Developing Ecological Models for Adaptive Management in Aquinnah, Martha's Vineyard

Vanessa Quintana

*This project was performed in collaboration with the Wampanoag Tribe of Gay Head (Aquinnah)**

EMRRP Webinar February 13th, 2025

ERDC US Army Corps of Engineers
Oak Ridge Institute For Science and Education

Overview

1. Introduction and Context
2. Background Information
3. Ecological Modeling
4. Model Demo and Results
5. Summary

Fishing for River Herring in Aquinnah, MA
(Provided by Wampanoag Tribe of Gay Head (Aquinnah) in 2023)

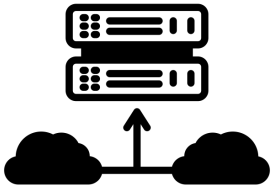
01

Introduction and Context

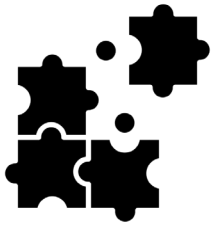
What is Ecological Modeling?

A tool to represent and analyze ecological systems and processes. Uses mathematical, statistical, or computational techniques to simulate real-world ecosystems.

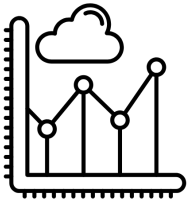
Significance of Ecological Modeling:



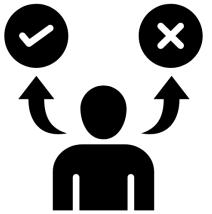
Integrate Data and Knowledge



Understand Complex Systems



Forecast Outcomes



Support Decision-Making

What Types of Questions can Ecological Models Address?

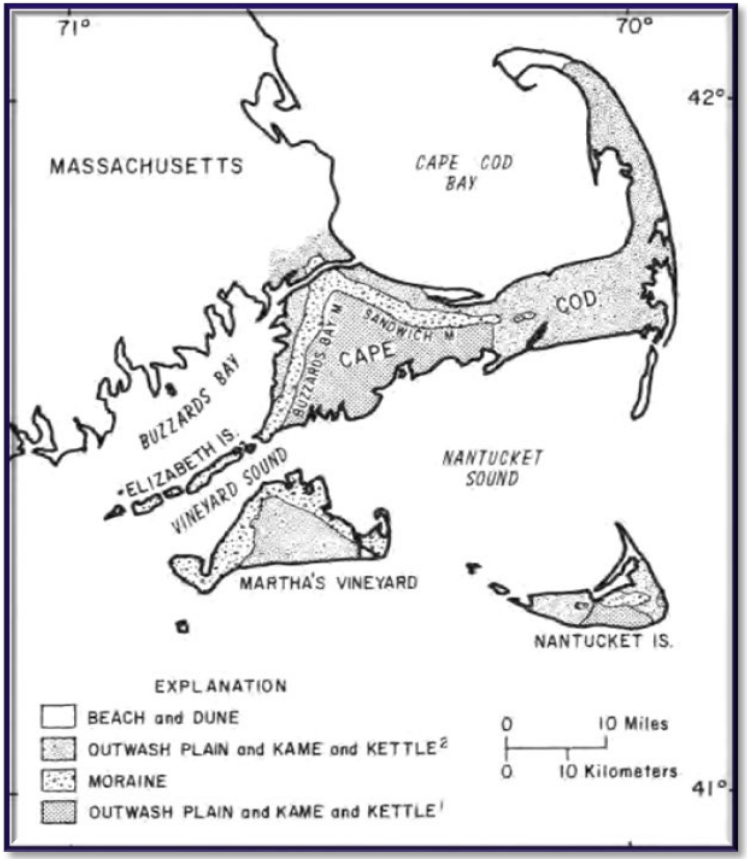
Habitat Models Assess habitat suitability and restoration impacts.	→ How will habitat for a species change under different restoration scenarios?
Agent-Based Models Analyze individual movements and dynamics.	→ What proportion of fish will navigate a culvert successfully under specific conditions?
Population Models Predict abundance, recruitment, and survival.	→ Which management action will increase abundance, recruitment, or survival?
Community Models Understand biodiversity and species richness.	→ How will restoration affect species richness or biodiversity?

(*Updating Ecological Modeling within USACE: Exploring Innovative Approaches and Implementation Strategies*, US Army Corps of Engineers Engineering Research and Development Center, Stowe et al., *draft*)

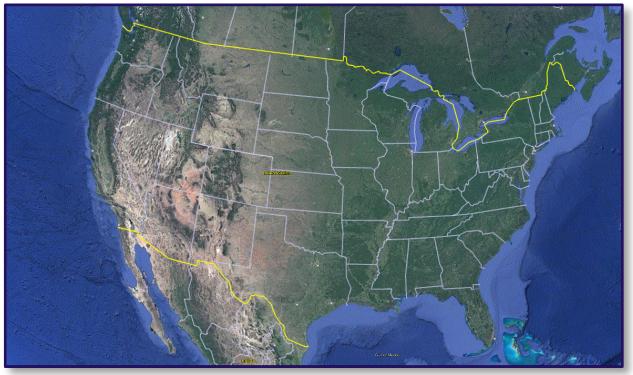
02

Background Information

Site Location



Map of Squibnocket and Menemsha Ponds (MEP 2017)



Herring Creek Fishery

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

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 **Wampanoag Tribe of Gay Head (Aquinnah)** resides in Aquinnah on Martha's Vineyard, upholding a continuous existence in their ancestral territory.

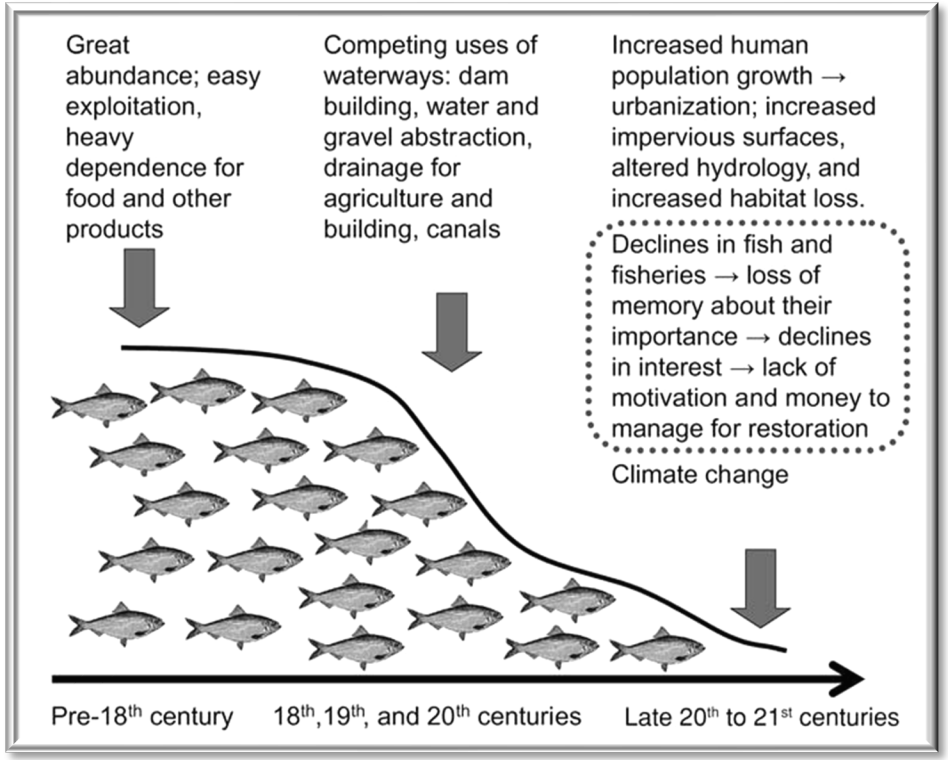
Historical Challenges in Fisheries

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.



Decline of Diadromous Fish (Limburg & Waldman, 2009)

Environmental Changes

Facing out towards Squibnocket Pond

Herring Creek South Opening 1900s
(*Provided by Wampanoag Tribe of Gay Head (Aquinnah) in 2023*)

Facing out towards Menemsha Pond

Herring Creek North Opening 2023

Project Background

Planning Assistance to the States (PAS): Support the Wampanoag Tribe of Gay Head (Aquinnah) in conserving their water- based resources and assessing environmental vulnerabilities, stressors, and interventions to best mitigate consequences of environmental degradation and adapt to climate change.

