A Proposed Framework for Analyzing Water Quality and Habitat Effects on Aquatic Living Resources of Chesapeake Bay

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• Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response

• Independent report from STAC

• Three supporting documents

• Testa, J. M., Dennison, W. C., Ball, W. P., Boomer, K., Gibson, D. M., Linker, L., Runge, M. C., & Sanford, L. (2023). *Knowledge gaps, uncertainties, and opportunities regarding the response of the Chesapeake Bay estuary to proposed TMDLs.*

• Rose, K., Monaco, M. E., Ihde, T., Hubbart, J., Smith, E., Stauffer, J., & Havens, K. J. (2023). *Proposed framework for analyzing water quality and habitat effects on the living resources of Chesapeake Bay.*
Context

• Many reasons to relate water quality and habitat changes to living resources
  
  o Valued by stakeholders and society
  o Restoration is costly
  o Realistic and feasible targets and goals
  o Ecological and economic efficiency (“reckoning”)
  o Expectations
  o Adaptive management
  o Winner and losers
1 Introduction

2 Why now?

3 Management Questions that Could Be Answered

4 Existing Links Between WQ/Habitat & LR
   4.1 Assessing Progress of Restoring LR of the CB
   4.2 Example of Analyses for CB Living Resources
      4.2.1 Habitat-based Assessment
      4.2.2 Statistical Analysis of LR Monitoring Data
      4.2.3 Living Resource Models

5 LR and Other Large-scale Restoration Efforts
6 Going Forward

7 Proposed Framework

7.1 Complex Life cycles and life history strategies
7.2 Variability, uncertainty, and stochasticity
7.3 Model complexity
7.4 Vital rates
7.5 Habitat suitability and capacity
7.6 Biological organization
7.7 Nonequilibrium theory and baseline
7.8 Multiple Influencing Factors
7.9 Tradeoffs (win-lose), Win-win, and Lose-lose
7.10 Power to detect responses
7.11 Explicit and implicit representations
7.12 Relative versus absolute predictions
8 Strategic determination of an analysis plan
  8.1 Selecting species
  8.2 Available Data
  8.3 Response and explanatory variables
  8.4 Biological, temporal, & spatial scales
  8.5 Analytical approaches
  8.6 Coordination and combining results

9 Final comments

10 Acknowledgements

11 References
Feasibility – Chesapeake Bay

• Historical focus on water quality

• Productivity and highly valued

• Information and data rich

• Many scientists = a lot of past and ongoing activities

• Done at other large-scale restoration efforts

• Q: How would we go about doing this (daunting) task?
Context

• TMDL

• 2025 assessment

• Not reaching some goals - why?

• Expectations
Historically

• Statuary lever is CWA
  – DO, nitrogen, chlorophyll

• Extensive analysis with lab data to derive WQS
  – Covered the entire Bay

• 2012 Agreement
  – Added many living resources goals
  – “in-situ” conditions
Chesapeake Bay is not alone!
Evaluation of the Predictive Ecological Model for the Edwards Aquifer Habitat Conservation Plan: 
An Interim Report as Part of Phase 2

Committee to Review the Edwards Aquifer Habitat Conservation Plan
Water Science and Technology Board
Division on Earth and Life Studies

The National Academies of
SCIENCES • ENGINEERING • MEDICINE
Question: Spending billions on restoration in the US and yet so many are unhappy
Proposed best modeling practices for assessing the effects of ecosystem restoration on fish

Kenneth A. Rose a,*, Shaye Sable b, Donald L. DeAngelis c, Simeon Yurek d, Joel C. Trexler e, William Graf f, Denise J. Reed g

Recommendations on the Use of Ecosystem Modeling for Informing Ecosystem-Based Fisheries Management and Restoration Outcomes in the Gulf of Mexico


D. Holzworth, J. Myskak, J. Reichl, R. Seppelt, T. Wagener, and P. Whitfield

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Dynamics, Management, and Ecosystem Science

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Strategies for Selecting Fish Modeling Approaches

Report: Version 1
Date: October 31, 2013
Prepared by: Kenneth A. Rose, Shaye Sable

Dynamic Solutions

The Water Institute of the Gulf
Management Questions

• What is the expected (projected) response of living resources to water quality and habitat conditions in the Bay:

  (a) without the TMDL and habitat targets

  (b) present TMDL and habitat attainment continued

  (c) under full TMDL and habitat goals
Management Questions

• Given the current state or condition, how can the analyses inform what types and magnitude of changes in water quality and habitat are needed to evoke an agreed-upon target set of the desired living resources’ responses?

