EMRRP WEBINAR 5/17

Agent-Based Modeling with GoFish

Modeling dynamic risk for fish in aquatic systems

Vanessa Quintana | GoFish Library

vmahan1998.github.io/GoFish

Webinar Breakdown

01	Welcome & framing	2 min
02	What is an ABM?	10 min
03	Introducing GoFish	7 min
04	Case Study	10 min
05	Your GoFish ABM Roadmap	7 min
06	Future Directions	4 min
07	Q&A & close	10 min+

Modeling Environmental Risk.

Static vs dynamic assessments

STATIC ASSESSMENT

Traditional USACE / regulatory approach

- **Maps risk hotspots**
  Where risk is modeled from discrete observations.
- **Compares environment to uniform benchmarks**
  Uses standardized environmental thresholds to classify risk.
- **Assumes uniform risk**
  All organisms in the zone are treated as uniformly at risk.
- **Ignores individual variation**
  Physiology, condition, and behavioral decision-making.
- **Point-in-time or seasonal average**
  Cannot capture dynamic shifts for risk in time and space.

Therefore We Need

DYNAMIC ASSESSMENT

Behavior-driven, individual-based approach

- **Tracks individual organisms through space & time**
  Agents respond to real environmental conditions every time step.
- **Links behavior to contaminant fields**
  Risk depends on where the organism is and what it is doing.
- **Captures environmental variability**
  Environmental conditions shift in time and space— risk shifts.
- **Distinguishes risk by organism decisions or environmental conditions**
  Different conditions and decisions impact risk differently.
- **Supports scenario and management testing**
  Restoration, flow changes, or remediation effects can be simulated.

Upgrade to dynamic when: ‣ Species of concern present ‣ Active remediation or restoration site ‣ Environmental shifts anticipated

02

Agent-Based Modeling

Creating dynamic environmental assessments

What is an agent-based model?

An ABM simulates the behavior of individuals and how their interactions with each other and the environment create larger-scale patterns.

A **Agents**
Individual organisms with traits, internal states, and rules

E **Environment**
Spatial patches containing environmental data

B **Behaviors**
Decision rules responding to internal & external cues

What ABMs can answer

- When & where are organisms most exposed to risk?
- How do behaviors influence risk patterns?
- How do environmental shifts affect risk?
- How do population risk patterns emerge from individuals?

What ABMs are not designed to do

× Replace field data or telemetry
× Predict exact population abundances
× Predict exact contaminant transformation dynamics

Implementation Example

How can we simulate behavioral interactions within an estuary?

1. **Individual agents** (fish) are simulated with autonomous behavioral rules — feeding, predator avoidance, habitat seeking — responding to their local environment.
2. **Emergent population behavior** arises from individual interactions — no top-down rules define group patterns; they emerge from the bottom up.
3. **Coupled to hydrodynamics** via Delft3D FM — agents move through a spatially explicit estuary with realistic tidal currents, salinity gradients, and temperature fields.

Translating biology into model components

Agent attributes

- Body size & mass
- Age & life stage
- Energy reserves
- Species identity
- Contaminant load

Environmental cues

- Water temperature
- Salinity gradient
- Flow velocity
- Water level
- Sediment (SPM)
- Contaminant field

Behavioral rules

- Migrate when cue detected
- Use tidal currents
- Conspecific behavior

Emergence: when individual rules create patterns

Migration timing

Synchronous runs emerge from individual cue detection

Route formation

Corridors form where least-cost paths overlap

Habitat use

Habitat use appears where agent spend the most time

Exposure hotspots

Risk zones emerge from behavioral overlap with contamination

ABM potential in USACE risk assessments and decision-making

ABMs answer three classes of questions that static models cannot — each directly relevant to USACE planning and permitting

⇄ Scenario Comparison

USACE examples:

- **Dam Removal and Fish Passage** — Evaluates ecosystem responses to restored connectivity and altered migration pathways.
- **Restoration alternatives** — Assesses ecological outcomes across restoration and management scenarios.
- **Coastal Resilience and Sea-Level Rise**— Examines ecosystem vulnerability under future climate and flooding conditions.
- **Navigation and Infrastructure** — Evaluates tradeoffs associated with modifications to waterways and habitat.

