ❖ # of Spawning Events
- ❖ # of Prey Consumed

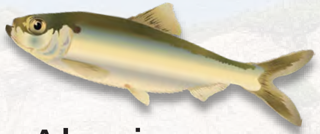
APPLICATION OF COUPLED MODEL

Figure 13. Seaward Migration Movement of Herring (Model Demo)



Seaward Migration

Agents:



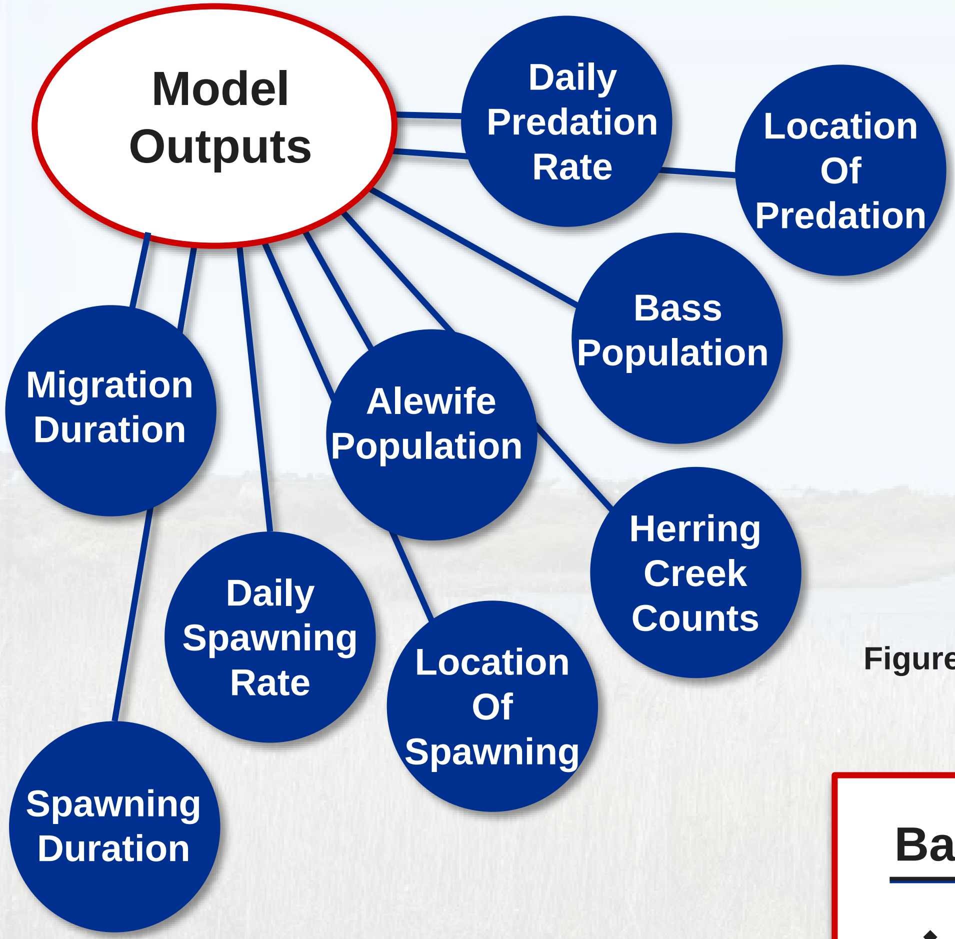
Behaviors:

- ❖ Migration
- ❖ Spawning
- ❖ Predation
- ❖ Schooling

Patch Attributes:

- ❖ Habitat Quality
- ❖ # of Spawning Events
- ❖ # of Prey Consumed

MODEL UTILITY



Model Outputs

Daily Predation Rate

Location Of Predation

Bass Population

Alewife Population

Herring Creek Counts

Migration Duration

Daily Spawning Rate

Location Of Spawning

Spawning Duration

Alewife Population Count During Simulated Migration

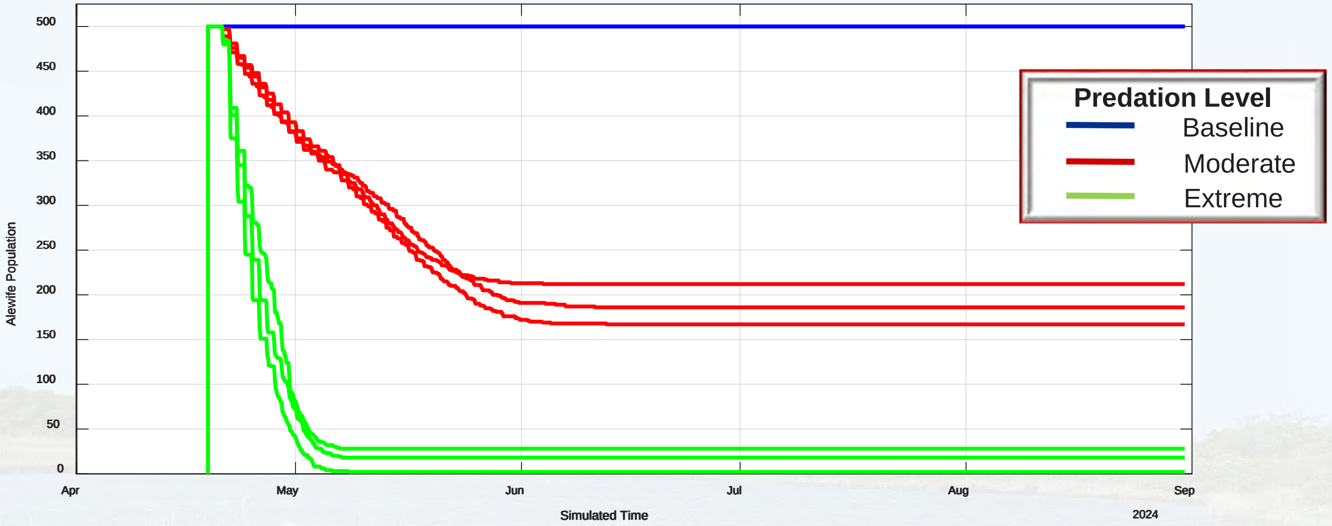


Figure 14. Population count of alewives throughout simulated migration for each experimental scenario

Experimental Design

Baseline Scenario	Moderate Scenario	Extreme Scenario
❖ 500 Alewives	❖ 500 Alewives	❖ 500 Alewives
❖ 0 Striped Bass	❖ 5 Striped Bass	❖ 25 Striped Bass

KEY FINDINGS AND INSIGHTS

Spawning Activity During Migration

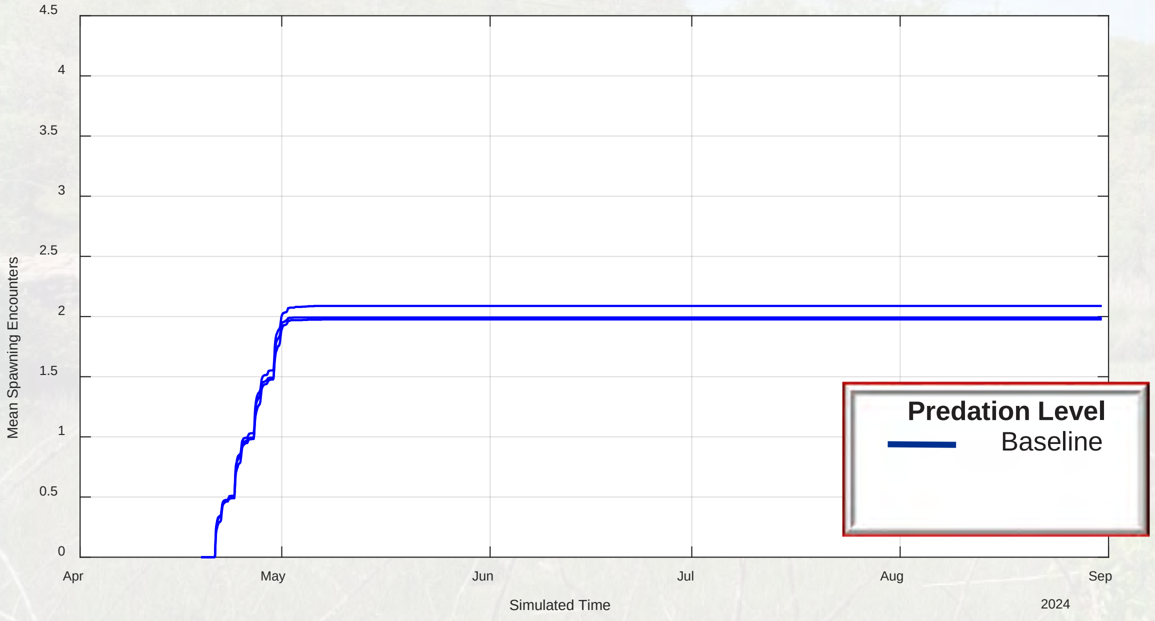


Figure 15. Spawning activity of alewives throughout simulated migration

Baseline Observations

- ❖ Shortest Duration of Spawning Activity ~ 10 days
- ❖ Maximum Mean Spawning Encounters ~ 2 encounters per alewife
- ❖ Alewives Never Reach Spawning Limit (4 encounters per alewife)