Key Partners: Wampanoag Tribe of Gay Head (Aquinnah), New England USACE, ERDC

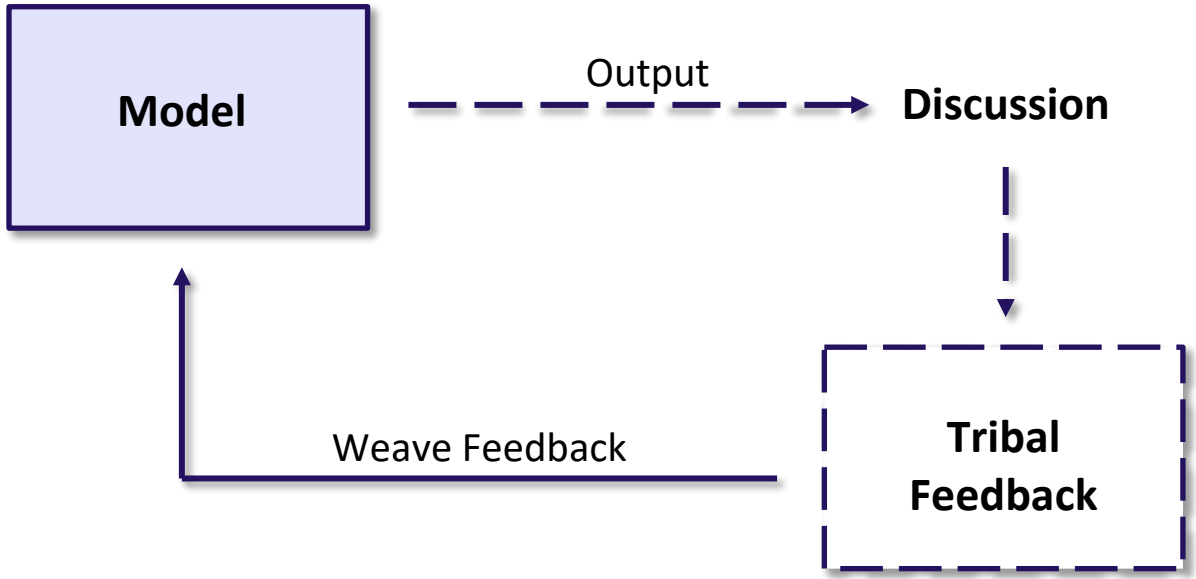
Initial Scope: Assess Current River Herring Habitat Suitability in Aquinnah

Map of Squibnocket and Menemsha Ponds (MEP 2017)

03

Ecological Modeling

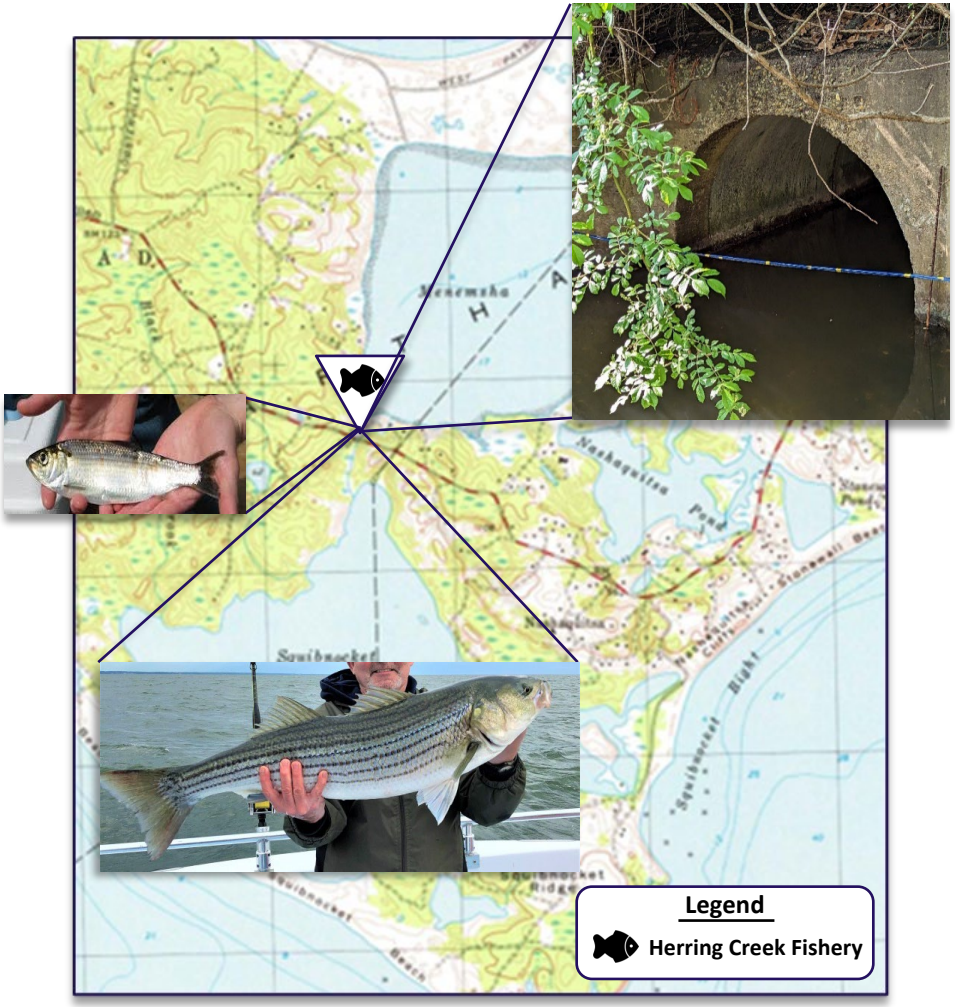
Model Development



Communication Feedback Loop for Model Development

Site Characteristics

- **Species-Specific Challenges:** Offshore fishing, and bycatch has led to the overall decline of river herring stock in Aquinnah.
- **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.



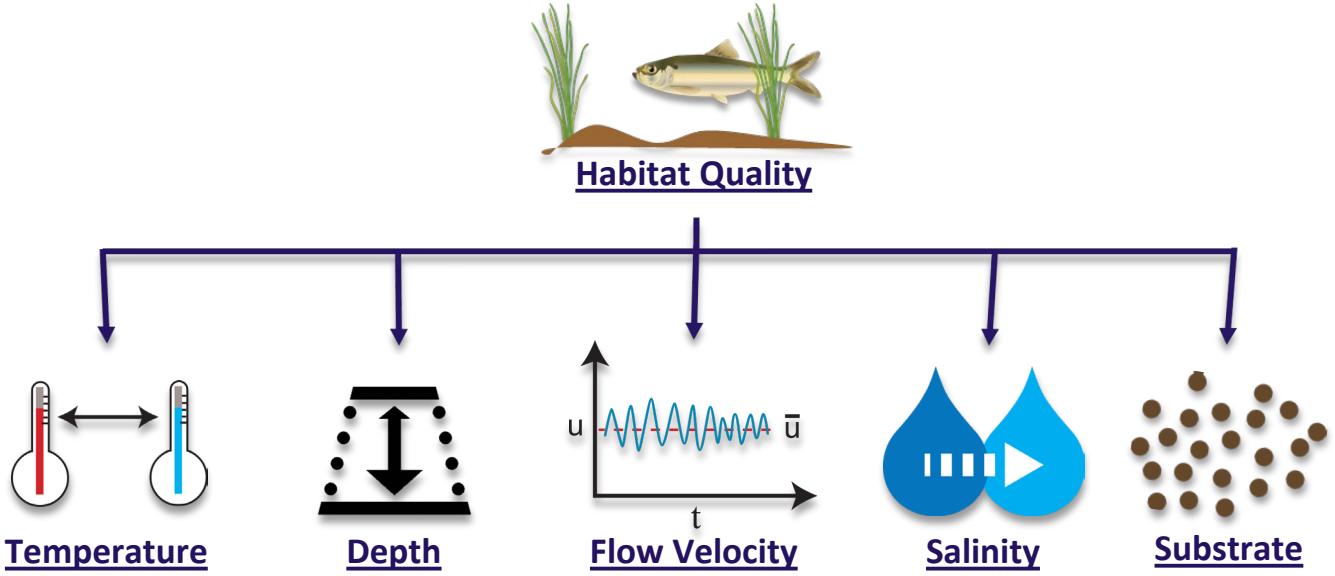
Map of Squibnocket and Menemsha Ponds (MEP 2017)

River Herring Management Questions

- How do different life stages of river herring utilize estuary habitat in Aquinnah, and what factors influence their spatial and temporal distribution?
- What are the key environmental conditions in estuaries required to sustain a viable river herring population, and are these conditions being met in Aquinnah?
- To what extent does predation by species like striped bass impact river herring populations in Aquinnah, and how can predation pressure be mitigated?
- How does the culvert in Aquinnah impact river herring migration?

