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Scenario Analyses in Ecological Modeling and Ecosystem Management

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OVERVIEW: Ecosystem management and restoration practitioners are challenged with complex problems, diverse project goals, multiple management alternatives, and potential future scenarios that change the systems of interest. Scenario analysis aids in forecasting, evaluating, and communicating outcomes of potential management actions under different plausible conditions, such as land-use change or sea level rise. However, little guidance exists for practitioners on the utility and execution of scenario analysis. Therefore, this technical note highlights the usefulness of scenario analysis as a tool for addressing uncertainty in potential project outcomes. The mechanics of the scenario-analysis process are explained, and examples of different types of scenario analyses are described for context on the breadth of its use. Lastly, two hypothetical case studies of scenario analysis in ecological modeling are presented showing a semiquantitative approach for assessing anadromous fish and a quantitative approach examining freshwater mussel habitat. Overall, this technical note provides a brief review of the utility and application of scenario analyses in the context of ecological modeling and ecosystem management decision-making.

INTRODUCTION TO SCENARIO ANALYSIS: In simple terms, scenario analysis can be defined as a method for exploring alternative futures and trajectories in systems. Scenario analysis is also a powerful tool to evaluate how potential project outcomes compare to each other by incorporating qualitative and quantitative factors in the system of interest. This tool may be used to assess complex systems by considering possible effects of a situation (for example, potential management alternatives); trend (for example, seasonal or long-term weather variability); or phenomenon (for example, stochastic atmospheric events) (Peterson, Cumming, and Carpenter 2003, 359–60; Yuan et al. 2017, 513–19). Scenarios can describe different formulations or hypotheses for a system of interest or explore how a system may be altered under different driving forces. Alcamo and Henrich (2008, 17–19) describe three purposes and uses of environmental scenario analysis: (1) education and public information to teach, raise awareness, inform, and consult with experts, stakeholders, or the public; (2) science and research during assessments, exploration, and speculation processes; and (3) decision support and strategic planning for collective inquiry, advocating for change, long-term planning, and policy making.

Scenarios can be used in project planning and decision-making to comprehensively and transparently analyze and compare possible outcomes under different management actions. We use the term *scenario* to refer to futures of a system under a well-defined set of management alternatives, including both action and no action. In general, scenario analysis is used in ecosystem management projects to provide clarity by allowing decision makers to assess trade-offs between alternative futures or management actions.

Scenario analyses can be conducted qualitatively, semiquantitatively, or quantitatively. A qualitative scenario analysis can represent multiple views of stakeholders and multidisciplinary experts presented in the form of diagrams, phrases, narratives, or outlines (Alcamo 2008, 124). Similar to conceptual modeling, qualitative scenario analyses may be used as a communication tool when presenting a project to stakeholders who are unfamiliar with the system or the analytical tools used for modeling. However, a qualitative scenario analysis does not provide the numerical information often required for choosing from potential alternatives; therefore, a quantitative analysis may be needed for many applications. Quantitative scenarios are commonly based on computer models, where scenario assumptions are represented in alternative model structures (that is, equations, coefficients) or inputs. Trade-offs in quantitative analysis typically occur among the need for model construction and interpretation of results (Alcamo 2008, 125–26). An intermediate between qualitative and quantitative analysis is semiquantitative analysis that includes a descriptive narrative with numbers without formal mathematical models. Notably, all types of scenario analysis can be used in the same project for different purposes. For example, qualitative and semiqualitative scenario analyses can be used to help project planners and scientists map out potential outcomes and use lessons learned to guide a quantitative analysis.

Ecological models are often used in scenario analyses because of their ability to quantify complex ecological interactions. Ecological models are simplified numerical representations of ecological systems designed to estimate ecological response of potential project-related activities. When comparing modeled scenarios, results are most often compared in a relative manner to outcomes generated from the same model because of the assumptions built into the model. A detailed description of modeling assumptions is beyond the present scope, but briefly, the conceptual and quantitative structures of a model are built on a set of assumptions unique to that model, thereby limiting the inference that can be made when comparing to other models (Ford 1999). For example, an ecological model for an endangered species population that assumes constant birth and death rates for all habitat patches will estimate a very different probability of extinction from a model with birth and death rates varying between patches.