Predation Activity During Migration

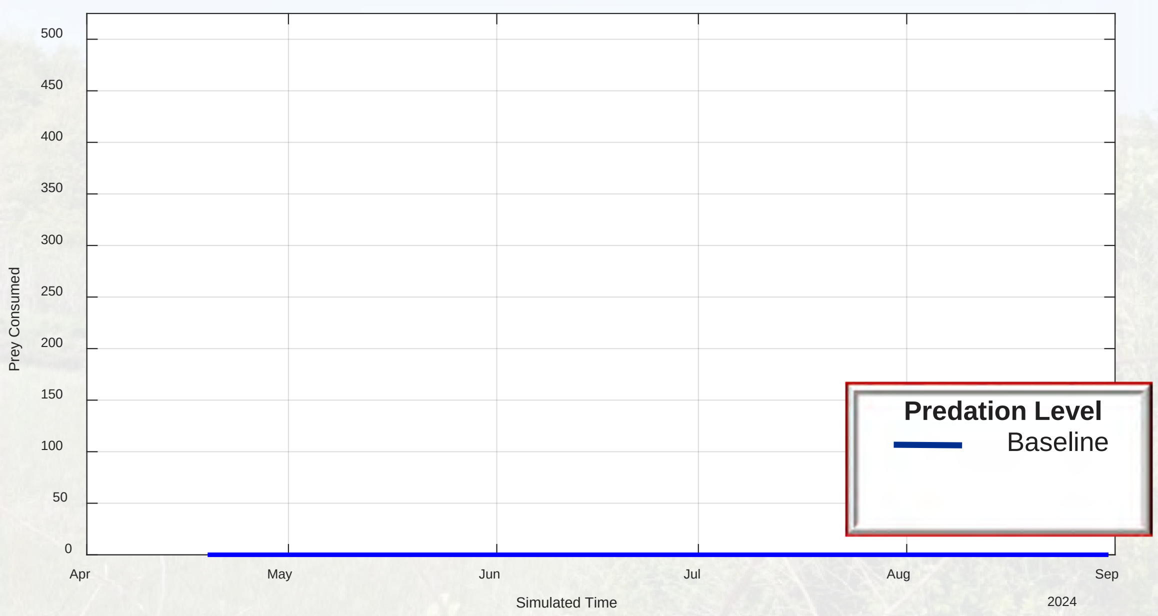


Figure 16. Predation activity by striped bass throughout simulated migration

Baseline Observations

- ❖ No Predation in Baseline Scenarios
- ❖ Migration Survival ~ 100%

KEY FINDINGS AND INSIGHTS

Spawning Activity During Migration

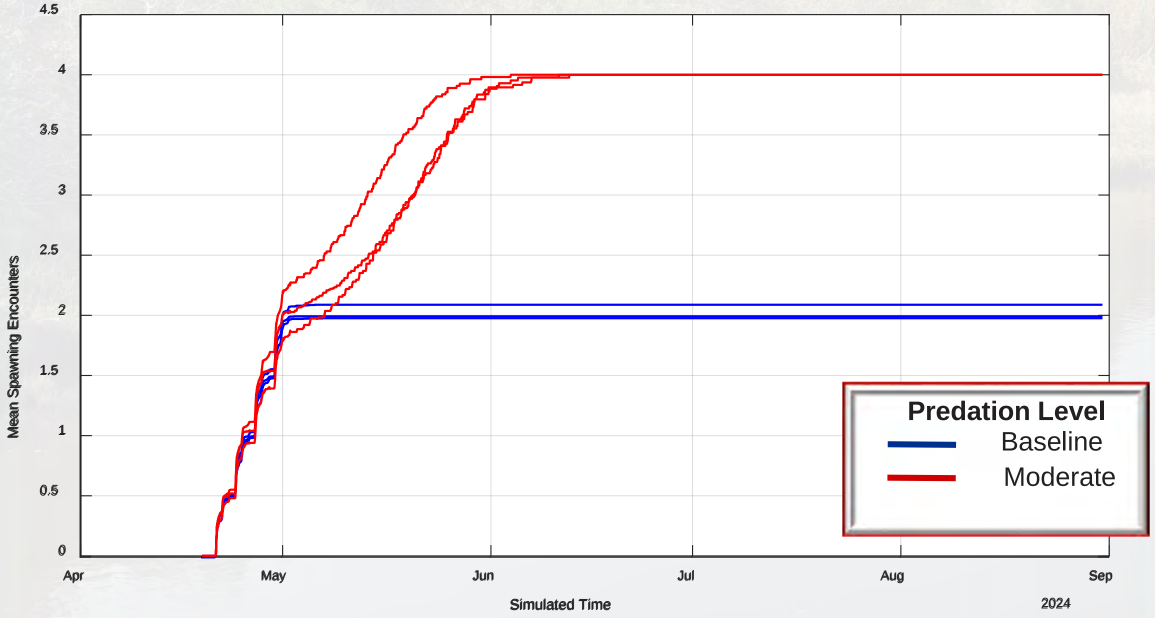


Figure 15. Spawning activity of alewives throughout simulated migration

Moderate Observations

- ❖ Longest Duration of Spawning Activity ~ 39 days
- ❖ Maximum Mean Spawning Encounters ~ 4 encounters per alewife
- ❖ Alewives Reach Spawning Limit (4 encounters per alewife)

Predation Activity During Migration

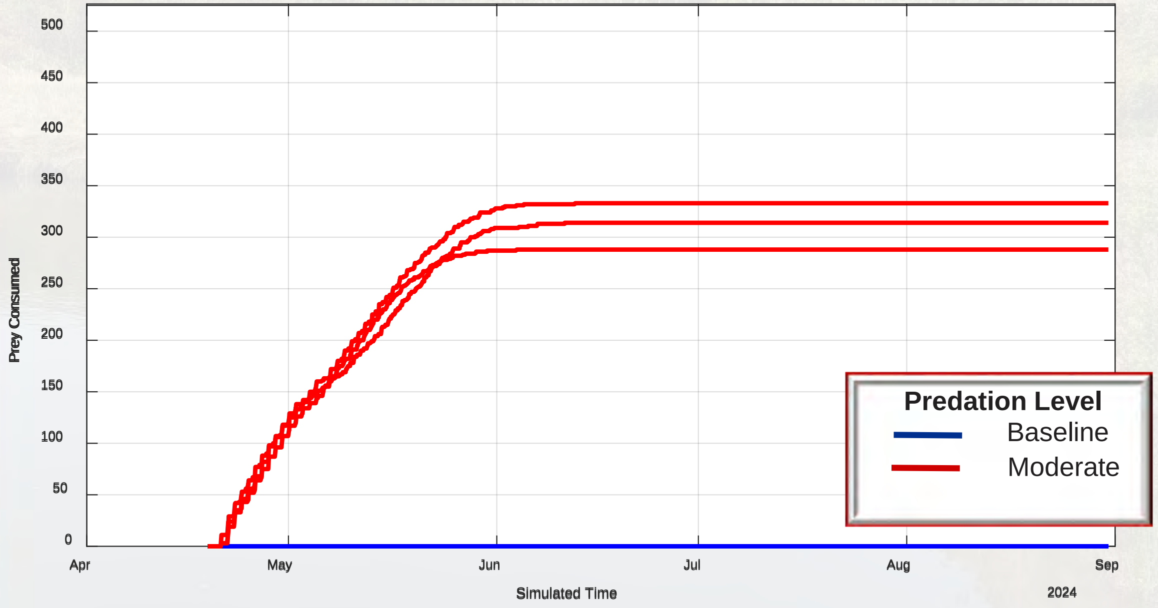


Figure 16. Predation activity by striped bass throughout simulated migration

Moderate Observations

- ❖ Predation Activity lasts ~ 39 days
- ❖ Over half of the alewife population is consumed
- ❖ Migration Survival ~ 37.2%

KEY FINDINGS AND INSIGHTS

Spawning Activity During Migration

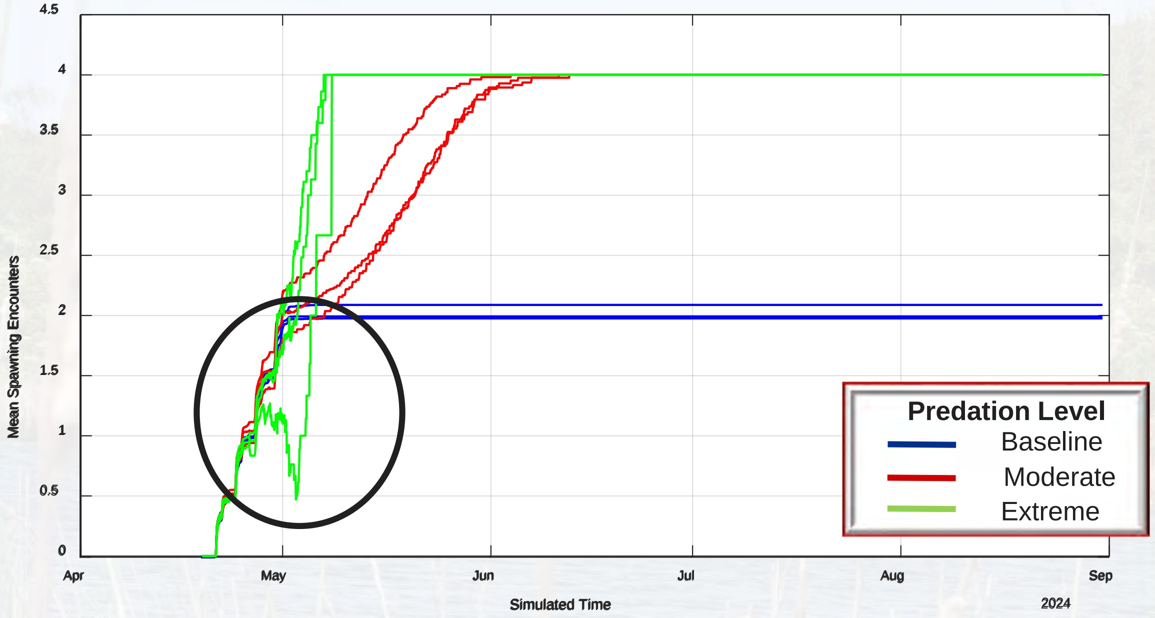


Figure 15. Spawning activity of alewives throughout simulated migration

Extreme Observations

- ❖ Short Duration Spawning Activity lasts ~ 15 days
- ❖ Maximum Mean Spawning Encounters ~ 4 encounters per alewife
- ❖ Alewives Reach Spawning Limit (4 encounters per alewife)