Which management action produces the best biological outcome?

Environmental Change

USACE examples:

- **Flow regime change** — Evaluates ecosystem responses to altered flow conditions.
- **Temperature and salinity shifts** — Assesses habitat change under shifting conditions.
- **Storm surge intrusion** — Examines impacts from coastal flooding and extreme events.
- **Sediment, Turbidity, and Contaminants** — Evaluates transport dynamics during storms and restoration activities.

How does a shift in physical conditions change biological risk?

Behavior Change

USACE examples:

- **Foraging vs. habitat use** — Evaluates habitat use, movement, and restoration effectiveness.
- **Spawning**— Assesses spawning success under different environmental conditions.
- **Predation pressure** — Examines predator–prey dynamics across management scenarios.
- **Mortality**— Evaluates survival outcomes under environmental stressors and restoration alternatives.

How does individual decision-making shape population-level risk?

Static models can describe where risk exists. ABMs can explain why, predict how it shifts, and test what happens if you intervene.

Learning Curve, Time Investment & Reuse Potential

Initial Build

- NetLogo familiarity needed (~2-4 weeks for new users)
- Data prep: hydrodynamic outputs, bathymetry, contaminant fields, pseudo data, data poor cases.
- ODD design and **behavioral rule writing** is the steepest step (how can I quantify processes relevant to system or species)
- First deployment: months to years depending on complexity

Developing ABMs for Reuse

- Modules can be portable across sites and species
- Same behavioral or movement logic applies across multiple species and habitats.
- Similar management and environmental questions asked across restoration or infrastructure planning locations (water quality → flow, turbidity, temp, salinity, contaminants)

Short-Term Projects

- Best fit: multi-year remediation or restoration projects
- Short-term use case: process-based restoration impact screening ecological impacts or process disruption
- ROI increases with modular development: build once, apply across districts and questions
- Open-source: no licensing cost; compute runs locally

USACE Application Examples

Agent-based models support biological assessment across project areas

Contaminant Risk

- Dynamic exposure tracking as fish move through contaminated patches
- Supports Superfund site risk assessments and remediation targeting
- Couples to Hg, PCB, or metals fields from transport models

Sediment Capping

- Simulate pre/post-cap exposure to compare effectiveness for mobile species
- Assess whether foraging behavior draws fish back to capped areas
- Quantify residual exposure risk over time as cap consolidates

Dam Removal

- Simulate passage success and habitat access before and after removal
- Test migration cue responses under restored flow regimes
- Assess sediment pulse effects on downstream exposure during removal

Infrastructure & Flood Risk

- Model behavioral disruption from new dam operations or flood control structures
- Simulate storm surge intrusion and salinity shock on estuarine species
- Assess fish stranding, passage blockage, or contaminant mobilization during flood events

Dredging & Navigation

- Time dredge windows to avoid peak migration; quantify exposure from SPM plumes
- Compare confined disposal vs. open-water placement for beneficial use
- Support 404 permitting and ESA Section 7 biological opinions

Restoration Alternatives

- Screen multiple restoration designs simultaneously — compare habitat use, migration success, and exposure across alternatives
- Test flow regime, channel geometry, or vegetation alternatives before construction

Measuring Adverse vs. Beneficial Impacts

ABMs quantify net biological outcomes from USACE actions — supporting both 404 permitting and beneficial use assessments

⚠ Adverse Impacts

- Migration delay or blockage from turbidity plumes
- Elevated contaminant exposure from resuspended sediment
- Disruption of spawning habitat or energy budget during critical life stage
- Population-level exposure disparity between behaviorally distinct groups
- Mortality/survival impacts