The purpose of this document is to

- highlight the utility of scenario analysis as a tool for addressing uncertainty
- describe a repeatable set of steps for executing scenario analysis
- review examples of scenario analysis with a focus on environmental applications
- present two example applications of scenario analyses in water resource planning

MECHANICS OF SCENCARIO ANALYSIS FOR ECOLOGICAL MODELING: Here, we describe a process for conducting scenario analysis, which is largely adapted from Peterson, Cumming, and Carpenter (2003) and augmented by US Army Corps of Engineers (USACE) sea level rise guidance (USACE 2011) as well as our experiences with USACE project planning. The process generally benefits from engaging multidisciplinary stakeholders (including technical expertise and community members) in the development of ecological models, scenarios, or both, and the process may be iterative or adaptive to a variety of planning needs and contexts. Although beyond this scope, the role of stakeholders cannot be overemphasized, as they can shape key aspects of the entire process, such as expected outcomes from models, key features of models, the types and structure of scenarios, and interpretation of scenario modeling outcomes.

The following seven steps (adapted from Peterson, Cumming, and Carpenter 2003, 360–63) describe the process of building and executing scenario analyses. Figure 1 presents these steps as a generalized scenario-analysis workflow. It is important to note that, although a scenario analysis can be simply a method for exploring potential outcomes in a system, Steps 1–3 must be well defined prior to conducting an analysis.

1. *Identification of the decision problem*—Scientists and practitioners should determine the main focal issues, goals, and objectives, as these direct all subsequent analyses.
2. *Assessment*—All components of the decision problem should be identified and evaluated from an early stage, including individuals, institutions, organisms, ecosystems, and associated relationships.
3. *Formulating a question*—Depending on the decision context and qualitative assessment, a question should be generated regarding the future of the system under evaluation. This question should be specific and objective enough to guide development of scenarios and alternatives to be evaluated.
4. *Identification of alternatives*—After evaluating forces driving system dynamics, alternative actions may be developed to solve the decision problem relative to the desired outcomes. Alternatives analysis alone may be a type of scenario analysis.
5. *Building scenarios*—Scenario development is the process through which scenarios are constructed and elaborated on. Scenarios should be considered as components that may change in a system (for example, sea level rise) or potential levels of project outcomes (for example, worst- and best-case scenarios).
    a. *Articulate different narratives about the system*—Write down how the system works in the present and historically when possible.
    b. *Identify system components*—List the main drivers of change in this system (for example, biological, physical, chemical, or social components).
    c. *Link system dynamics*—Identify relationships between system components and focal outcomes of the decision problem.
    d. *List possible futures in scenarios*[*]—Qualitatively describe scenarios and pinpoint how scenarios affect system components and dynamics represented in model.
    e. *Match possible future scenarios with management actions*[†]—Connect management actions identified in Step 4 with scenarios listed in Step 5d.
    f. *Build a qualitative model*—Conceptually map system components into a qualitative model that will serve as a guide for a quantitative model (if needed). This map could be formatted as a narrative, table, diagram, or conceptual model. List and describe key assumptions.
    g. *Develop quantitative input parameters for each scenario*[‡]—Translate information from previous steps into measurable parameters for each scenario in the format of model inputs (for example, increase in agricultural land becomes a 20% increase in row crop area).

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[*] A scenario analysis can include just scenarios, just management alternatives, or a combination of both.

[†] See above.

[‡] Steps for building a quantitative model are not needed if only qualitative models are used.

h. *Build a quantitative model**—Use qualitative models and quantitative input parameters to build or apply quantitative models for each scenario. Document key assumptions.

6. *Identification of potential outcomes*—Outcomes should then be identified in combination with the scenarios to assess how actions could change under each different scenario.
7. *Evaluating outcomes*—Plausible alternative and scenario outcomes should then be evaluated depending on their ability to address the initial decision problem. For instance, USACE guidance on sea level rise (USACE 2011) suggests two possible methods for evaluating scenarios: (1) identifying a preferred alternative for a single scenario or (2) comparing all alternatives and scenarios.