Predation Activity During Migration

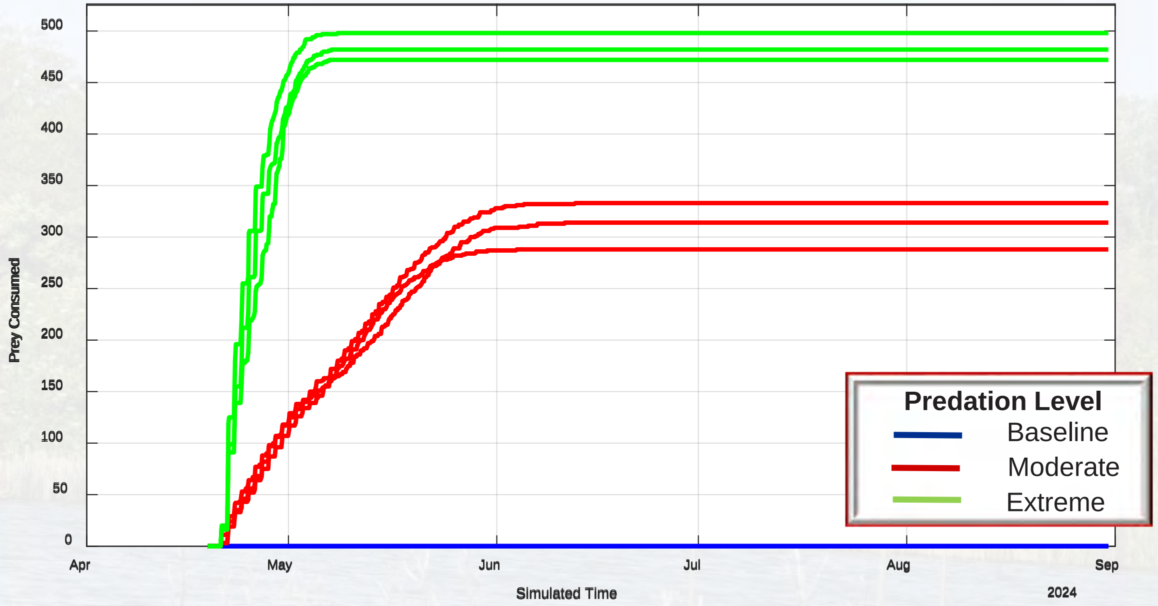


Figure 16. Predation activity by striped bass throughout simulated migration

Extreme Observations

- ❖ Predation Activity lasts ~ 15 days
- ❖ Almost all of the alewife population is consumed
- ❖ Migration Survival ~ 2.8%

MANAGEMENT IMPLICATIONS

ERDC

Predation acts as a migration barrier, prolonging upstream migration time and increasing the duration of spawning activity.

Moderate predation pressure increases reproductive success within the prey population

Elevated predation at migration pinch-points highlights a need for potential management interventions to decrease high levels of predation

BIOACCUMULATION AND FISH PASSAGE IN THE PENOBSCOT RIVER

Vanessa Quintana, Kimberly Huguenard, Todd Swannack, Kyle McKay

BACKGROUND INFORMATION

Penobscot River, Maine

Figure 17. Map of Penobscot River, Maine

Diadromous Fish Habitat

The Penobscot River in Maine, vital for diadromous fish, providing essential spawning grounds and migration routes crucial for their life cycles. Despite its historical significance as a fisheries resource, toxicity in fish has led to consumption and fishing advisories.

Mercury Contamination?

Historical mercury contamination in the river stems from industrial activities, including lumber mills and chemical manufacturing.

MERCURY CONTAMINATION

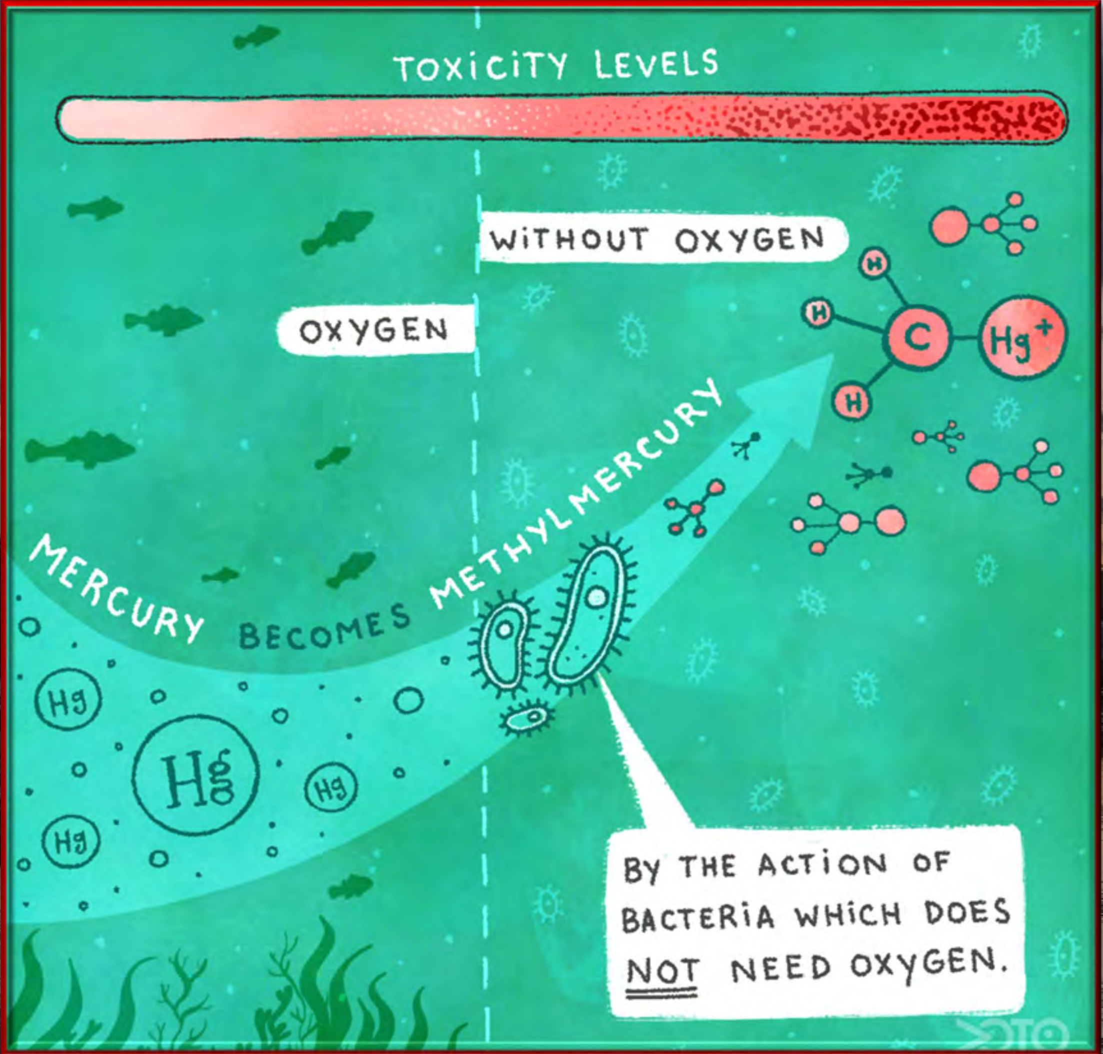
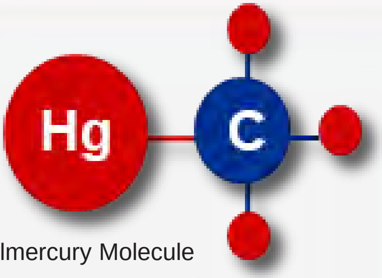


Figure 27. Bacterial Methylation of Mercury (Voice of the Ocean, 2023)



Methylmercury Molecule

Methylmercury Risks

- ❖ Neurological Damage
- ❖ Developmental Effects
- ❖ **Bioaccumulation**
- ❖ Cardiovascular Risks
- ❖ Reproductive effects
- ❖ Endocrine disruption

MERCURY CONTAMINATION

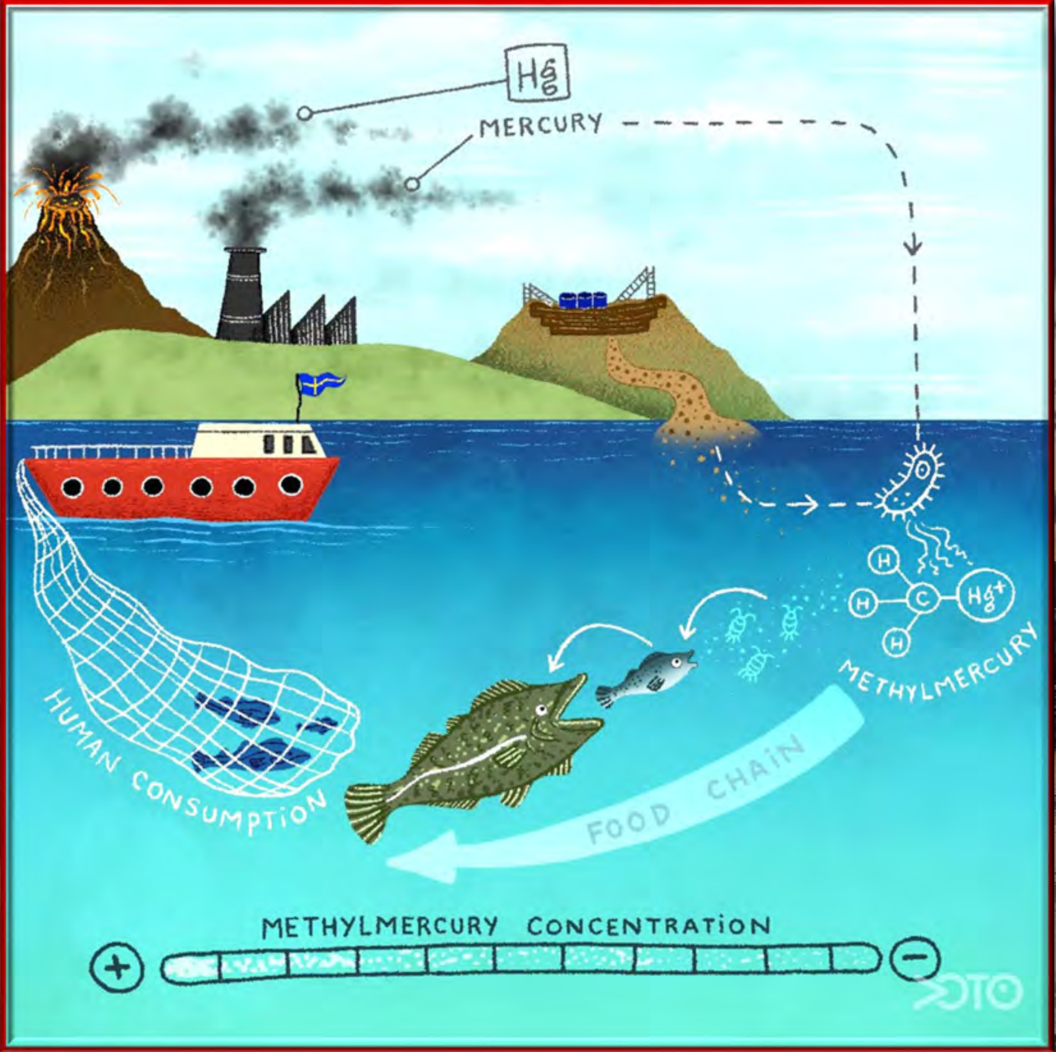
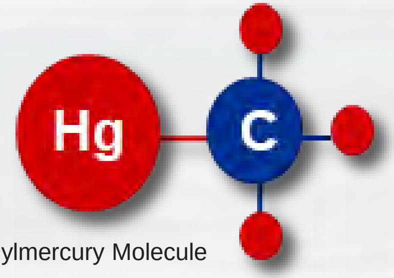