✔ Beneficial Impacts

- Reduced contaminant hot spots following dredge removal; agents show lower cumulative exposure
- Beneficial use placement creates habitat — agents shift to lower-stress zones, spawning habitat, or reduced energy costs
- Flow restoration (dam removal) expands accessible habitat; simulated passage success increases
- Quantify net change per agent — provides defensible before/after comparison for agency review

The Problem with How ABMs Are Built Today

Monolithic design limits reuse, inflates cost, and locks ABMs out of short-term USACE projects

⚠ STATUS QUO: Monolithic Design

How most ABMs in USACE projects are built:

- Built from scratch for a single site and question — species, stressor, and domain all tightly coupled
- Logic buried in code — singular model documentation summarizing all behaviors together; hard to review, audit, or understand underlying behavior mechanisms.
- Rebuilding required for each new project — time and cost locked to initial development
- Infeasible for short-term or lower-budget USACE studies
- No shared behavioral standards — similar species modeled differently across districts and projects

→

✔ DESIGN FOR REUSE: Modular Approach

Design for reuse from the start — a modular approach:

- ✔ Each behavior is a self-contained, documented module, interchangeable without touching the rest of the model, make logic more transparent, auditable, and reproducible by agency reviewers
- ✔ Second deployment on a similar system: days to weeks instead of months
- ✔ Opens ABM to shorter, lower-budget USACE feasibility studies and alternatives screening
- ✔ Shared behavioral representations develop standard functions across species and districts — improving consistency and comparability

03

Introducing GoFish

A Modular ToolKit for Modeling Migratory Fish

https://vmahan1998.github.io/GoFish/

Migratory Fish in Estuaries as a Modular Testbed

Estuaries are where many USACE management conflicts, restoration actions, infrastructure projects, and regulatory evaluations converge simultaneously.

Estuaries as Management Hotspots

- Dam removal and fish passage projects
- Navigation and dredging activities
- Beneficial use and sediment management
- Coastal resilience and sea-level rise adaptation
- Contaminant remediation and habitat restoration

Why Migratory Fish?

- Migration behavior
- Foraging and habitat use
- Predation pressure
- Spawning success
- Mortality risk

Why use an estuary as a case study?

Estuaries are biodiversity hotspots and often contain overlapping infrastructure, restoration, and regulatory priorities requiring integrated ecosystem assessment.

Migratory fish provide an ideal case study due to their use of marine and freshwater habitats, diverse behavioral adaptations, and importance in evaluating project-driven ecosystem impacts.

Estuaries and migratory fish provide an ideal case study for modular ecological modeling because they integrate diverse environmental processes, management actions, and behavioral responses across connected marine and freshwater systems.

GoFish: a modular behavioral library

Each function is a self-contained, independently documented module — purpose, state variables, equations, and NetLogo implementation in one place.

Metabolism

Allometric scaling, Q10 temperature, age effects

Digestion

Prey breakdown, energy conversion, contaminant uptake

Salinity Exposure

Chloride cell dynamics, osmoregulatory cost

Contaminant Exp.

Gill uptake, SPM modulation, cumulative burden

Landward Movement

Least-cost routing, hydrodynamic difficulty

Seaward Movement

Downstream path, velocity-scaled speed

Schooling

Separation, cohesion, alignment (BOIDS)

Tidal Transport

Passive drift when flow > swim capacity

Filter Feeding

SPM ingestion, Gaussian preference, BMF

Lipid Catabolism

Endogenous energy mobilization during fasting

Migration Cues

Photoperiod + temperature trigger detection

Predation

Chase, flee, capture, contaminant transfer

The modularity advantage

Metabolism | Movement | Contaminant Exp. | Foraging | Predation

Each module shares state variables — metabolism efficiency feeds into movement cost feeds into contaminant uptake.

Build incrementally

Add one module at a time. Each works as a standalone and can be tested independently before integration.

Swap components

Replace a foraging module with one for a different species or feeding strategy — the rest of the model is unaffected.

Reuse across systems

The same metabolism or schooling module applies to river herring in Maine or shad in a different estuary.