Ecological Modeling Approach

Task: Assess Current River Herring Habitat Suitability in Aquinnah



Conceptual Model for Habitat Suitability of River Herring

River Herring Management Questions

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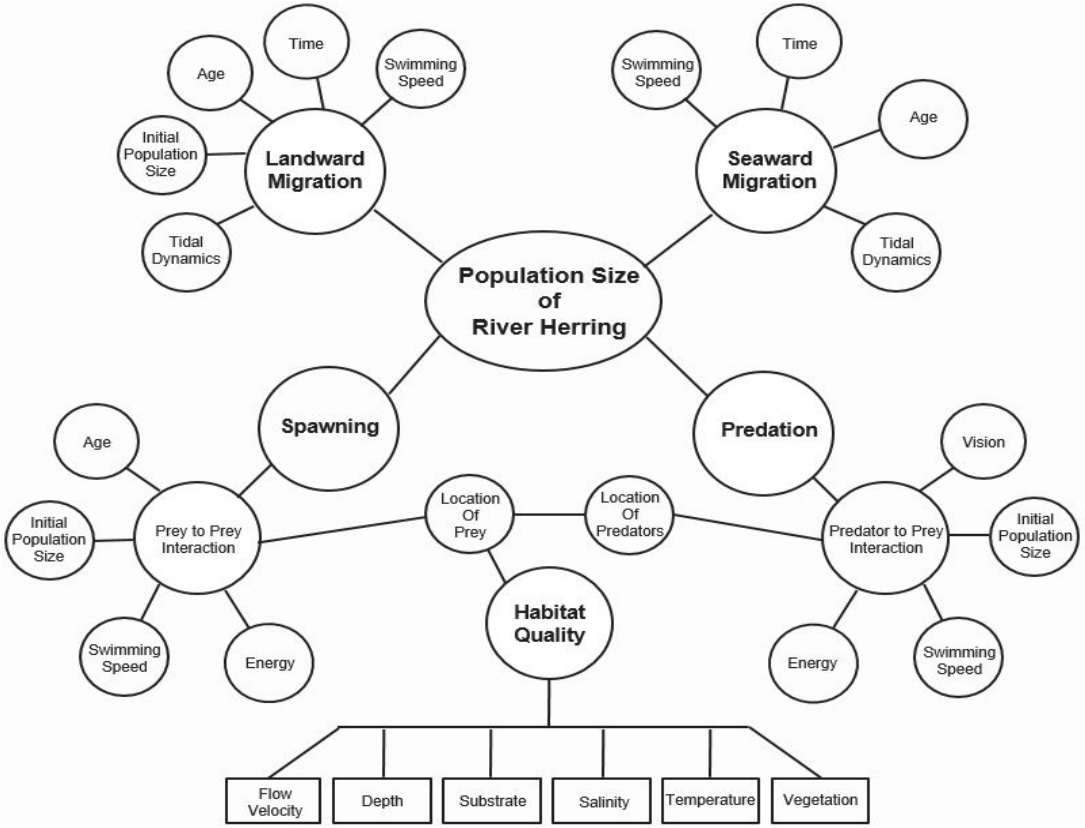
Ecological Modeling Approach



Conceptual Diagram for Coupled Modeling Framework

Agent-based Modeling

- Spatially Explicit
- Temporally Explicit
- Site-Specific
- Replicate Intraspecific & Interspecific Interactions

River Herring Management Questions

- How do different life stages of river herring utilize estuary habitat in Aquinnah, and what factors influence their spatial and temporal distribution?
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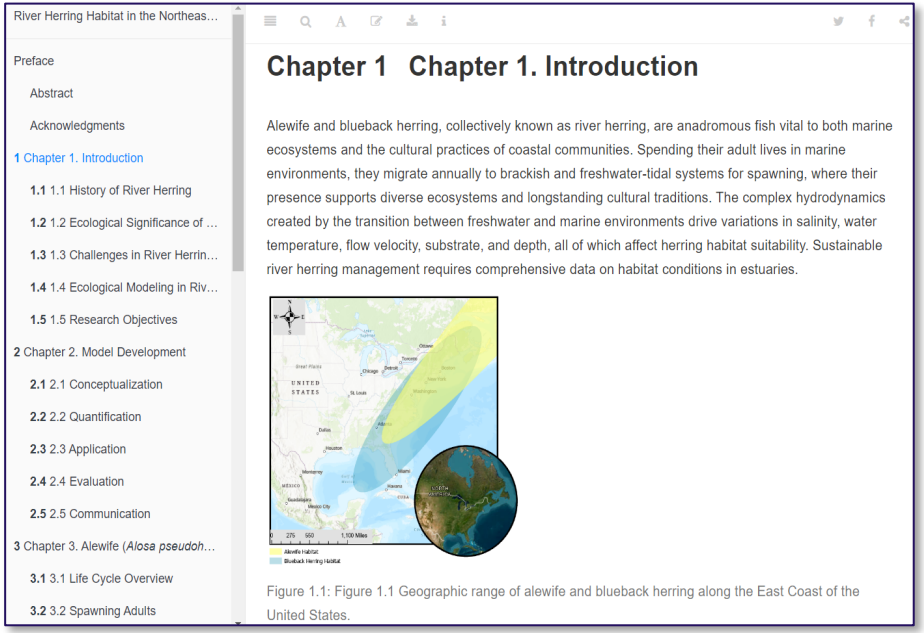
Model Quantification

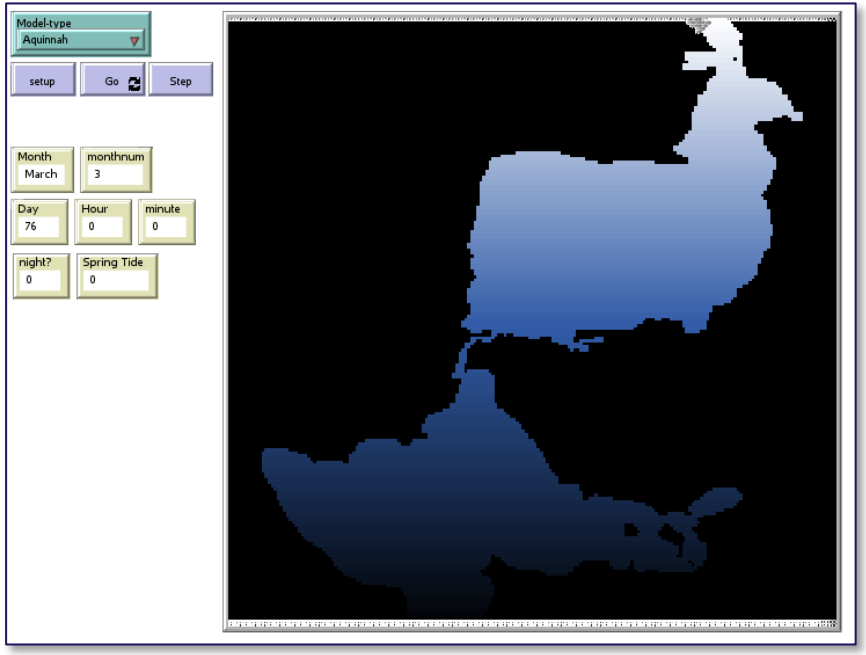


Bookdown Document

Habitat Model

- **Language**: R, ArcGIS for pre-processing
- **Packages**: terra, gstat, dplyr, ggplot2, ggmap, bookdown
- **Documentation Style**: Model Code and Demo and source references are all embedded within a Bookdown Document
- **Version Control**: GitHub

Model Quantification



NetLogo User Interface

Migration Model

Language: NetLogo, R for post-processing

Packages: GIS, BehaviorSpace (batch simulations)

Documentation Style: Model is documented using ODD protocol in Rmarkdown, model code is in NetLogo.