Figure 28. Bioaccumulation of Methylmercury (Voice of the Ocean, 2023)



Methylmercury Molecule

Bioaccumulation Risks

- ❖ Fishing Bans
- ❖ Consumption Limits
- ❖ **Human Health Risk**
- ❖ Threat to Biodiversity
- ❖ Economic Decline
- ❖ Cultural Disruption

MANAGEMENT HURDLES IN LOCAL SYSTEM

Figure 20. Veazie Dam (Press Harold 2015)

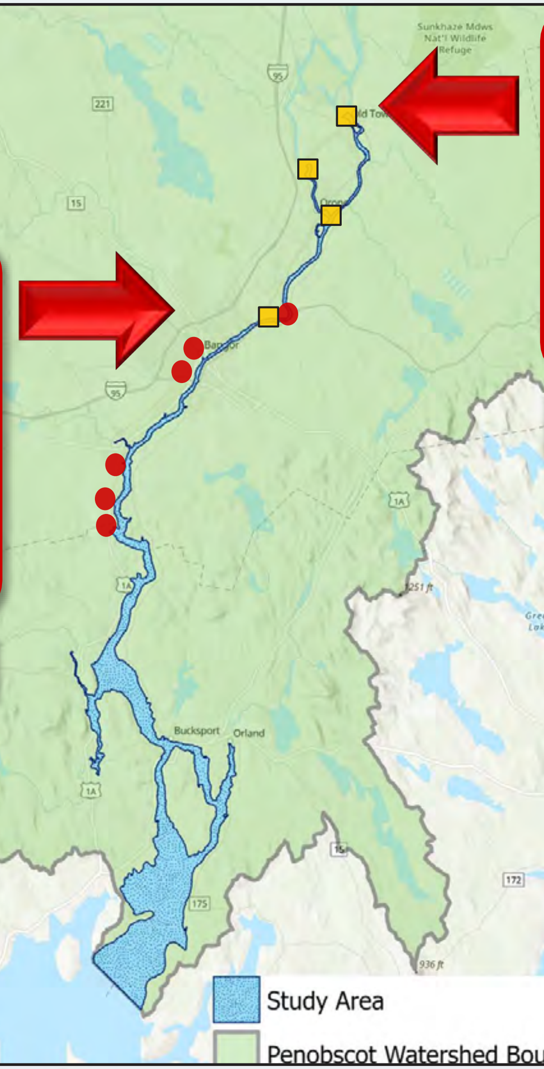


Figure 18. Map of Penobscot River, Maine

Figure 19. Milford Dam

Legend

● Culverts

■ Dams

MANAGEMENT HURDLES IN LOCAL SYSTEM

Figure 21. Underpass

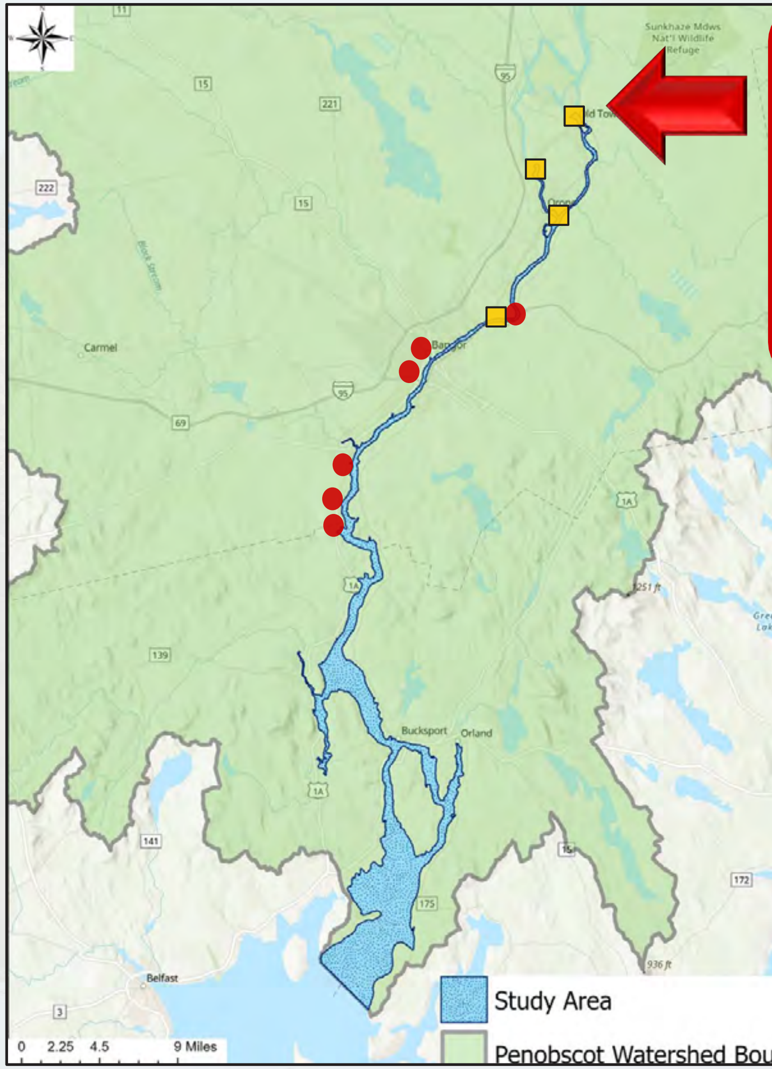


Figure 18. Map of Penobscot River, Maine

Figure 19. Milford Dam

Figure 22. Fish Passageway (USFW 2022)

Figure 23. Pipe Culvert (USFW 2022)

Legend

● Culverts

🟨 Dams

MANAGEMENT HURDLES IN LOCAL SYSTEM

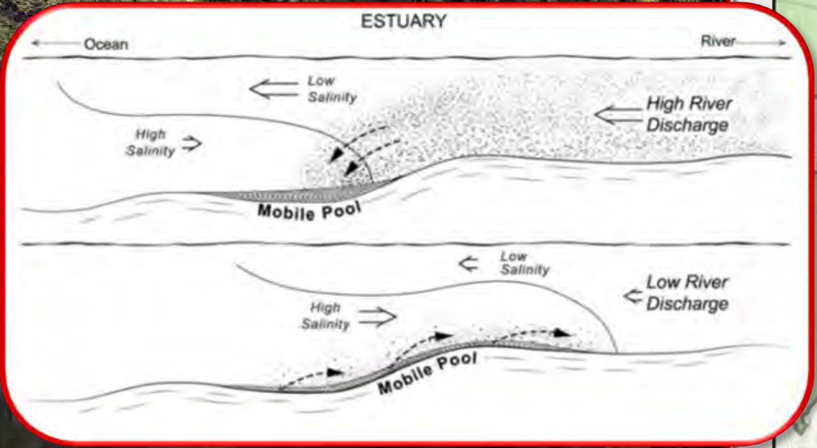


Figure 25. Mercury Transport in the Penobscot River
(Rockwell Geyer & Ralston, 2018)