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* See above.

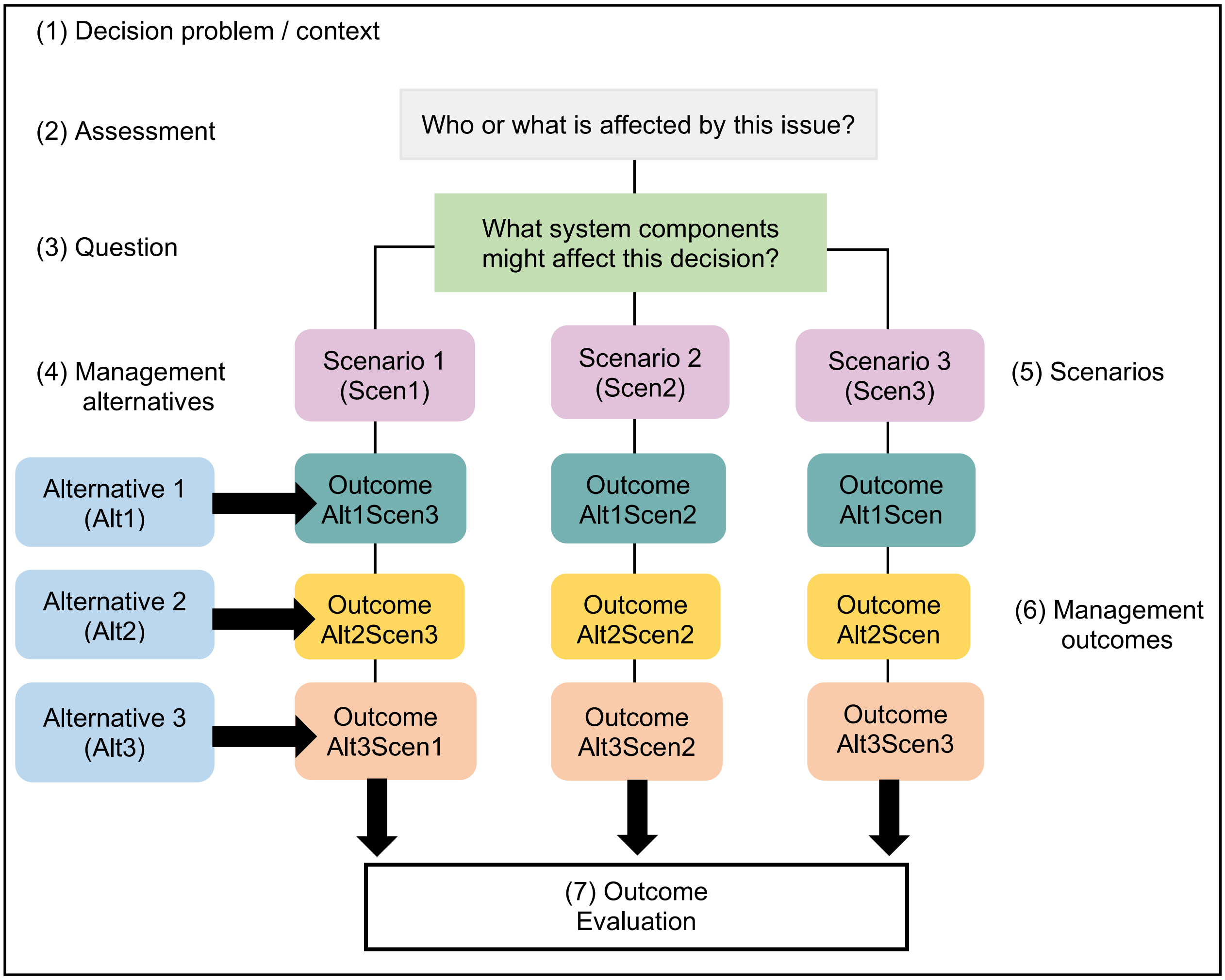

Figure 1. General diagram of a scenario-analysis workflow. Each Step (1–7) is numbered to match the process of conducting a scenario analysis modified from Peterson, Cumming, and Carpenter (2003).