• What are the certainties and critical uncertainties of the analyses and how can they help guide future monitoring and modeling efforts?
Continued Status-Quo

- Provides much useful information on progress

- Focused on the first question
  - WQ
  - Habitat goals reached
  - Simple population status indicators

- Comprehensive approach - answer all questions

- Status-quo → moderate → major → comprehensive
  - More relevant questions and answers
  - Tradeoff is effort and uncertainties
Existing links WQ/Habitat to LR

- WQS
- Agreement indicators
- Report cards
- Others
Existing links WQ/Habitat to LR

- Seitz et al. 2009
- Woodland et al. 2021
- Adamack et al. 2017
- Fulford et al. 2010
- Ihde et al. 2016

- Monitoring data
- WQ modeling system
- Habitat $\rightarrow$ population $\rightarrow$ food web
Existing links WQ/Habitat to LR

• Many completed analyses
  – Excellent
  – Independent

• Species, methods, spatial/temporal coverage vary

• Addressed study-specific questions
  – Not “TMDL” and CBP habitat restoration
Different Situation to “WQ”

• Many critters move

• Affected by many factors in complex life cycles

• Responses are on longer time scales

• Challenging to isolate responses
Going Forward
Foundational Concepts: Examples

• Variability, uncertainty, stochasticity

• Vital rates
  – Growth, mortality, reproduction
  – Movement

• Model complexity
Foundational Concepts: Examples

• Habitat suitability and capacity
  – What is habitat?
  – How does it relate to abundance?

• Biological organization
  – Life stages (recruitment)
  – Population
  – Multi-species and Food web

• Complex life cycles and strategies
Foundational Concepts – Life Cycles

Life History Classification of Animals
Winemiller and Rose (1992)

A) OPPORTUNISTIC

The opportunistic life history combines low juvenile survival, $l_0$, low fecundity, $m$, and early maturity, $\alpha$.

B) PERIODIC

The periodic life history combines low juvenile survival, $l_0$, high fecundity, $m$, and late maturity, $\alpha$.

C) EQUILIBRIUM

The equilibrium life history combines high juvenile survival, $l_0$, low fecundity, $m$, and late maturity, $\alpha$.

Fig. 12.21 in Molles 2006


Potter et al. 2015
Foundational Concepts: Examples

• Multiple Stressors and Influencing Factors
  – Ocean conditions
  – Fisheries management
  – Climate change

• Tradeoffs
  – Win-lose
  – Win-win
  – Lose-lose

• Nonequilibrium theory and baseline
Foundational Concepts – Nonequilibrium Theory

- Classic Stability
- Bounded Stability
- Episodic Stability
- Regime Shift
- Shifting Baseline
Foundational Concepts: Examples

• Power – ability to truly distinguish differences

• Relative versus absolute predictions

• Explicit and implicit representations
Foundational Concepts – Explicit vs Implicit Representations

• Turbidity not in model but can assess its effects

• Formulations
  – Implied in the model so can still answer questions
  – Bridge calculations

• Do not believe labels

• Aside: Define habitat
Lessons Learned

Proposed best modeling practices for assessing the effects of ecosystem restoration on fish

Kenneth A. Rose\textsuperscript{a,*}, Shaye Sable\textsuperscript{b}, Donald L. DeAngelis\textsuperscript{c}, Simeon Yurek\textsuperscript{d}, Joel C. Trexler\textsuperscript{e}, William Graf\textsuperscript{f}, Denise J. Reed\textsuperscript{g}
Framework

• Uses the results of the watershed and estuary
  – Types, timing, locations, magnitude
  – WQ and habitat

• Describes how to translate these changes into responses of living resources
  – Habitat suitability
  – Recruitment, population
  – Stages in subregions
  – Food web
Framework

• Clearly show the linkages
  – Long-lived, complex life cycles
  – Affected by other factors than TMDL

• Realistic expectations

• Interpretative guide
  – Generally
  – Case-by-case basis

• Someone could actually implement the framework
  – Step-wise
Living Resources: Framework

1. Selecting species
2. Available data
3. Response and explanatory variables
4. Biological, temporal, and spatial scales
5. Analytical approaches
6. Coordination and combining results
Living Resources
Laboratory, Tolerances, Spatial Distributions, Seasonal, Status & Trends

WQ Criteria
Designated Uses

Vital Habitats
Wetlands, stream health, brook trout, fish passage, SAV

Sustainable Fisheries Goals
Blue crabs, oysters, forage, invasives

TMDLs

Restoration Actions

Temperature
River-flows
Primary productivity
Climate
Seasonal, Inter-annual, Spatial
Chesapeake Bay

Assessment of the Degree of Attainment of WQ Criteria
DO, Chl-a, Clarity/SAV
Ambient or Predicted Water Quality in CB

Assessment of Improvements in habitats targeted for restoration
Wetlands, Streams, Passage, SAV
Ambient or Predicted Habitat in CB

Blue Crabs, oysters, forage

Responses of species with goals
Ambient or Predicted Living Resources in CB

External Factors
Food Web
Climate

Rivers – Bay – Shelf
Harvest

Feedback and Adaptive Management
Figure 11. Example of a formal process for integrating and synthesizing information analysis results to assess the responses of the ecosystem to restoration. (from Diefenderfer et al. 2016).
Final Comments

• We know the question(s)

• Incentive (demand?) and ingredients are available
  – “most studied estuary in the world”
  – Other restoration programs are assessing LR response

• Leverage existing analyses; identify new analyses

• Follow the framework, we can add analyses
  – “meta-methods”
  – “meta-results”
Final Comments

• Living Resource Modeling & Assessment WG

• Assessment of LR responses and likely responses
  – “expectations”

• Use it to “optimize” WQ and habitat efforts
  – “inverse problem”

• Start with feasibility using low hanging fruit
  – “test the waters”