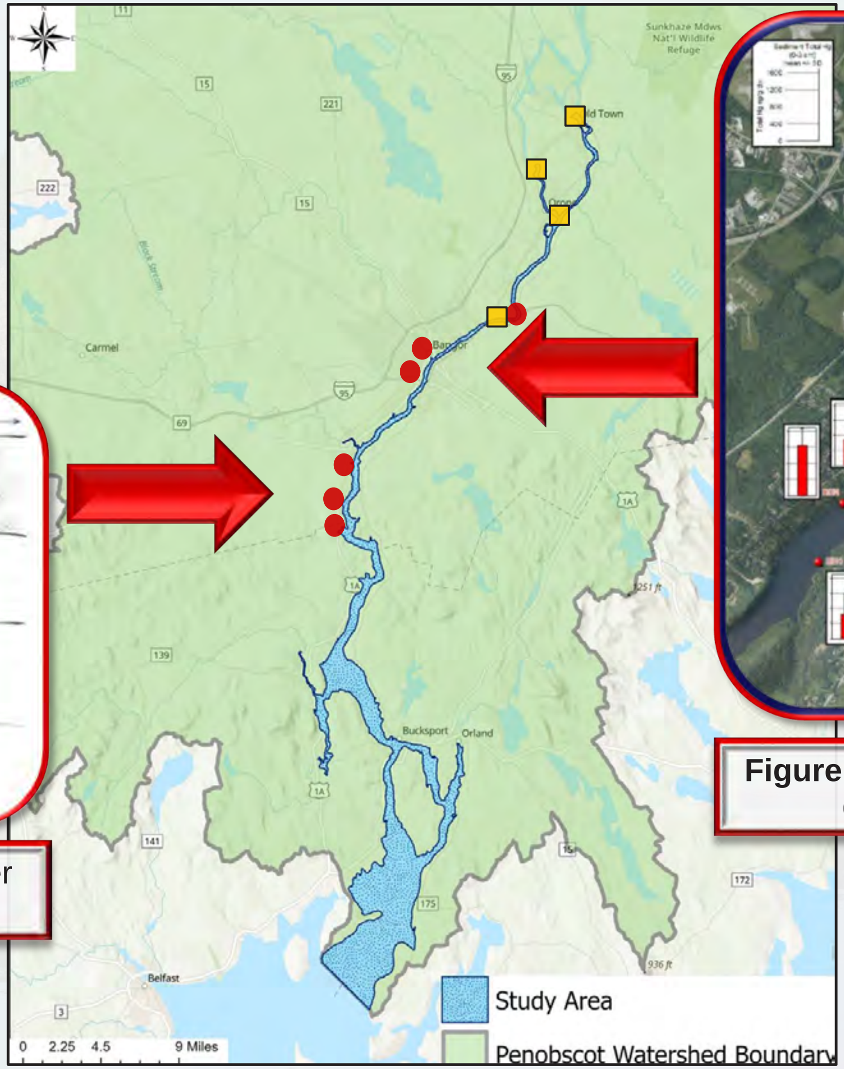


Figure 18. Map of Penobscot River, Maine

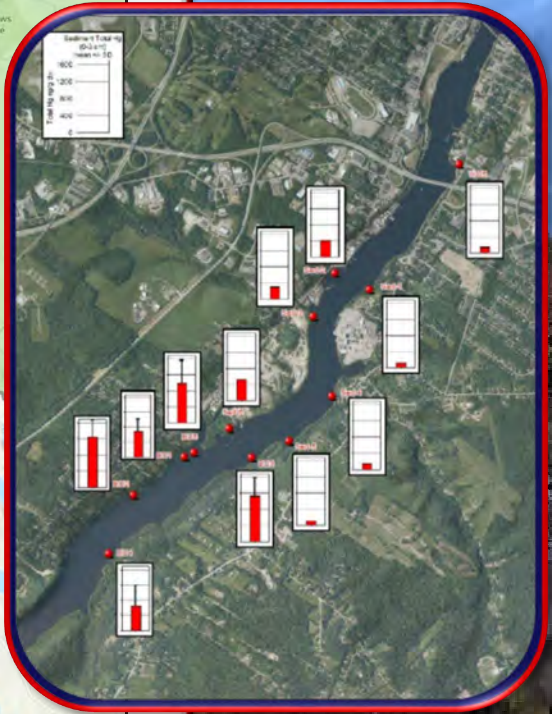


Figure 24. Mercury Contamination
(Bodaly & Kopec, 2013)

Legend

● Culverts

🟨 Dams

MODEL ADAPTATIONS

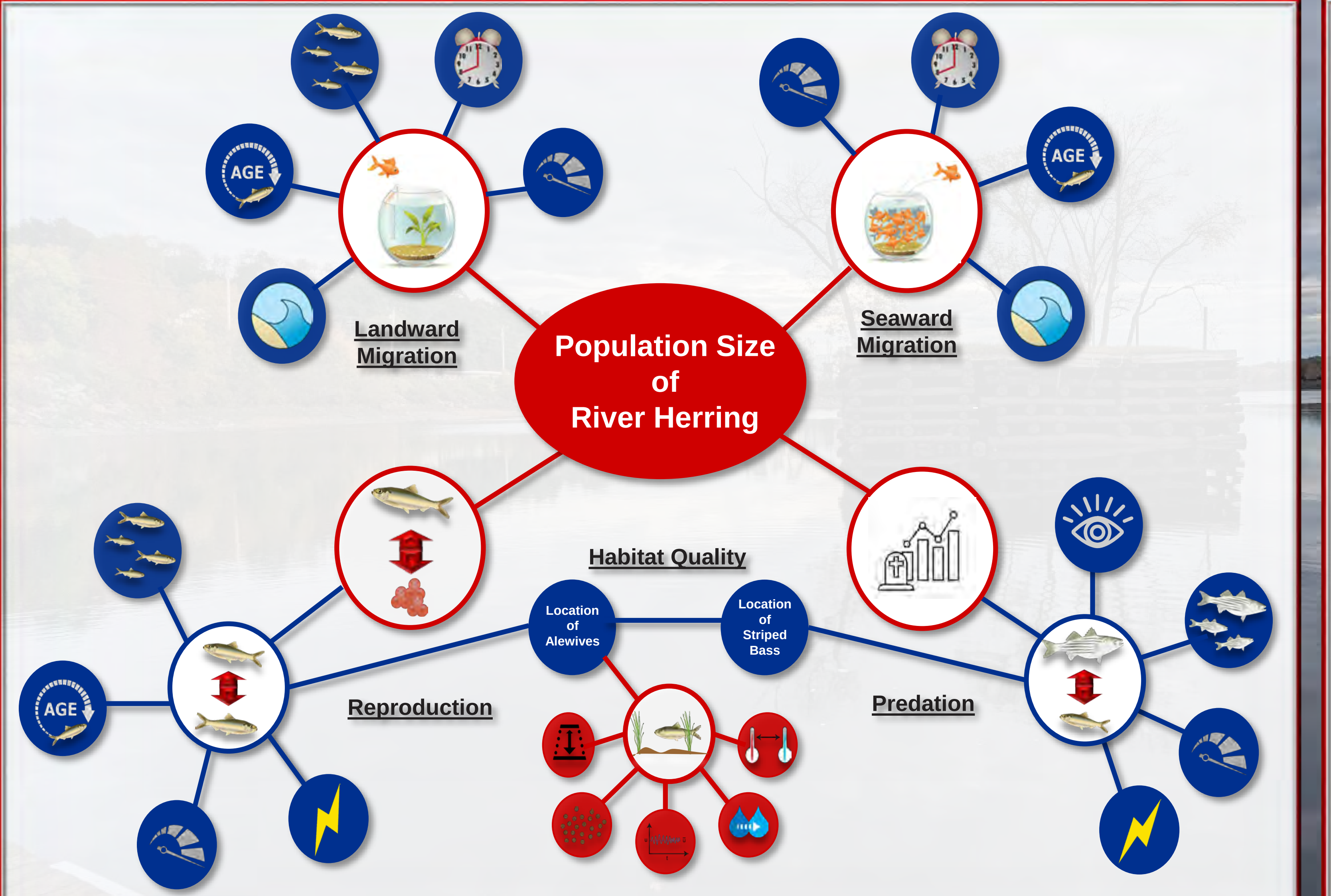


Figure 10. Conceptual Diagram for Coupled Modeling Framework

Project Objectives Addressed:

- How suitable is the habitat for spawning alewives?
- What areas experience the most predation by striped bass?
- Where is spawning occurring within the environment?
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MODEL ADAPTATIONS

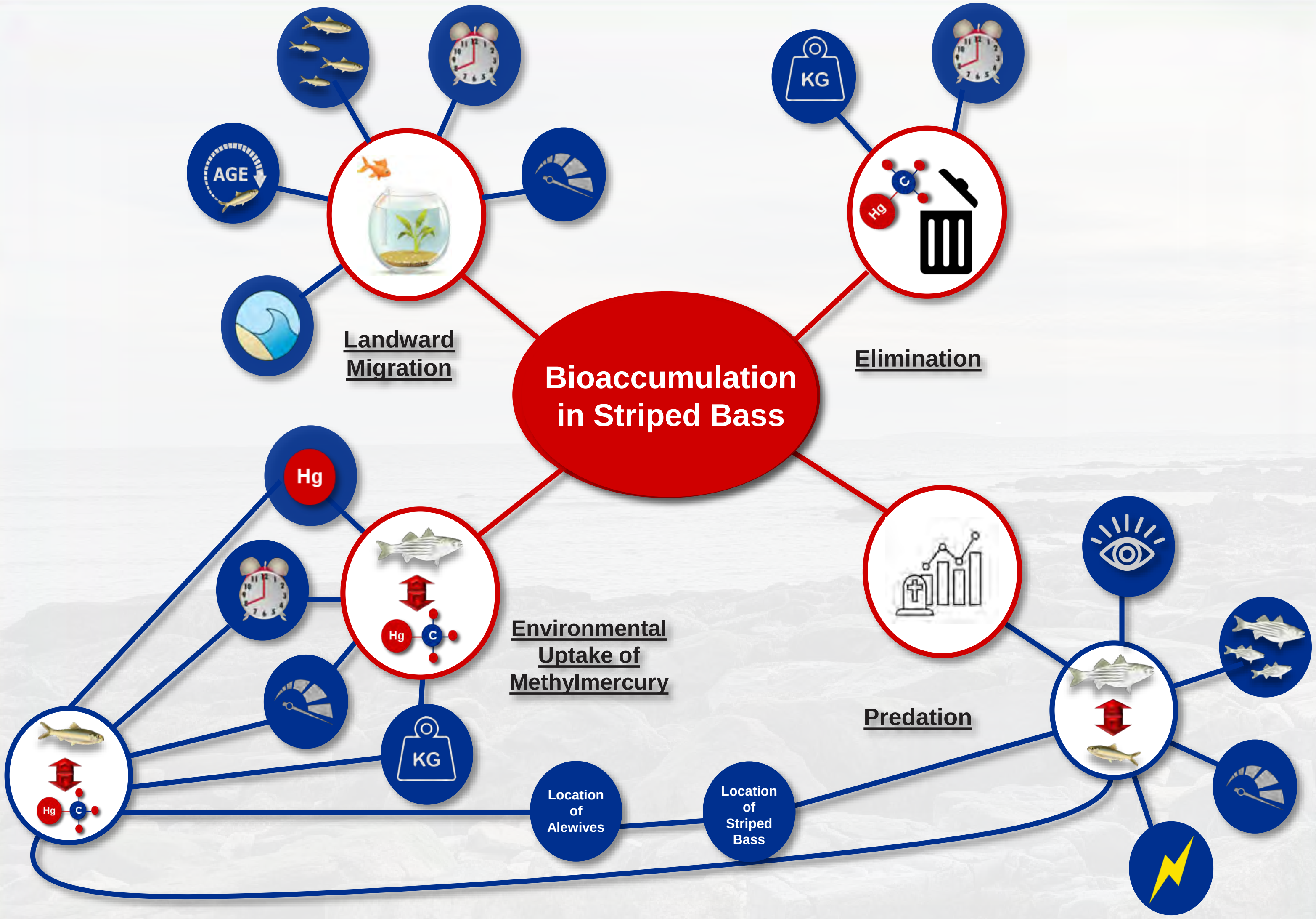
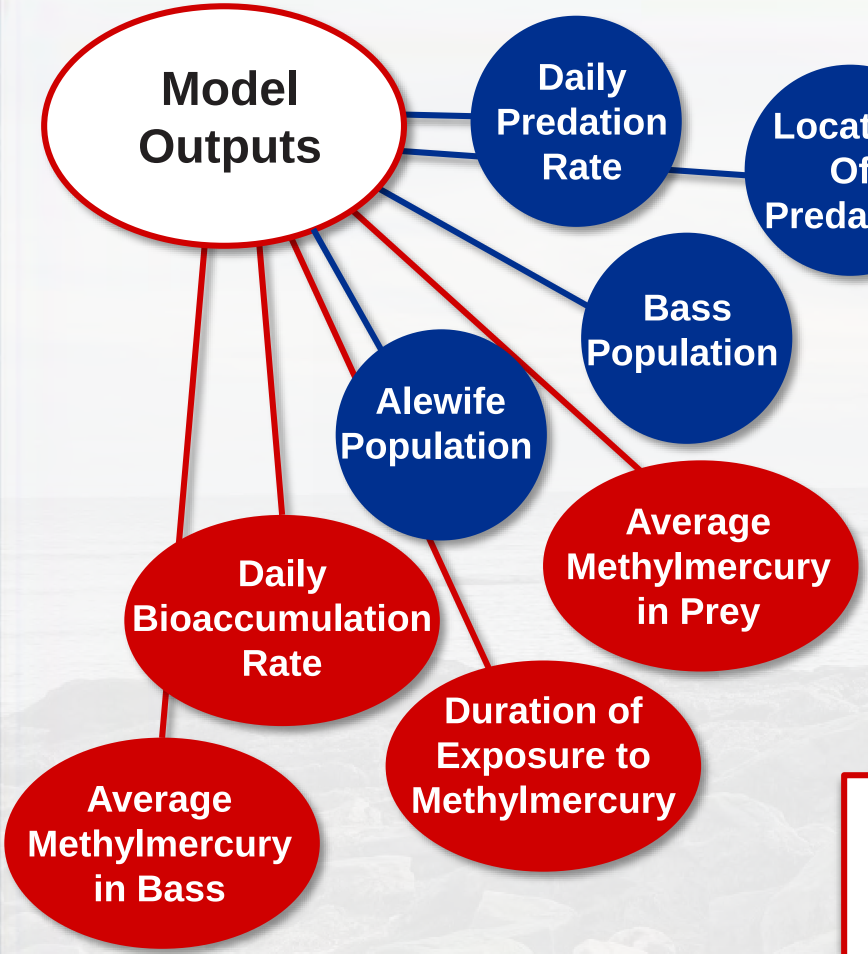