Version Control: GitHub

Translating Models into Actionable Tools

River Herring Ecological Modeling

Homepage | Species Information | Project Description | Ecological Modeling | Input Data | Key References | Glossary

Welcome!

This app transforms ecological data into an accessible tool for the Wampanoag Tribe of Gayhead (Aquinnah), promoting informed decisions, conservation, and understanding of river herring challenges in Aquinnah, Massachusetts.

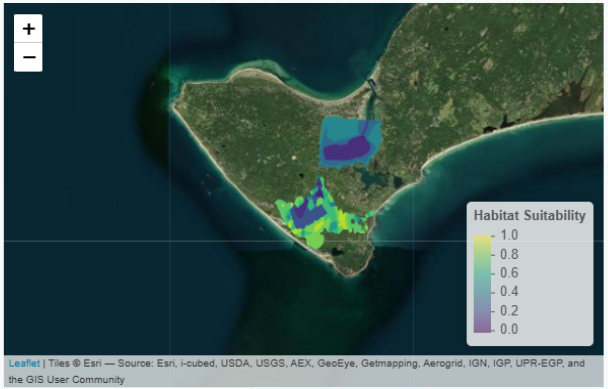
Data and information in this app are based on the following reports:

Quintana, V., Huguenard, K., Stevens, J., Galaitsi, S., Jacobs, A. & McKay, K. (2024). River Herring Habitat in the Eastern United States. [Manuscript in preparation.]

Quintana, V., Galaitsi, S., Jacobs, A., DuPuy, P., McKay, K., Huguenard, K., & Swannack, T. (2024). Weaving Traditional Ecological Knowledge into Ecological Modeling. [Manuscript in preparation.]

Spawning Adult Alewives | Alewife Eggs & Larvae | Non-Migratory Juvenile Alewives | Spawning Adult Blueback Herring | Blueback Herring Eggs & Larvae | Non-Migratory Juvenile Blueback Herring | River Herring Migration Model

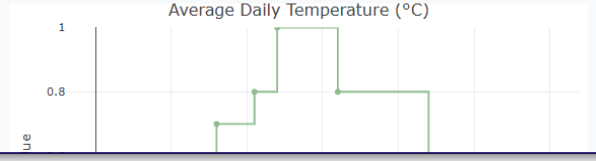
Net Habitat Suitability



Spawning adult alewives find the most suitable habitats in Squibnocket Pond, where high-quality areas cluster along the southwestern and eastern shores, with additional favorable conditions near the northern point. Menemsha Pond and Herring Creek, by contrast, provide less suitable environments, offering only moderate-quality habitats and lacking high-quality zones. Moderate-quality habitat dominates much of the landscape, while low-quality areas occur in deeper sections of the ponds. Squibnocket Pond emerges as the most critical location for spawning adult alewives, offering a combination of diverse and optimal habitat conditions essential for successful reproduction.

Average Daily Temperature | Depth | Salinity | Average Daily Flow Velocity | Substrate | Sub-Aquatic Vegetation

Suitability Index



Temperature Suitability

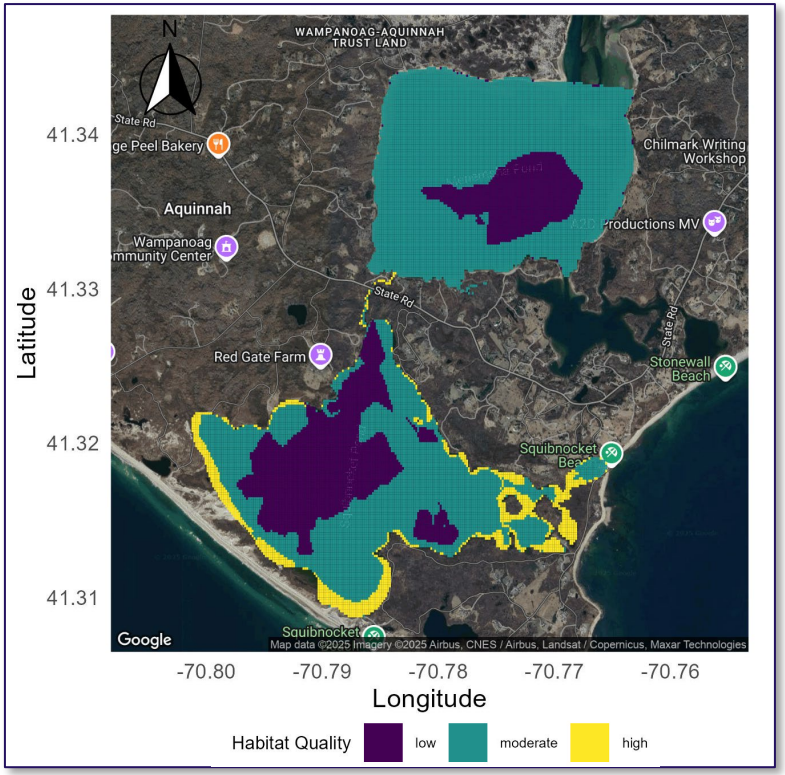
Interactive Shiny App

04

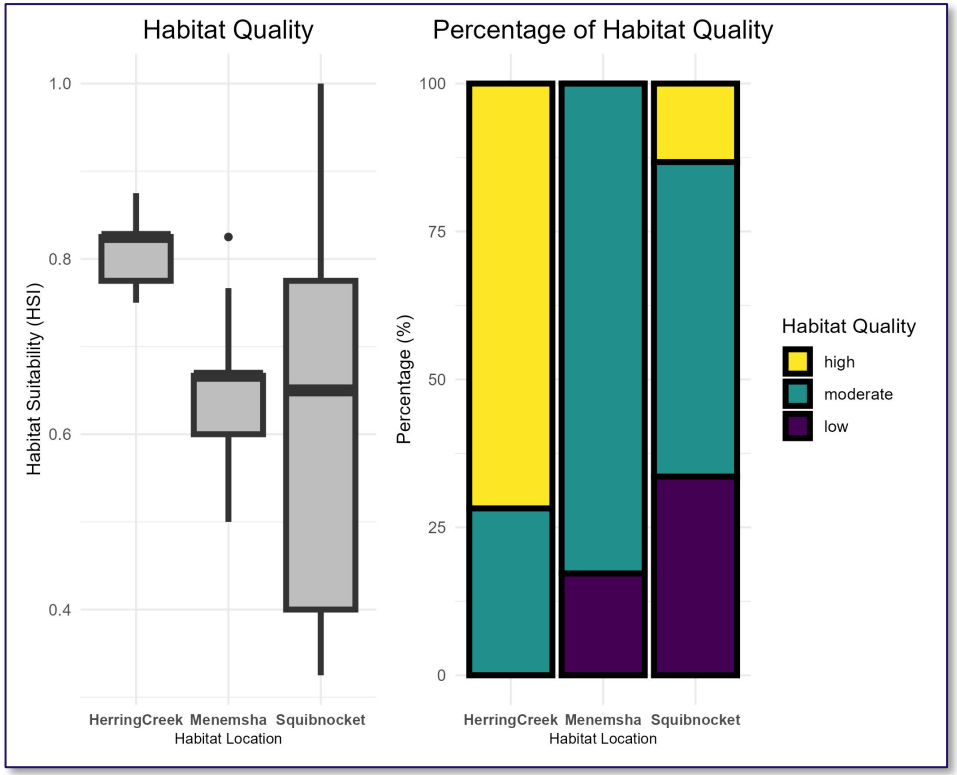
Model Demo and Results

*The results presented here are illustrative examples and do not reflect final project outcomes.**