Every module follows the ODD protocol

ODD = Overview, Design concepts, Details. A standardized framework that makes models transparent, reproducible, and adaptable.

Overview

- Purpose & patterns
- Entities, state variables & scales
- Process overview & scheduling

Design Concepts

- Emergence
- Adaptation & sensing
- Stochasticity & interaction

Details

- Initialization values
- Input data required
- Submodel equations & code

04

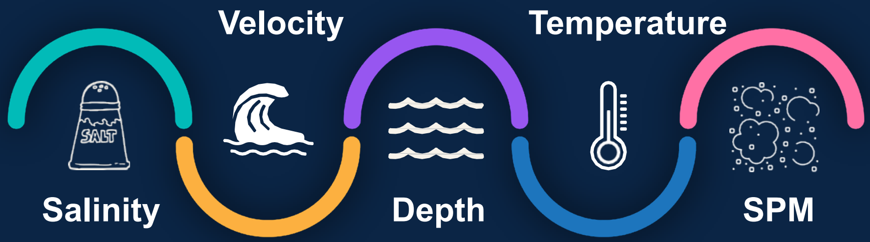
Case Study

Linking Individual Behaviors to Ecosystem Response

P-MEM MODEL WORKFLOW

How Does an Applied ABM Work?

Linking environmental conditions to toxicity risk

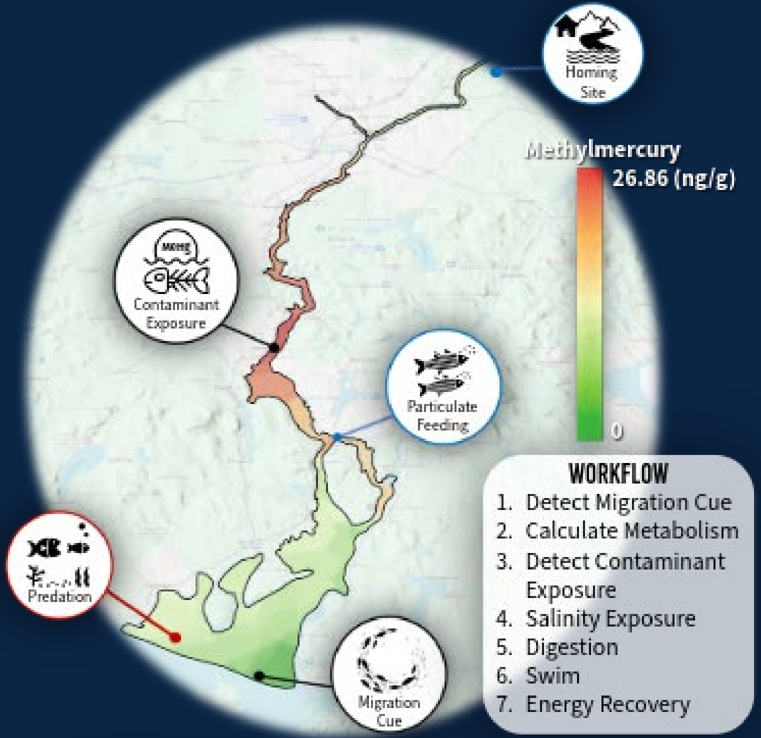


Alewives- Migratory Spawners

Alewives are obligate migrants moving upstream to spawn, following directed movement with limited feeding. Their behavior is driven by migration cues and continuous transit through the estuary.

Striped Bass- Migratory Foragers

Striped bass move flexibly through the estuary, actively feeding and preying on fish. Their behavior is driven by prey availability, leading to dynamic and repeated interaction with the system.