Figure 29. Conceptual Diagram for Modeling Framework

Project Objectives Addressed:

- How does migratory fish passage design impact bioaccumulation in contaminated systems?
- What fish passage types attribute to the highest rates of bioaccumulation?
- How might changes in fish passage influence river herring survival?
- How do barriers from predation, impact the duration of exposure to methylmercury in prey?

MODEL UTILITY



Model Outputs

Daily Predation Rate

Location Of Predation

Bass Population

Alewife Population

Average Methylmercury in Prey

Daily Bioaccumulation Rate

Duration of Exposure to Methylmercury

Average Methylmercury in Bass

Alewife Population Count During Simulated Migration

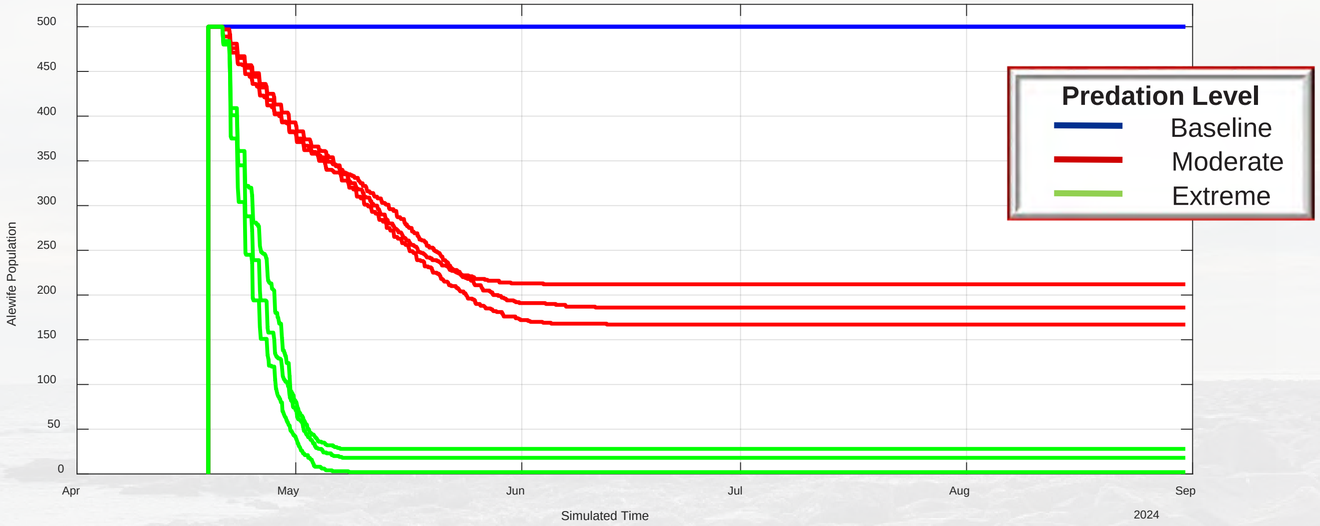


Figure 30. Population count of alewives throughout simulated migration for each experimental scenario

Experimental Design

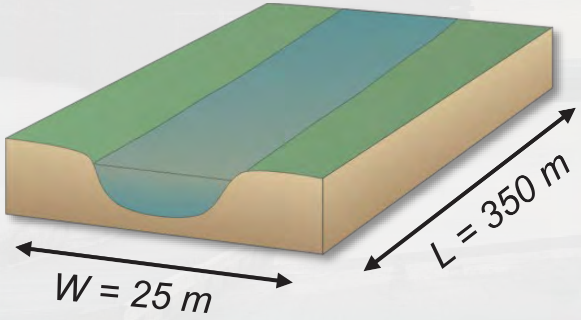
Baseline Scenario	Moderate Scenario	Extreme Scenario
❖ 500 Alewives ❖ 0 Striped Bass	❖ 500 Alewives ❖ 5 Striped Bass	❖ 500 Alewives ❖ 25 Striped Bass

MODELING FISH PASSAGE

Null Design

Figure 31. Uninhibited Fish Passage

Modeled Channel



Ecosystem-Based

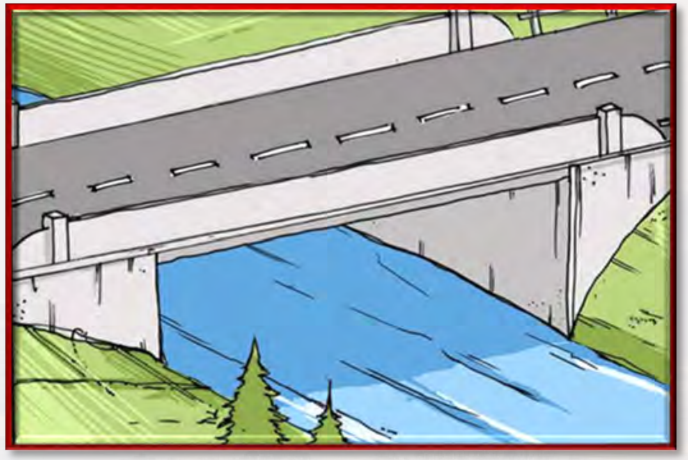
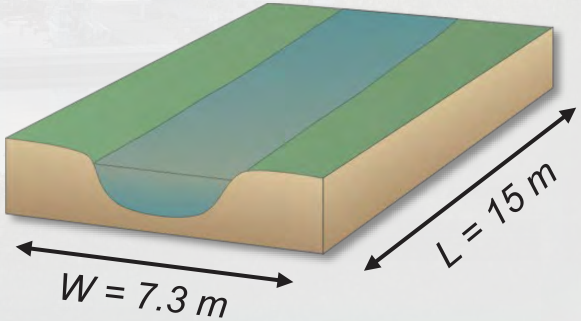


Figure 32. Nature-Based Passage Design (FEMA, 2022)

Modeled Channel



Standard Pipe

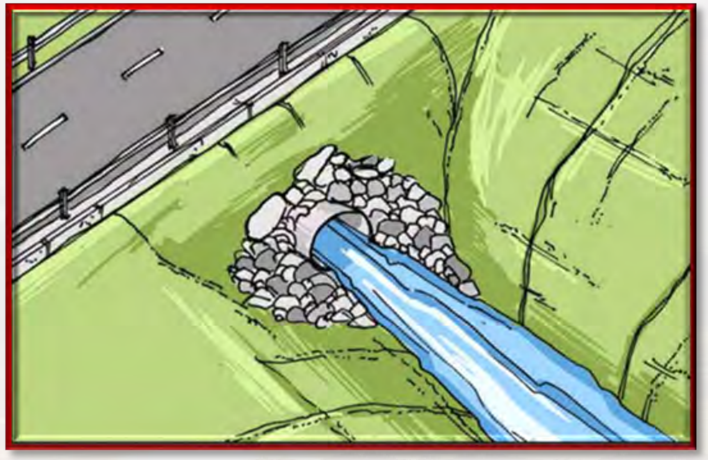
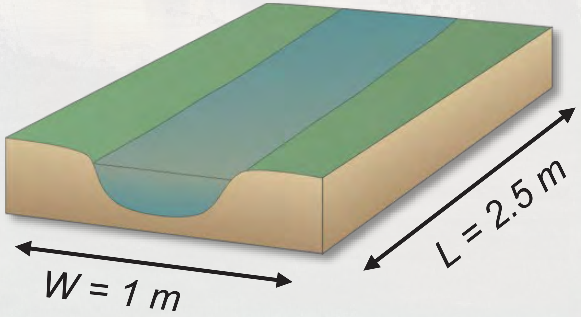


Figure 33. Basic Fish Passage Design (FEMA, 2022)