Example Results: Spawning Adult Alewives

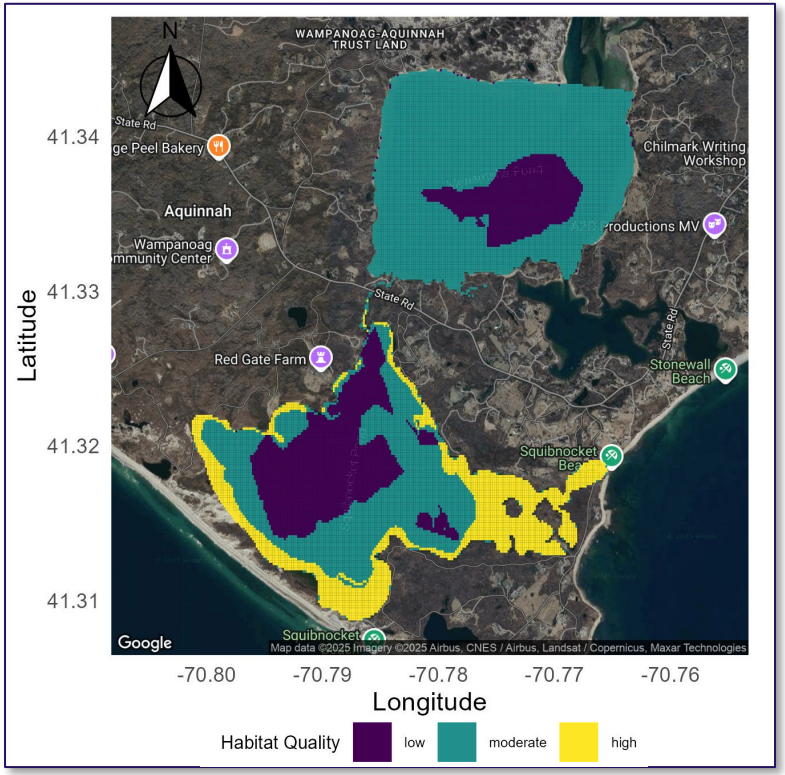


Map of Adult Alewife Habitat Quality

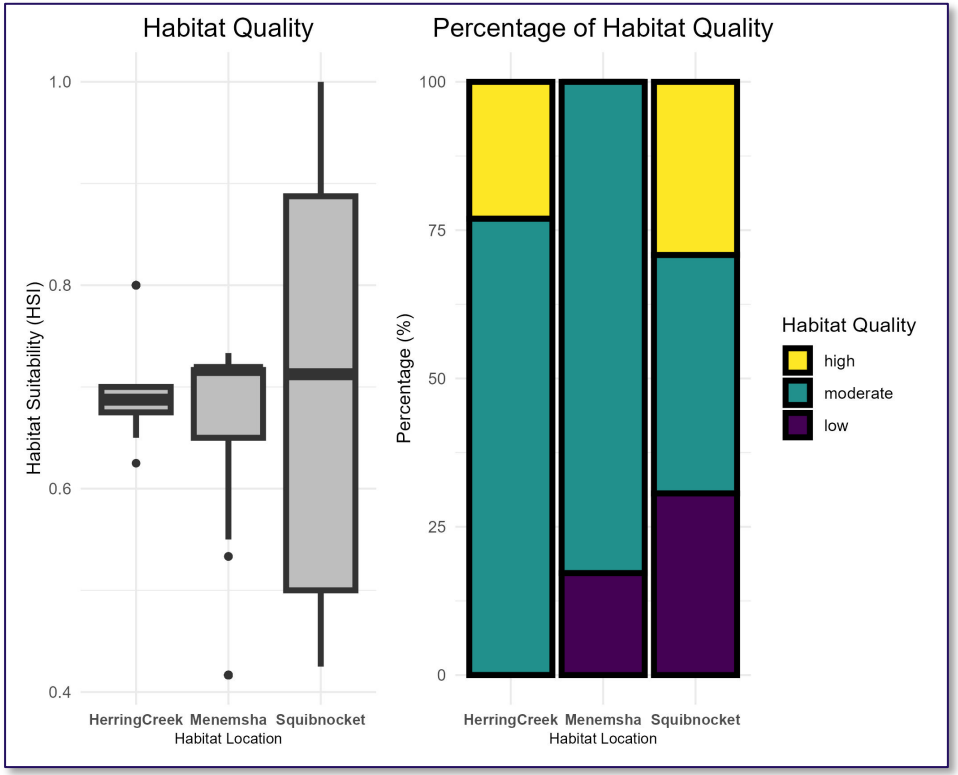


Distribution of Adult Alewife Habitat Quality

Example Results: Alewife Eggs & Larvae

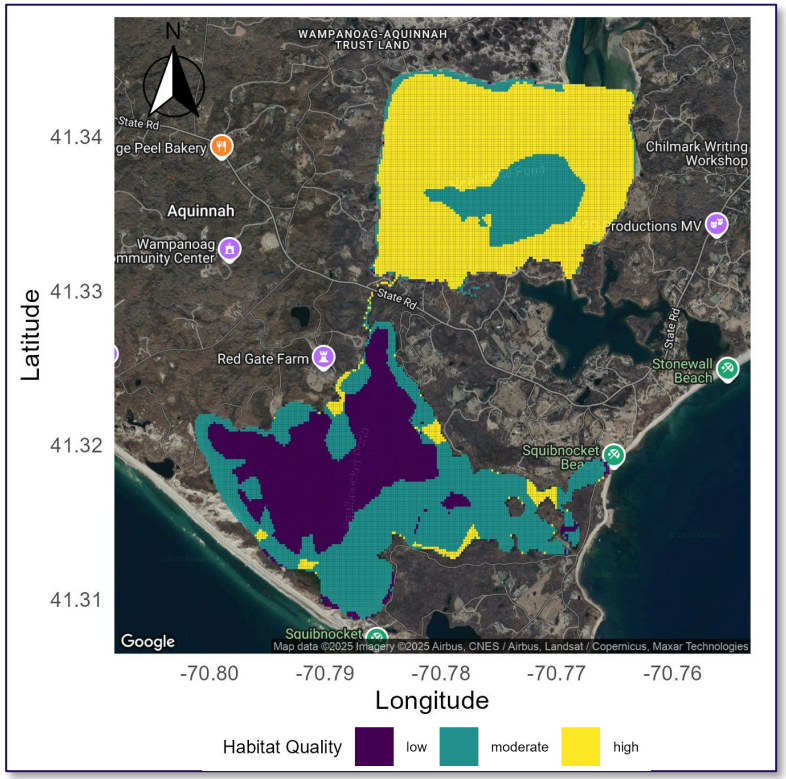


Map of Alewife Eggs & Larvae Habitat Quality

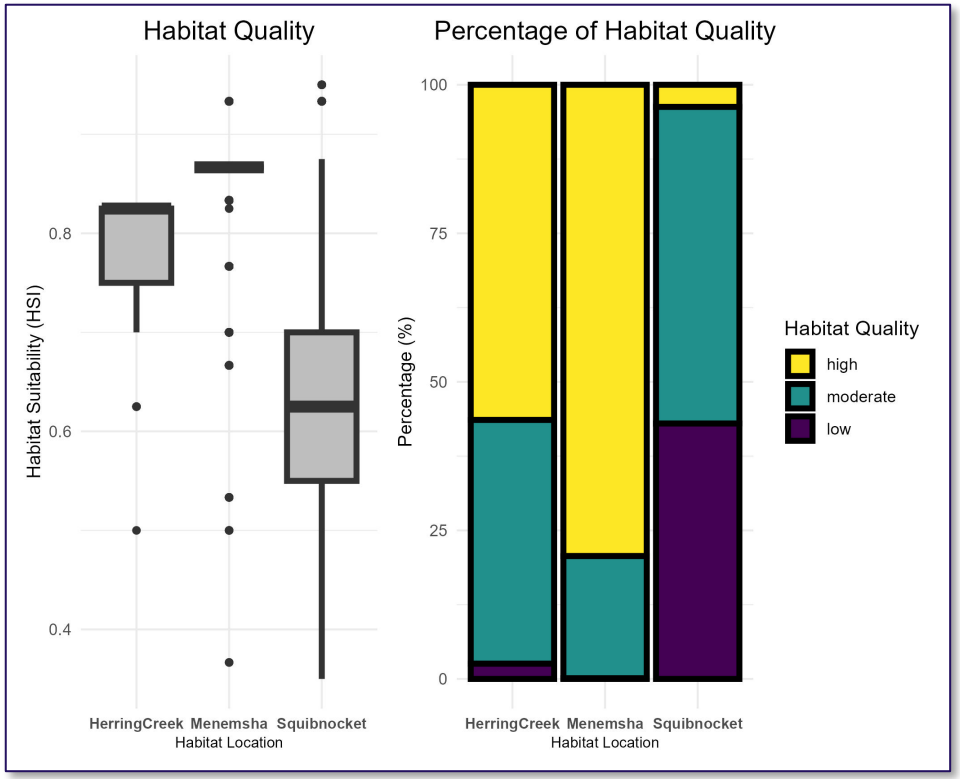


Distribution of Alewife Eggs & Larvae Habitat Quality

Example Results: Juvenile Alewife



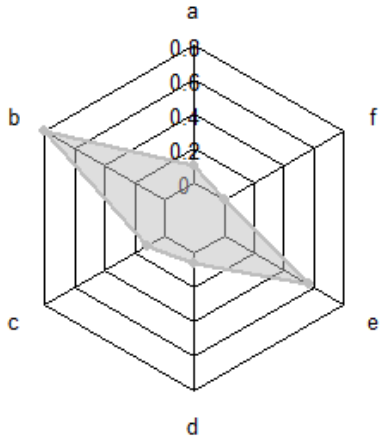
Map of Juvenile Alewife Habitat Quality



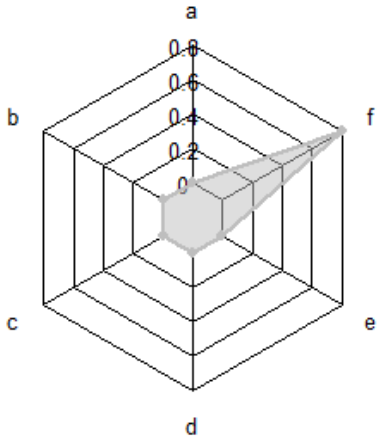
Distribution of Juvenile Alewife Habitat Quality

Habitat Model Evaluation

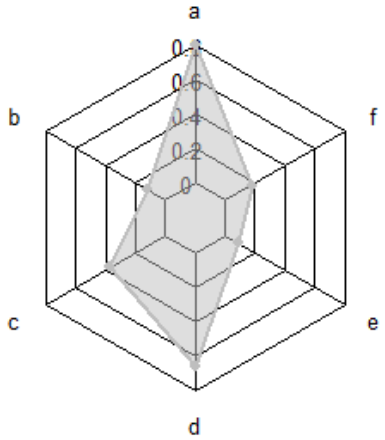
t-values



p-values



Standard Error