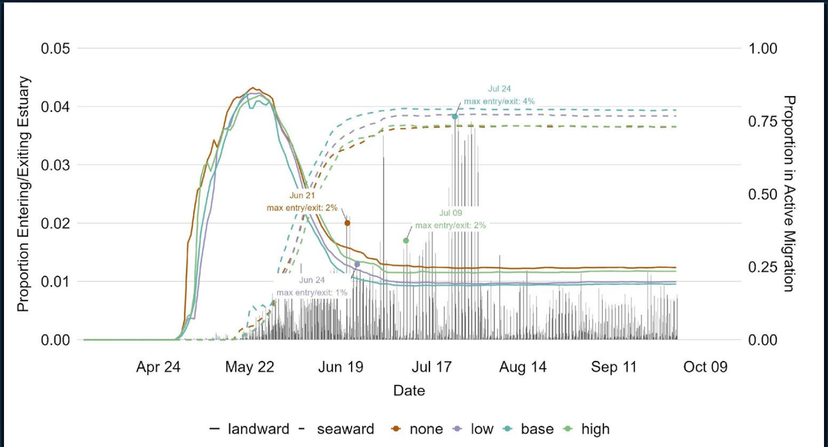
Penobscot Mercury Exposure Model (P-MEM)

Simulating Fish Behavior and Exposure with P-MEM

Behavior follows process-based rules — migration timing, passage, and estuary use emerge as 4,000 simulated fish respond to real 2023 hydrodynamics.

Daily Entry / Exit into the Penobscot Estuary

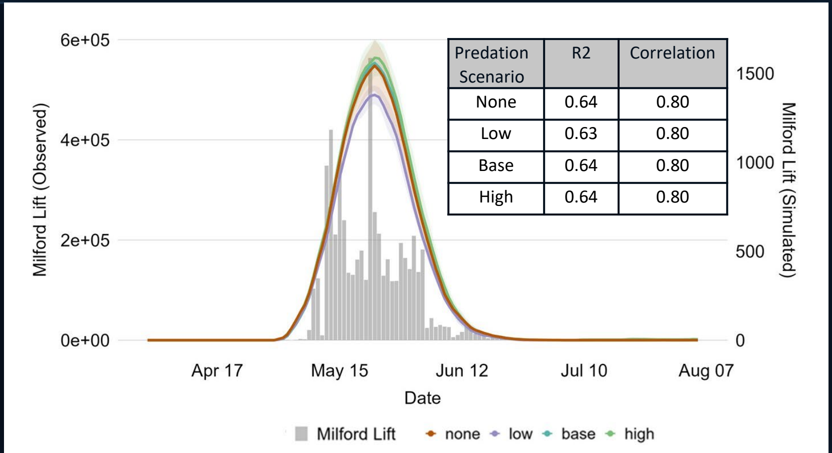
Alewives · N = 4,000 · Predation scenarios: none / low / base / high



Proportion entering/exiting estuary (left axis) and in active migration (right axis)

Validation: Simulated vs. Observed Fish Passage

Milford Dam fish passage counts · All predation scenarios



Predation Scenario	R2	Correlation
None	0.64	0.80
Low	0.63	0.80
Base	0.64	0.80
High	0.64	0.80