Modeled Channel



MODEL DEMONSTRATION

Null Design

Figure 34. Uninhibited Fish Passage

Ecosystem-Based

Figure 35. Nature-Based Fish Passage Design

Standard Pipe

Figure 36. Basic Fish Passage Design

BIOACCUMULATION RATE IN PREDATORS

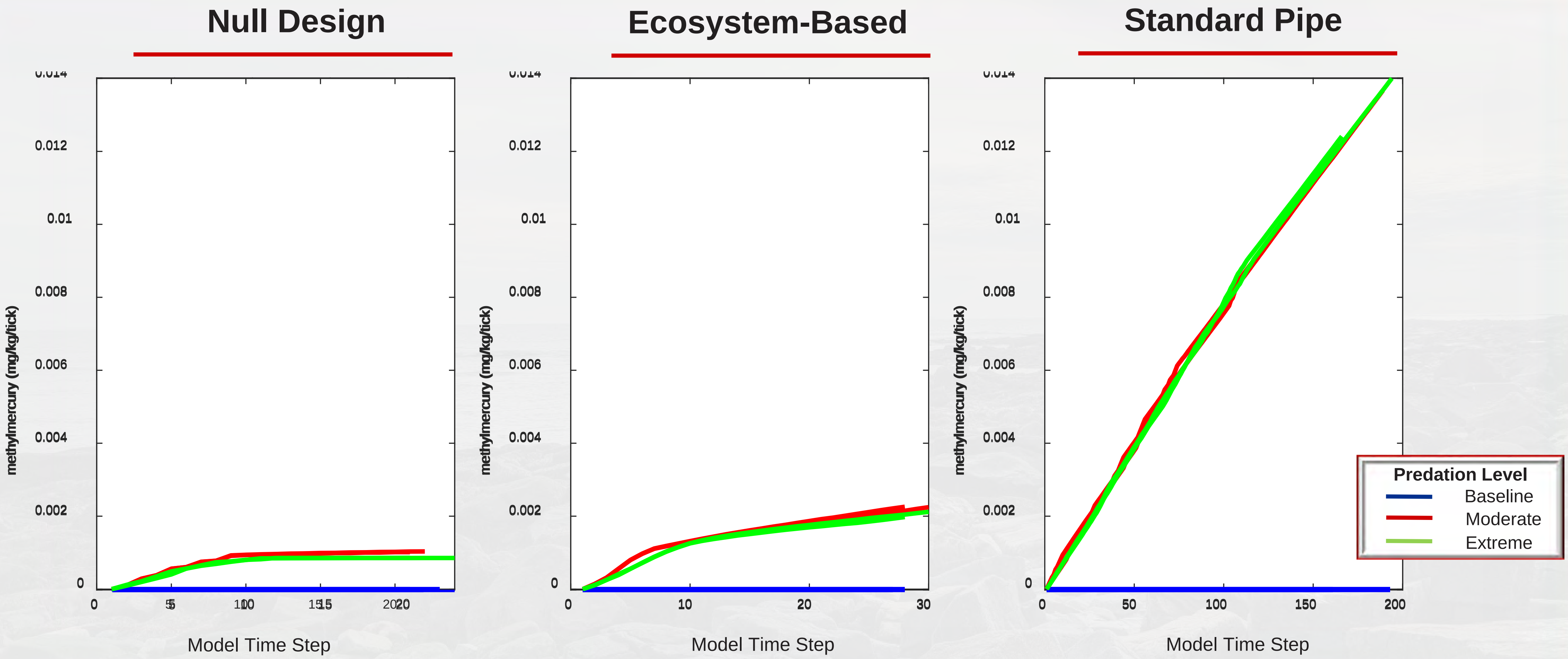


Figure 38. Bioaccumulation Rate in Predators throughout Baseline, Moderate, and Extreme Predation Scenarios

EXPOSURE TO MERCURY IN PREY

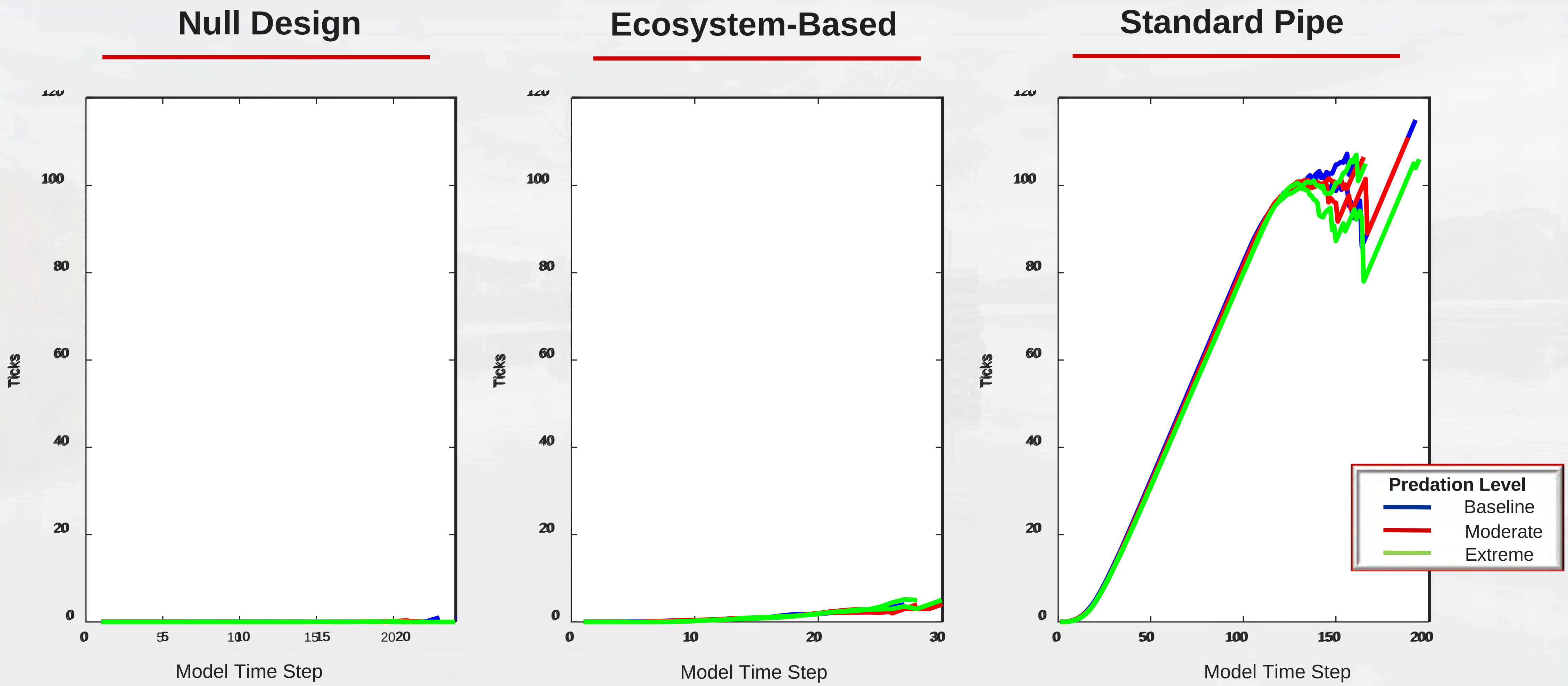
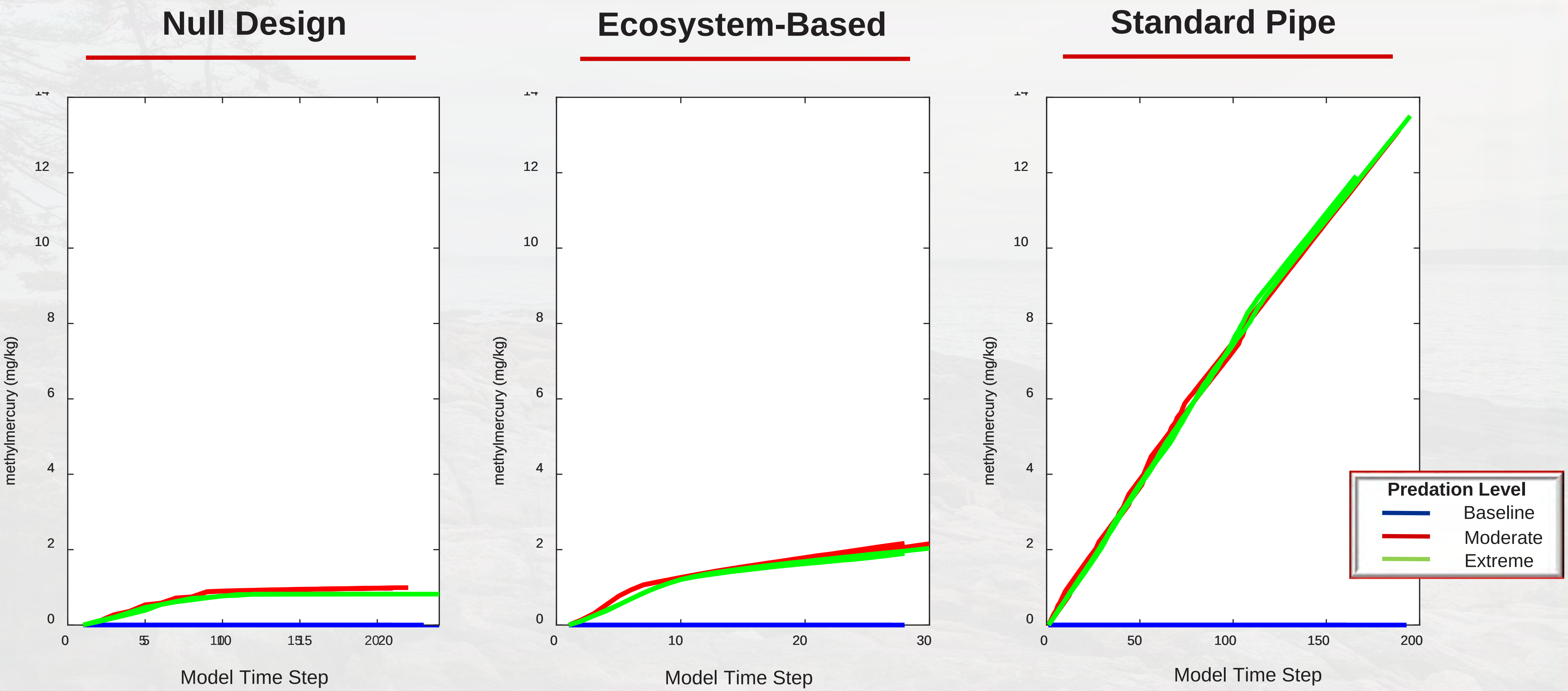


Figure 39. Duration of Exposure to Mercury in Prey throughout Baseline, Moderate, and Extreme Predation Scenarios

METHYLMERCURY IN PREDATORS



Null Design

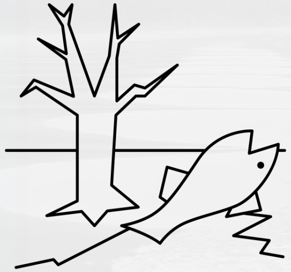
Ecosystem-Based

Standard Pipe

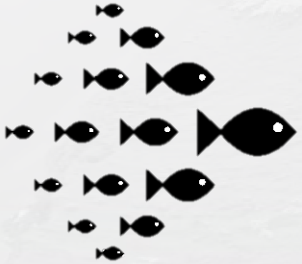
Figure 37. Mean Methylmercury Concentration in Predators throughout Baseline, Moderate, and Extreme Predation Scenarios

POTENTIAL MANAGEMENT IMPLICATIONS

Migration pinch-points increase bioaccumulation rates and methylmercury concentrations in the predator population.