Variable	Estimate	Std. Error	t-value	p-value
Intercept	0.055	0.0057	9.7	<2e-16
a. Temperature	0.28	0.0057	49	<2e-16
b. Depth	0.32	0.00087	370	<2e-16
c. Salinity	0.15	0.0026	56	<2e-16
d. Velocity	0.14	0.0047	28	<2e-16
e. Substrate	0.17	0.00065	270	<2e-16
f. SAV	0.0025	0.0013	2.0	0.047

Legacy and Change

Spawning Adults

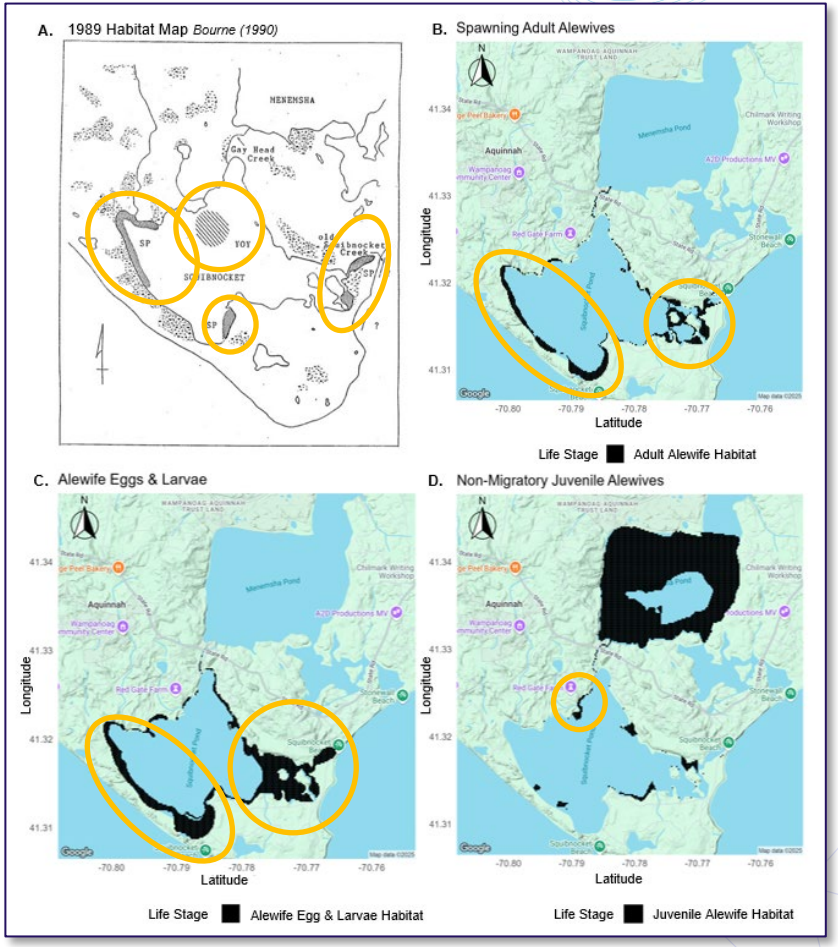
- Habitats align with historical spawning zones (SP)

Eggs & Larvae

- Habitats align with historical spawning zones (SP)

Non-Migratory Juvenile

- Habitats align with historical young-of-the-year zones (YOY)



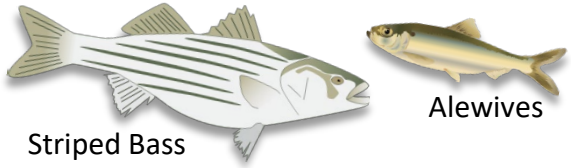
Historical Comparison of Adult Alewife Habitat

Sea

Estuary

ABM Demo

Agents:



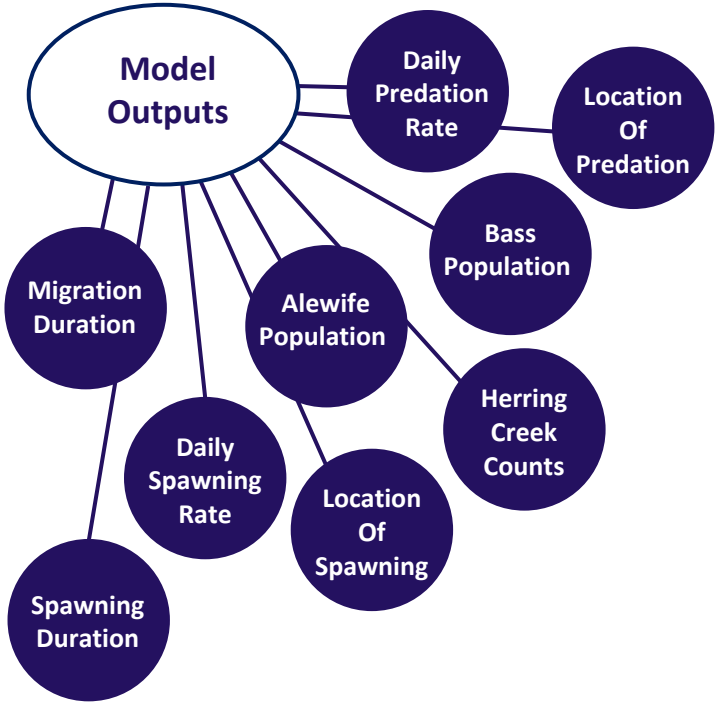
Behaviors:

- Migration
- Predation
- Spawning
- Schooling

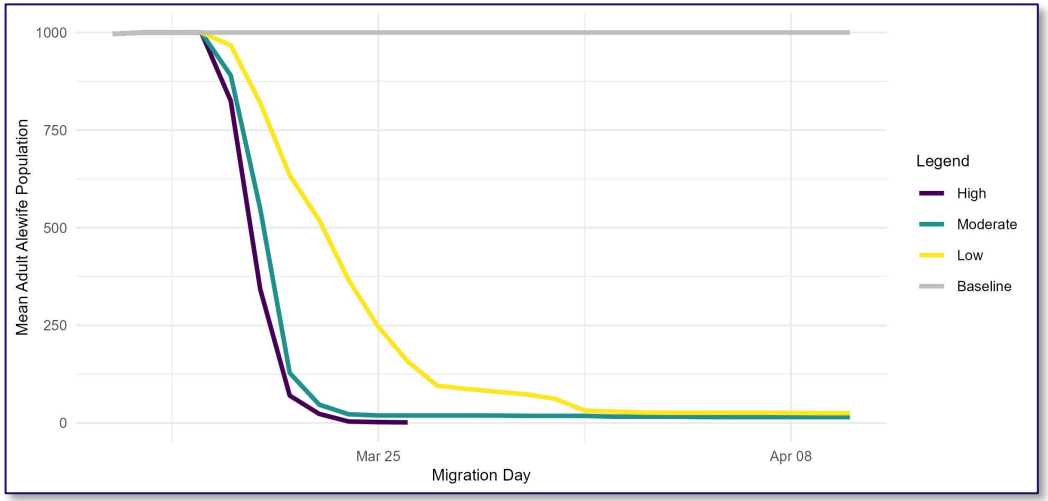
Patch Attributes:

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

Agent-Based Model Demo for Aquinnah Pond System



Agent-Based Model

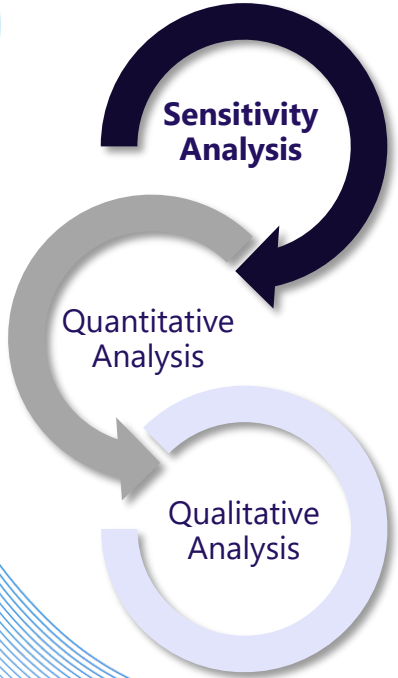


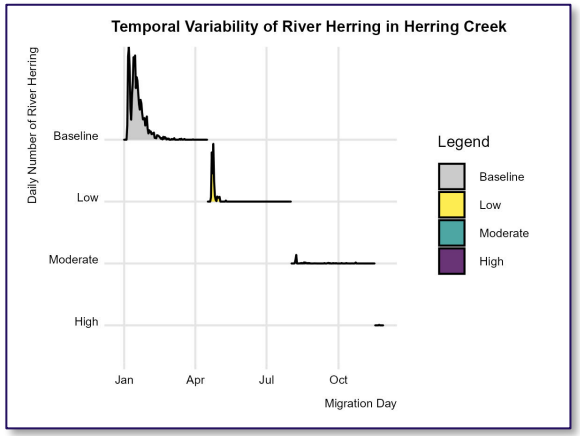
River Herring Population During Simulated Migration

Experimental Conditions

Baseline	Low	Moderate	Extreme
❖ 1000 Alewives	❖ 1000 Alewives	❖ 1000 Alewives	❖ 1000 Alewives
❖ 0 Striped Bass	❖ 1 Striped Bass	❖ 5 Striped Bass	❖ 10 Striped Bass

Model Evaluation

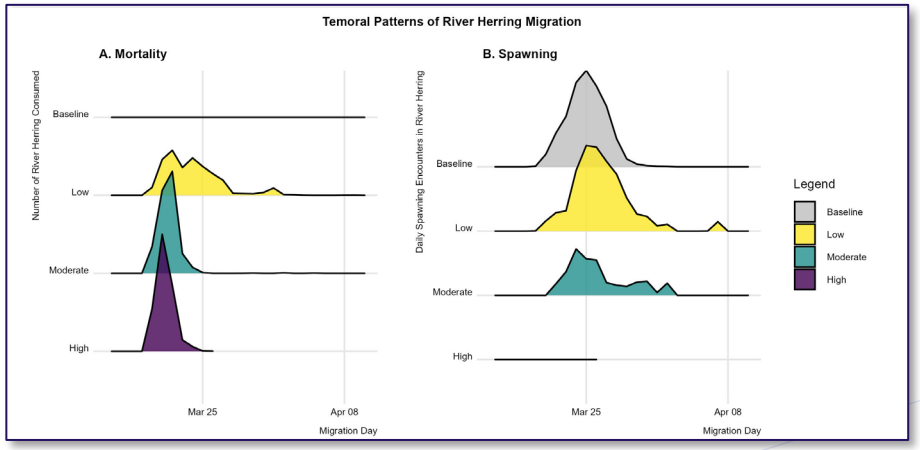




Simulated Herring Count Data

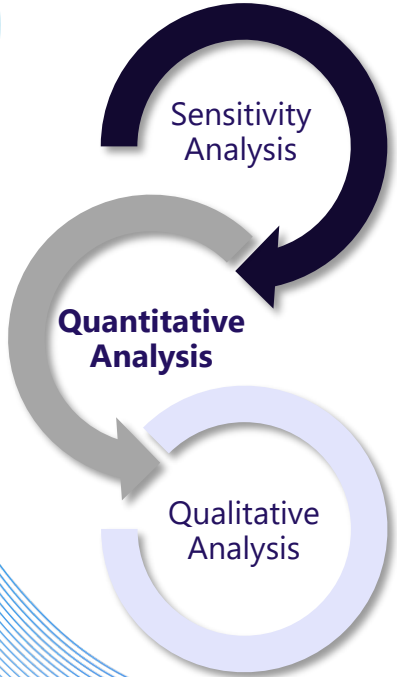
Emergent Behaviors

Are patterns that arise from the interactions of agents within the model, analyzed to evaluate sensitivity and model behavior.