Simulated fish passage shape and timing matches Milford Dam observations

Nothing Hard-Coded

Results emerge from fish–environment interactions

Validated Against Observations

R^2 = 0.64 · Correlation = 0.80

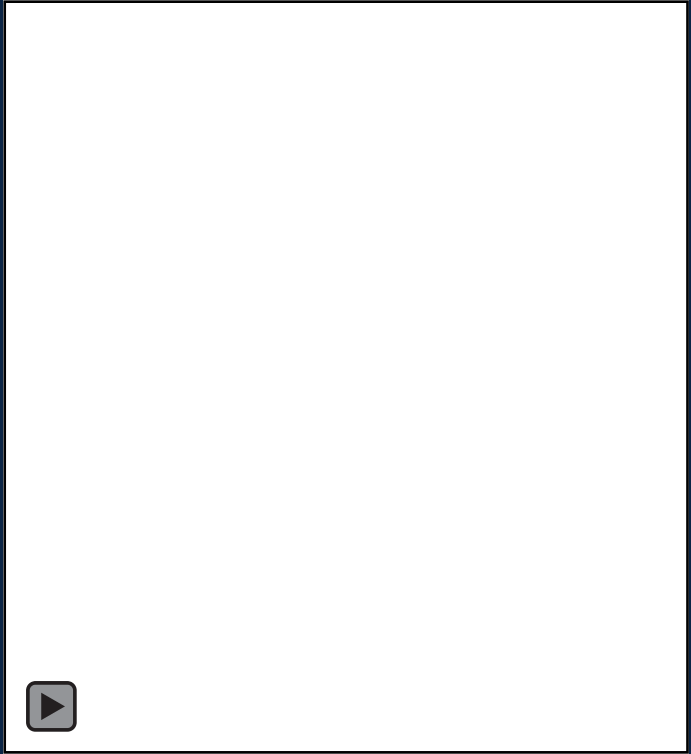
Driven by Real 2023 Conditions

Simulated hydrodynamics feed every behavioral decision

P-MEM in Action: Risk Emerges from the Landscape

Simulation: Alewives (N = 4,000) and striped bass (N = 4), used to demonstrate P-MEM capability. Results shown are preliminary and provided as an example.

Simulated Mercury Risk
(Alewives)



Visual Demonstration of P-MEM

Alewives

Net Realized Risk · none / low / base / high predation

Simulated Cumulative Mercury Risk for Alewives

Striped Bass

Net Realized Risk · none / low / base / high predation

Simulated Cumulative Mercury Risk for Striped Bass

How Can Applied ABMs Improve USACE Risk Assessments and Decision-Making

01 — Compare Management Alternatives

ABMs can test how restoration, infrastructure, or operational scenarios may change ecological outcomes before implementation.

02 — Identify Dynamic Risk Hotspots

ABMs show where and when risk emerges as organisms move through changing environmental conditions.

03 — Support More Defensible Decisions

Behavior-aware models help explain why project impacts may differ across species, seasons, locations, and scenarios.

GoFish supports reproducible and extensible ecological modeling by combining modular behavioral processes with spatial and environmental dynamics across aquatic systems.

Who Benefits

Project Teams
Compare alternatives and anticipate ecological tradeoffs.

Regulatory Reviewers
Evaluate dynamic impacts for permitting and ESA consultations.

Restoration Managers
Identify when and where interventions are most effective.

Communities
Improve transparency around project risks, benefits, and uncertainty.

When is ABM worth the investment?

Supporting USACE decisions: time, cost, and biological defensibility

HIGH VALUE USE CASES

- ✔ How do ecosystem responses change under different management scenarios?
- ✔ Where and when do ecological stressors emerge across the landscape?
- ✔ How do cumulative environmental changes propagate through connected ecosystems?
- ✔ How do environmental conditions shift risk across space and time?

CONSIDER ABM WHEN

- Questions involve dynamic ecological responses over time and space
- Multiple stressors or restoration alternatives interact simultaneously
- Organism behavior influences project outcomes or ecological risk
- Traditional static assessments cannot capture system dynamics

REALISTIC TIME COSTS

New system, new species: 3–6 months

Adapted from similar: 2–6 weeks

Scenario re-run on existing model: hours to days

NOT RECOMMENDED WHEN

- ✘ Limited information exists on the ecological processes, organism responses, or environmental dynamics relevant to the study system.
- ✘ Decision timeline is under 2 weeks and no prior model exists
- ✘ Risk question can be answered adequately by static benchmarks

05

Your GoFish ABM Roadmap

A practical guide for building your own ABM for fish

Six steps to build an ABM with GoFish

1

Define your agents

What are the key state variables? Species, size, age, energy, behavior flags.

2

Describe the environment

Spatial extent, patch resolution, time step. What physico-chemical variables matter?

3

Write behavioral rules

Plain language first. If you can't write it, you can't code it.

4

Identify GoFish modules

Which submodels fit your organism and system? Start with movement + metabolism.