The standard pipe design of fish passage substantially increases the exposure duration to contaminants in prey populations.



Bioaccumulation should be a dynamic considered when designing fish passage in contaminated environments

REFLECTIONS

MODELING STRENGTHS

Specific

Is specific to dynamic environments and can incorporate real environmental conditions and observed behaviors.

Adaptable

Adaptable across diverse environmental settings, allowing for the exploration of varied scenarios and research questions using generalized and interchangeable behaviors.

Scenario Testing

Can facilitate scenario testing to assess the potential impact of different management strategies.

MODELING LIMITATIONS

Complexity

Managing and interpreting the results and interactions from the model are complex, posing challenges for implementation.

Adaptable

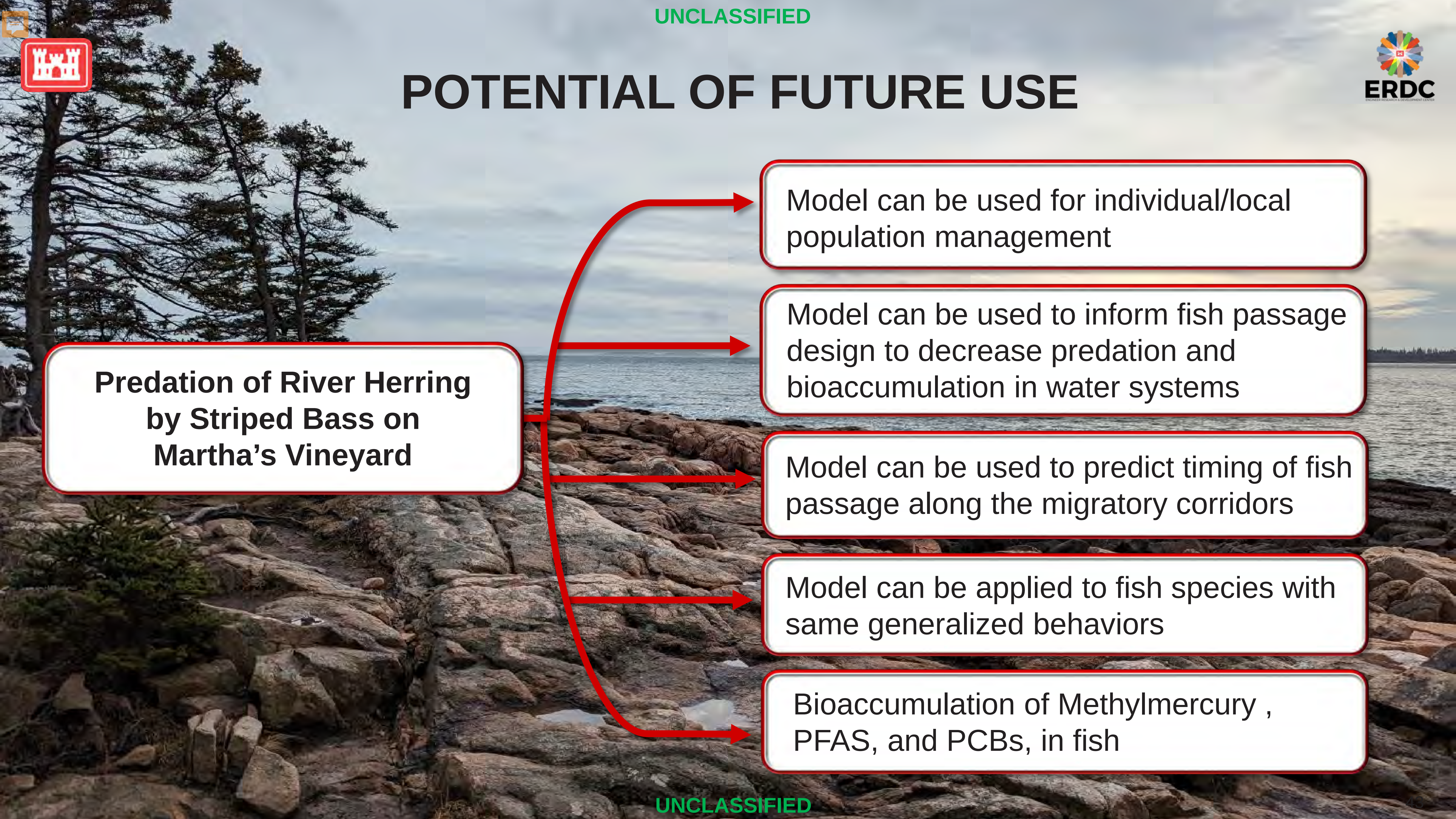
Sensitivity

Inaccurate assumptions during model development can introduce biases or errors into the model's predictions, which impact the reliability of model results.

Communication

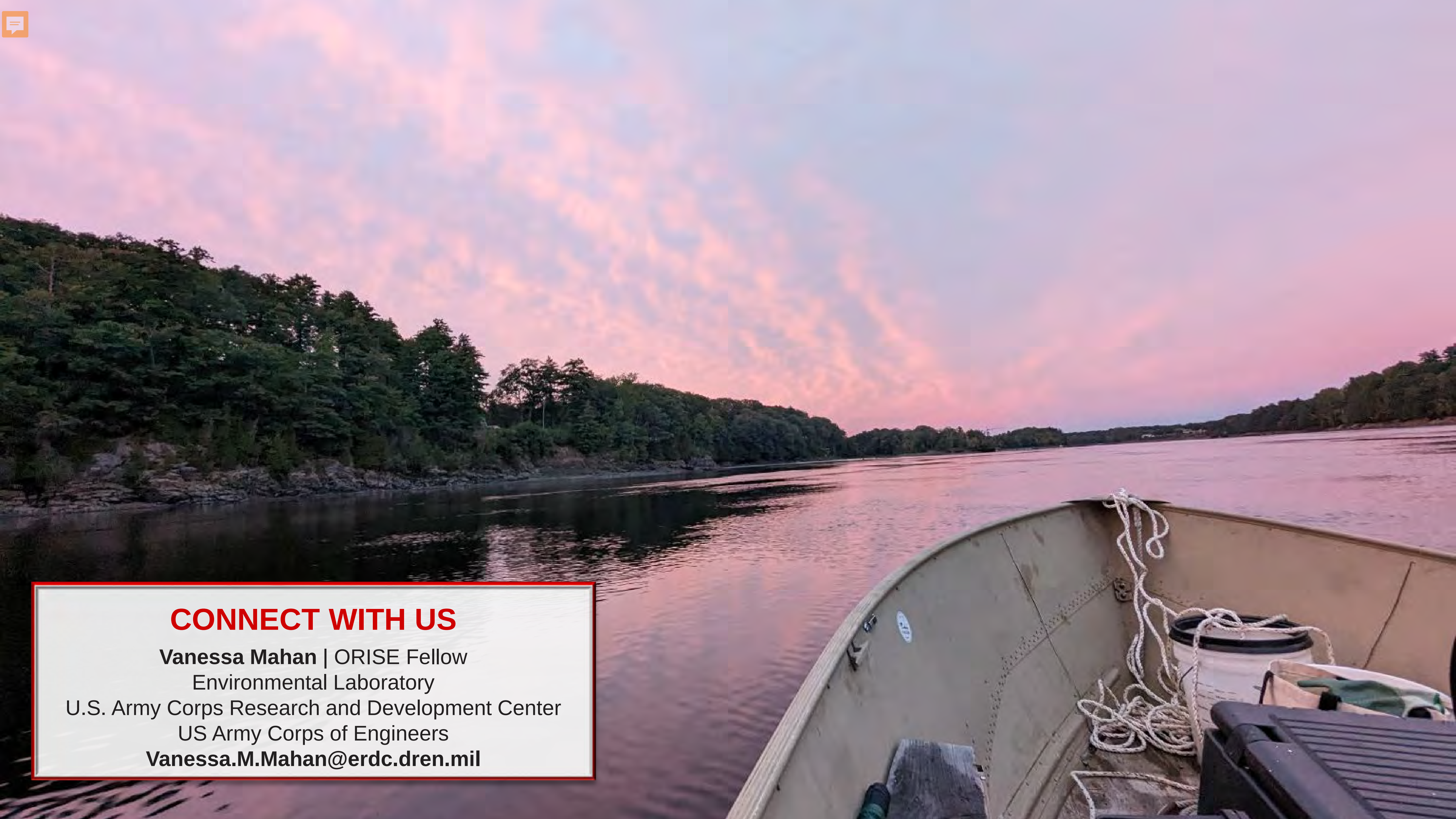
Effective communication is crucial for translating model outcomes into actionable management strategies and informed decision-making.

POTENTIAL OF FUTURE USE



Predation of River Herring by Striped Bass on Martha’s Vineyard

- Model can be used for individual/local population management
- Model can be used to inform fish passage design to decrease predation and bioaccumulation in water systems
- Model can be used to predict timing of fish passage along the migratory corridors
- Model can be applied to fish species with same generalized behaviors
- Bioaccumulation of Methylmercury , PFAS, and PCBs, in fish



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