LIMITATIONS OF SCENARIO ANALYSIS: Scenario analysis does not predict system futures but rather helps analysts explore and describe what might happen in systems (Schultz et al. 2011, 1–2). It is simply another tool for collecting information to make informed decisions. Scenario analysis provides transparency and aids decision-making, but additional analyses are often needed to understand potential adverse effects and account for uncertainties. However, scenario analysis can still provide initial insights into potential uncertainties in processes and models as well as highlight key risks.

Risk and uncertainty analyses add crucial information to further assist decision makers' choice of the most appropriate management strategies. In general, *uncertainty* can be defined as a lack of information or confidence in the information available (see detailed review by Ascough et al. 2008). Some types of uncertainties include *knowledge uncertainty* (for example, data error and correct input parameters and models) and *variability uncertainty* (for example, inherent randomness of nature and human bias). Knowledge uncertainty can be addressed by using sensitivity analysis to test the influence of key parameters and assumptions on outcomes (Schultz et al. 2011, 3–4). Once scenarios are built and modeled, additional risk analyses may be conducted to explore potential negative effects of scenarios and management alternatives (see USACE risk-informed planning guidance in Yoe and Harper 2017).

EXAMPLES OF SCENARIO ANALYSES IN ECOLOGICAL MODELING: Scenario analysis is a particularly valuable tool when assessing future projections in complex ecological systems and applied-management problems. This technique helps bridge communication between scientists, stakeholders, and project managers from multiple disciplines; it improves public understanding of ecology; and it aids in evaluating the future of complex ecological systems (Bennett et al. 2003). Here, we present three classes of complex ecological problems where scenario analysis has been coupled with ecological models to improve decision-making or reduce uncertainty: socioecological systems analysis, climate change, and biodiversity conservation (see also Table 1).

Socioecological systems. Governments and policymakers are increasingly using the concept of *ecosystem services* to protect natural resources that benefit human well-being. Scenario analysis provides a mechanism for informing management decisions by evaluating management actions that protect or restore ecological resources that in turn benefit people (Martinez-Harms et al. 2015). The Millennium Ecosystem Assessment (MEA, 2005) provides a large-scale example of scenario analysis of ecosystem services, where four scenarios were developed to explore features of global change (for example, policy, technology, trade, economy, security) and socioeconomic factors that drive change (for example, population growth, land-use change, pollution) in ecosystems services (for example, water, food, air quality, recreation). Findings from the MEA sought to inform policy development at regional and global levels that would mitigate negative impacts of global change on ecosystem services. Importantly, ecosystem-service scenario analyses can also be conducted at smaller scales (for example, national, regional, provincial). For instance, Bohensky, Reyers, and Van Jaarsveld (2006) explored possible futures of ecosystem services in the highly altered Gariep River Basin in southern Africa and reported plausible futures qualitatively in a narrative form.

Climate change. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science of climate change, its impacts and future risks, and options for adaptation and mitigation. For decades, the IPCC has used scenarios to describe alternative futures and associated climate consequences. The IPCC constructs qualitative scenarios on greenhouse gas and aerosol precursor emissions using different narratives representing divergent demographic, social, economic, technological, and environmental components in scenarios (Nakicenovic et al. 2000). These qualitative scenarios are then translated into quantifiable parameters, and ultimately climate scientists build global climate change models to project the scenarios. In addition to direct application for climate assessment, these scenarios and models have been examined in hundreds of ecologically relevant analyses ranging from hydrologic change to species habitat-range assessments. For instance, IPCC scenarios and associated general circulation models were used to determine the impacts low stream flows would have on the River Thames (Diaz-Nieto and Wilby 2005).

Table 1. Select examples of scenario analyses in ecological modeling and ecosystem management.