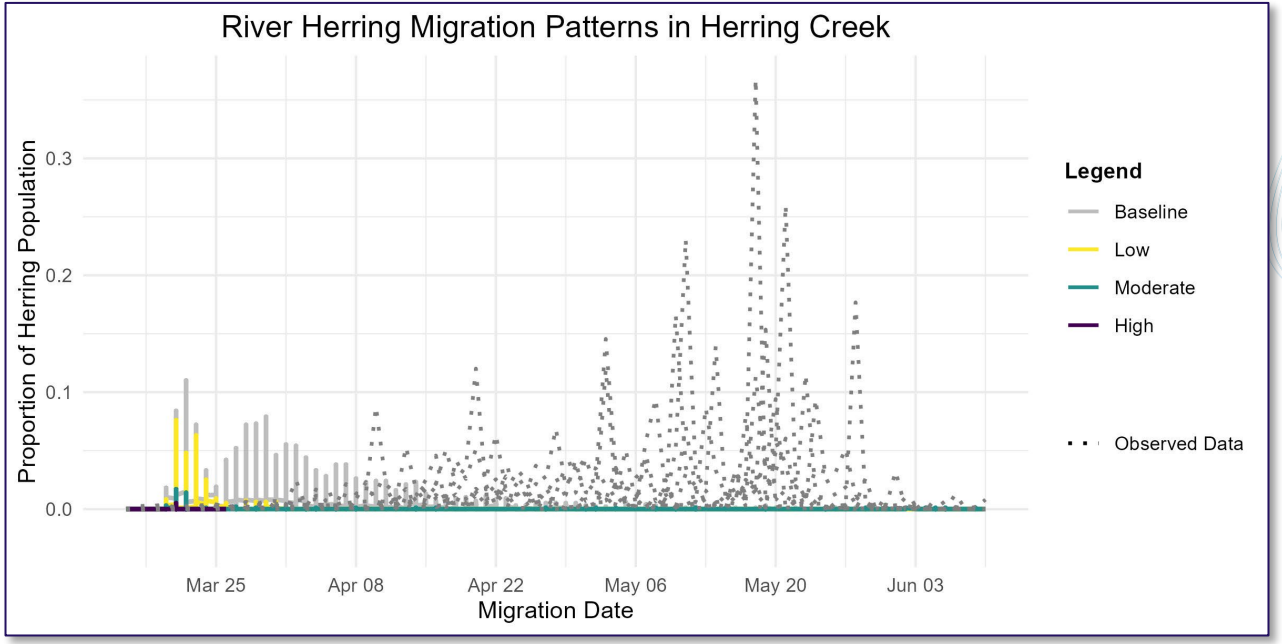


Simulated Predation and Spawning Data

Model Evaluation



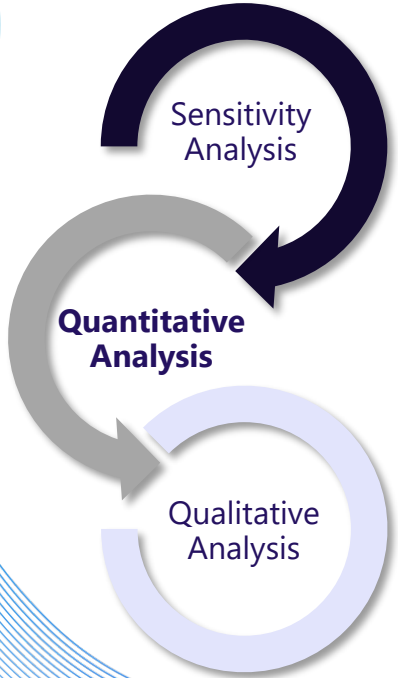
Modeled and Observed Herring Count Data



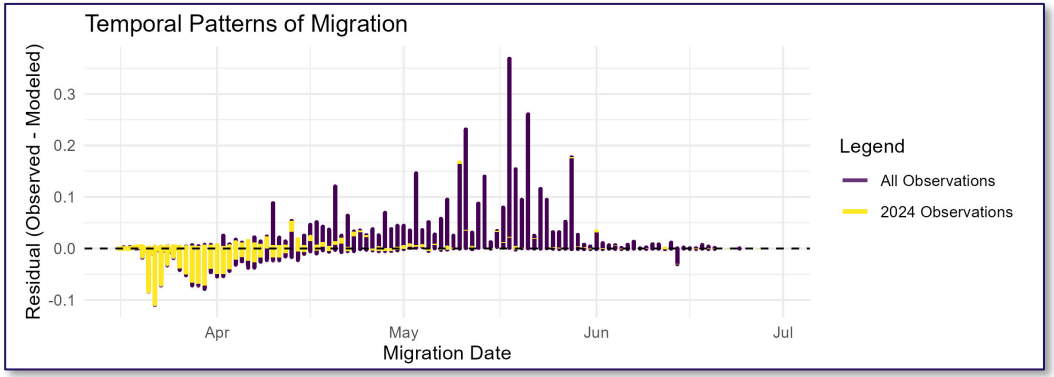
Replicating Data

Herring counts at Herring Creek Fishery were identified as a key output metric, aligning with Tribal priorities for managing the herring population and replicating the yearly data collected.

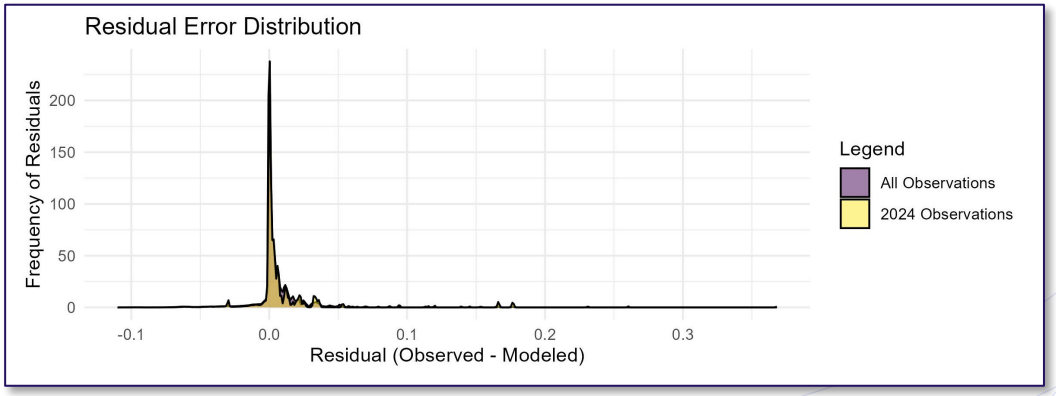
Model Evaluation



Evaluating Residual Error

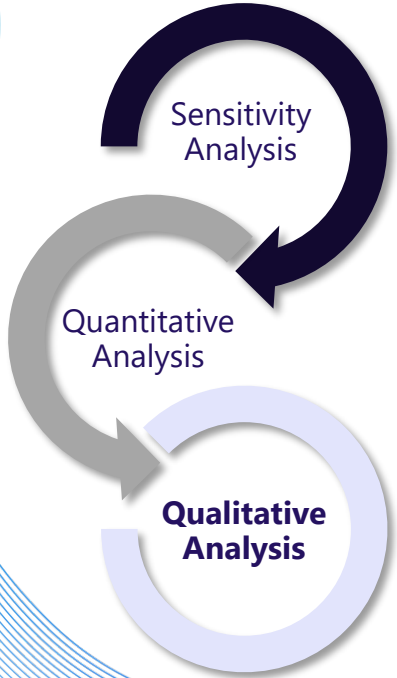


Comparing Model Accuracy Across Migration Days

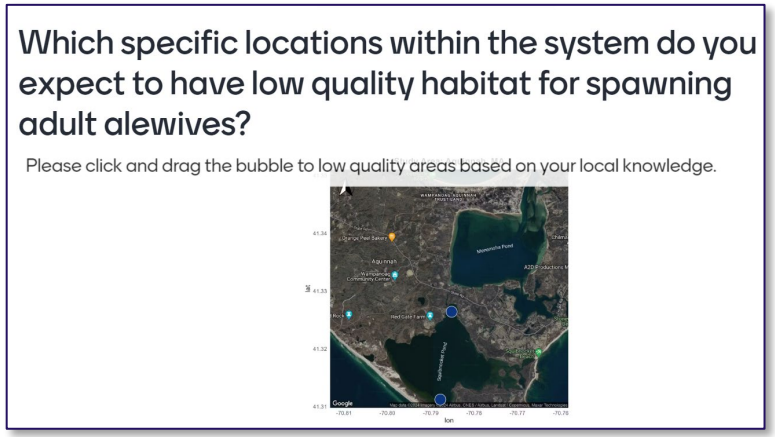


Comparing River Herring Residuals

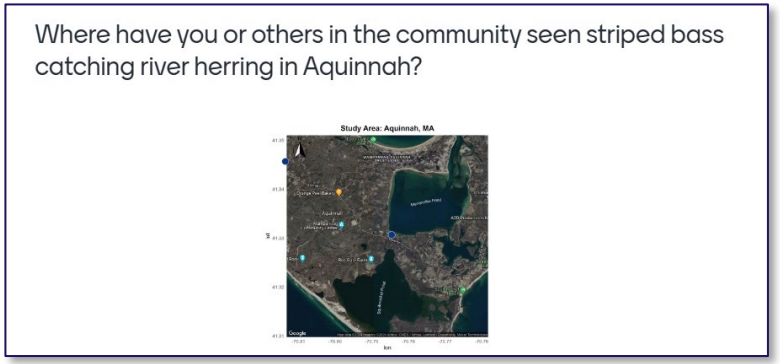
Model Evaluation



Interactive Survey



Example of Alewife Survey Question



Example of Striped Bass Survey Question

Mentimeter Software

- Translates observations from the Tribe to Model Evaluation Criteria
- Gathers responses in multiple forms allowing for diverse feedback
- Directly engages with Indigenous knowledge holders
- Preserves data sovereignty by recording and allowing participants to save responses.

05

Summary

Lessons Learned

Understanding the core problem or management question often requires digging deeper through collaborative discussions and iterative inquiry.

Developing models that integrate diverse perspectives takes time and a willingness to embrace different ways of knowing.

The model initially identified may not always be the most suitable or comprehensive fit to fully address the underlying management needs.

Key Takeaways

- Effective environmental management requires proactively guiding stakeholders to select models that address their specific questions.

- Model development, utility and evaluation was improved through the inclusion of localized community knowledge.

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Thank You!