5

Build incrementally

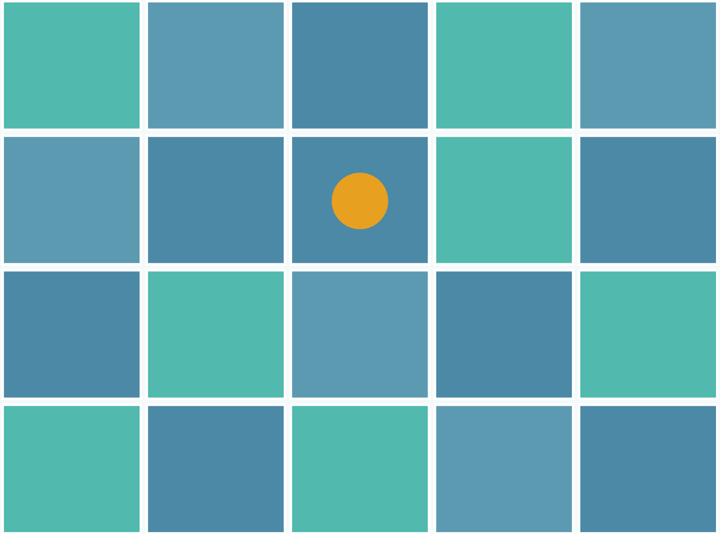
One module at a time. Test each for plausible outputs before combining.

6

Look for emergence

What population patterns arise? Do they match what you know about your system?

Does spatial and temporal explicitness matter?



Even **simple models can effectively represent core ecological mechanisms** and system behavior.

Spatially and temporally explicit models add context by identifying **when, and where** those processes emerge.

Heterogeneous risk

Not all locations have the same risk at the same time — position at each time step could matter

Environmental Conditions

Contaminants are suspended at different times — when a fish is somewhere matters as much as where

Behavioral state

Different behaviors performed at the same place and time can produce very different ecological outcomes and risk exposure.

Data Requirements: Coupling GoFish to USACE Models

Minimum Information Needed

Ecological Understanding of:

- Organism behaviors and movement patterns
- Environmental responses and stressors
- Key ecological or physical processes
- System interactions relevant to the management question

Information sources may include:

- Literature and conceptual understanding
- Field observations or monitoring
- Existing environmental models
- Telemetry or biological datasets
- Expert knowledge or agency experience

Simple vs. Complex Models

Simple Models:

- Conceptual understanding of ecological processes
- Literature-derived behavior or physiology
- Generalized environmental conditions
- Expert knowledge or field observations
- Simplified or hypothetical scenarios

Spatially and Temporally Explicit Models:

- Hydrodynamic or hydrological model outputs
- Remote sensing and spatial habitat datasets
- Time-varying environmental conditions
- Infrastructure and restoration scenario layers
- Telemetry, monitoring, or field validation data
- Contaminant, sediment transport, or water quality fields

Future Directions

ABM automation development, expanded species libraries, and process modules for USACE applications

ABM Automation

- AI-assisted generation of modular ecological submodels
- Rapid deployment of species and system-specific ABMs
- Accelerates scenario testing for restoration and management questions
- Supports scalable ecological decision-support workflows

Species Libraries

- Expanding modular frameworks beyond fish to broader ecological systems
- Reusable behavioral and environmental modules across taxa and habitats
- Shared repositories support cross-district collaboration and model reuse
- Enables scalable comparison of management and restoration scenarios

New Process Modules

- Movement, connectivity, and barrier interaction dynamics
- Reproduction and life-history behaviors across taxa
- Disturbance response to infrastructure, noise, and human activity
- Climate and environmental stress adaptation processes

Thank You

Questions & Discussion

ACKNOWLEDGEMENTS

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GoFish Link

https://vmahan1998.github.io/GoFish/

Agent-based models help evaluate how ecological responses emerge under changing environmental and management conditions relevant to USACE projects.

Vanessa.M.Quintana@erdc.dren.mil
Vanessa.M.Quintana@usace.army.mil