Project	Goals for scenario analysis	Example scenarios
Millennium Ecosystem Assessment (MEA 2005; Nakicenovic et al. 2005)	• To explore plausible futures for ecosystems and human well-being • To inform decisions makers about development, response strategies, and policy to mitigate or adapt to change	• Low human population growth and high economic growth • Low economic growth rates and high human population growth • Economic growth increases gradually and population near to highest • High economic growth rate and midrange population growth
Ecosystem services in the Gariep River Basin, southern Africa (Bohensky, Reyers, and Van Jaarsveld 2006)	• To explore futures for ecosystem services and human well-being • To compare regional scenarios with global scenarios	• Increases in industrialization, urbanization, income disparities • Fair trade, technology, intensive and organic farming, conservation, ecotourism • Social class disparities, environmental decline, lack of access to water rights, reduced industrial activity • Local conservation, self-reliant community • Enforcement of national environmental standards
Urban change in Algarve, Portugal (Vaz et al. 2012)	To combine urban growth with multicriteria evaluation for strategic and sustainable development	• Business as usual • Ecological interest • Economic interest
Climate Change in the Thames River (Diaz-Nieto and Wilby 2005)	To project future changes in river low flows	• Comparison of baseline period (1961–1990) to out years (2020, 2050, 2080) • Medium-low precipitation change • Medium-high precipitation change
Global Biodiversity Scenarios for the Year 2100 (Sala et al. 2000)	To rank important drivers of biodiversity change, calculate expected change of drivers in each biome and produce scenarios using drivers and expected changes	• Levels of interaction among drivers of biodiversity change: ○ No interaction ○ Antagonistic interactions ○ Synergistic interactions
Biological ensemble modeling to evaluate potential futures of living marine resources (Gårdmark et al. 2013)	To study long-term response of the Eastern Baltic cod to alternative fisheries management scenarios under different climatic regimes	• Intensive fishing • Less fishing • Increasing temperature, decreasing salinity • No further climate change

Biodiversity conservation. Complex questions about natural resources, land-use change, and biodiversity may also be assessed with scenario analysis to inform sustainable development. For instance, Sala et al. (2000) used scenario analysis to understand drivers of global change across 10 biomes and long timescales. At more local scales, policy maker concerns and economic history (qualitative data) were combined with remotely sensed land-cover imagery and cellular automata models to inform strategic development for tourism in Portugal, which combined qualitative and quantitative approaches to develop robust scenarios (Vaz et al. 2012). Scenario analysis has also been used to address complex natural resource management issues alongside climate change, such as Gårdmark et al.'s (2013) simulation of Eastern Baltic cod populations in response to combinations of changes in salinity, temperature, and fishing pressure.

APPLICATIONS OF SCENARIO ANALYSES FOR HYPOTHETICAL US ARMY CORPS OF ENGINEERS (USACE) PROJECTS:

Semiquantitative example: Anadromous fish. As explained above, scenario analyses may be qualitative or quantitative. Figure 2 demonstrates a hypothetical qualitative scenario analysis case in the form of a bubble diagram. Guided by the scenario analysis steps described in the section above, and the workflow in Figure 1, a group of decision makers and stakeholders evaluated potential project alternative outcomes under different scenarios. The following steps describe how the group conducted the scenario analysis:

- *Decision problem* (Step 1)—The project focused primarily on habitat restoration for anadromous fish under three different hydrological scenarios.
- *Assessment* (Step 2)—Organisms involved were sensitive and endangered anadromous fish in a northwestern United States watershed affected by the proposed management decisions and non-project-related changes in the system. Target groups of stakeholders were federal, state, and local agency researchers and practitioners, communities surrounding the watershed, and recreational fishers.
- *Question* (Step 3)—This focal question guided the analysis: how do hydrological changes driven by effects of climate change affect the ecological outcomes of the management alternatives in this restoration project?
- *Management alternatives* (Step 4)—They identified increasing river connectivity at all dams and reforesting 100 m of riparian buffer as their potential alternatives. A no-action plan was included to compare ecological outcomes relative to the current state of the ecosystem.
- *Building scenarios* (Step 5)—Scenarios of plausible futures independent of management actions were then constructed using historical data from rain gauges surrounding the watershed (that is, a decrease in precipitation, no change in precipitation, and an increase in precipitation) and the following substeps to build scenarios:
    - *Narratives about the system*—Historical data showed an overall decrease in water levels and longer periods without precipitation.
    - *System components*—Main components of interest were listed as anadromous fish populations, water availability, percent habitat connectivity, precipitation, water quality, and riparian buffer zones.
    - *System dynamics*—Relationships between components were thought out as water quality affected by precipitation, connectivity, and buffer zones. Specifically, assumptions were made that improving water quality and connectivity would increase anadromous fish populations.
    - *Futures in scenarios*—Potential scenarios from precipitation change were an increase in precipitation, a decrease in precipitation, or no change in precipitation and how these changes would affect the water quality and connectivity.

  - *Future scenarios with management actions*—Scenarios were linked to management actions in the following ways: increasing buffer zones to improve habitat quality under the three precipitation scenarios and increasing fish passage by removing dams and therefore increasing habitat connectivity and quality under the three precipitation scenarios.
  - *Built a qualitative or semiqualitative model*—A semiqualitative model (Figure 2) was built by constructing a bubble chart to project possible outcomes of habitat quality changed as ecological outputs that change depending on the three precipitation scenarios and three management actions.
- *Graphed potential outcomes* (Step 6)—Potential ecological outcomes from the alternatives and scenarios were plotted in the bubble chart (Figure 2). Relevant outcomes are explained in the text below.
- *Evaluated outcomes* (Step 7)—During the outcome evaluation, stakeholders asked whether these alternatives or scenarios improved the habitat quality of anadromous fish. They also assessed trade-offs between alternatives under different scenarios to come up with the informed recommendations for the project execution.

Figure 2 shows how management actions (y-axis) affect overall habitat quality (*Hab*) and connectivity (*Con*), represented by changes in bubble size (ranging from ≤20% to a 100% change). These changes were evaluated under the three different scenarios (Figure 2*A–C*) within the project's lifetime (x-axis; 0–25 years). Under a decrease in precipitation scenario (Figure 2*A*), the no-action plans would result in a reduction of quality and connectivity over time because of potential drying and fragmentation. However, increasing buffer and connectivity might result in higher ecological outcomes than the no-action plans in most cases. However, the effects of increasing buffer on connectivity (*Buffer Con*) would have no apparent change in ecological outcomes and resulted in similar outcomes to the no-action plan for connectivity.

Under the *no change in precipitation* scenario (Figure 2*B*), the stakeholders evaluated the effects of only the management actions over time. Increasing passage connectivity increased both overall habitat quality and connectivity over time. Increasing riparian buffer had a positive effect in ecological outcomes of habitat quality (*Buffer Hab*), but increasing riparian buffer had no effect on connectivity (*Buffer Con*), which is expected under a scenario of no change in precipitation or decrease in precipitation.

The *increase in precipitation* scenario (Figure 2*C*) showed the stakeholders that this hydrological change would have gradual negative effects on habitat quality over time under a no-action plan, possibly because of increased bank erosion and scouring. However, connectivity would still increase under the no-action plan, because this scenario would cause a higher potential to naturally create new side channels and increase the habitat area overall increase. Increasing riparian buffer would improve outcomes of habitat quality compared to the no-action plan, because this scenario would help control bank stabilization and erosion. Comparisons can also be made between scenarios where for example, a decrease in precipitation (Figure 2*A*) generally shows fewer benefits in ecological outcomes of the different management alternatives than an increase in precipitation (Figure 2*C*).

Overall, this scenario analysis allowed stakeholders and decision makers to acquire more information on their system of interest and evaluate the effects that potential management actions and the hydrological scenarios would have on anadromous fish habitat. Management actions that were closer to their project goals and objectives were separated from those that did not meet their goals. A quantitative ecological model was then used for further scenario analysis to provide more information on the recommended actions.

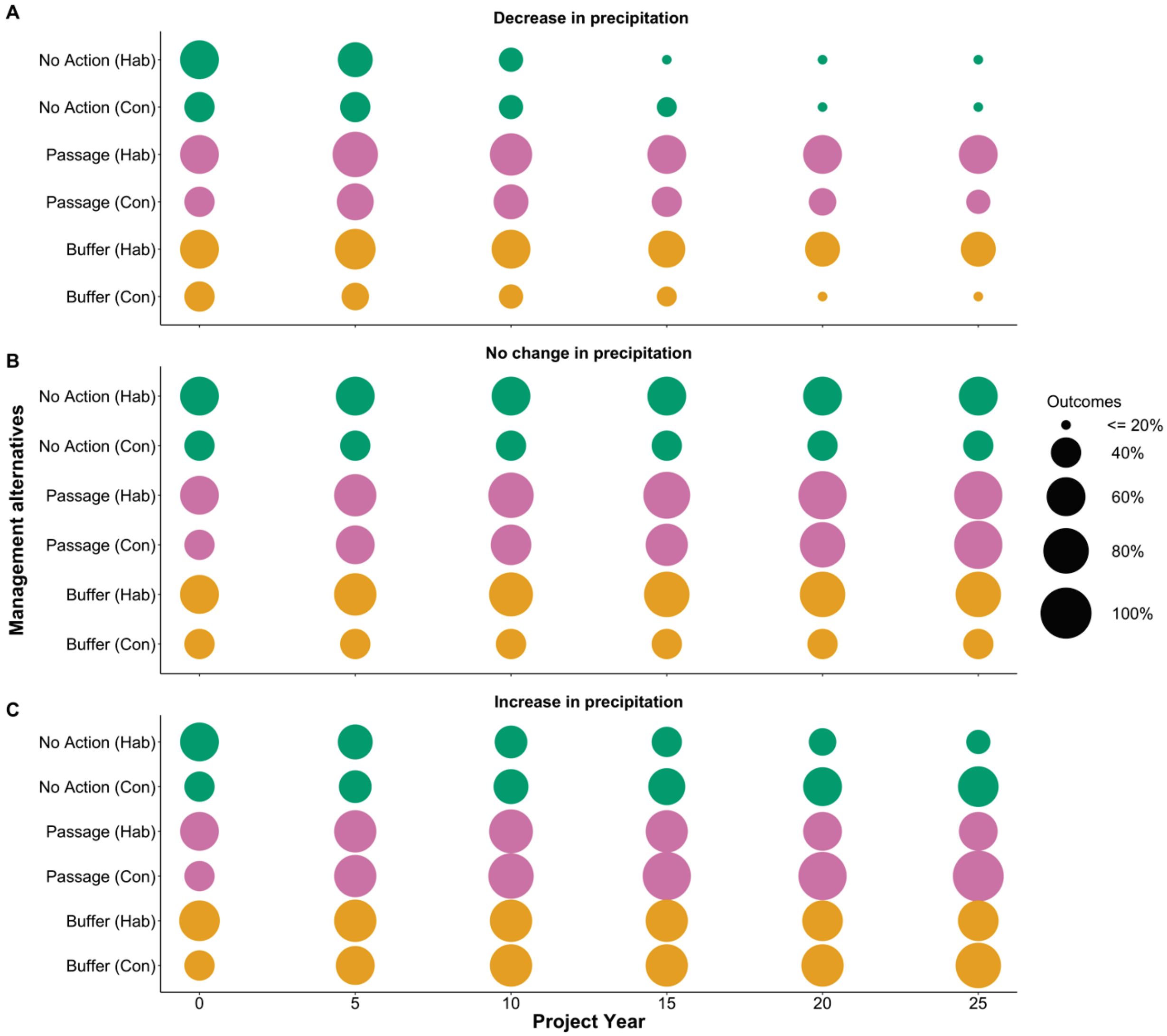

Figure 2. Semiqualitative example of a scenario analysis for a restoration project for a northwestern United States watershed anadromous fish habitat.

Quantitative and example freshwater mussel habitat model. A quantitative scenario analysis approach can be conducted through computational ecological modeling tools. During the USACE planning process, an ecological model is required to assist in recommending a proposed ecosystem restoration plan. The following steps were considered when creating this model:

- *Decision* (Step 1)—Develop a general standard freshwater mussel model that can be used in different areas and for different projects to decrease the cost and labor associated with building a new model for each new project USACE needs when dealing with mussel habitats.
- *Assessment* (Step 2)—A stakeholder workshop that included US Army Engineer Research and Development Center (ERDC) and USACE mussel experts was held to discuss and develop a general model flexible enough for countrywide application; sensitive enough to distinguish between proposed freshwater mussel restoration actions or measures; containing parameters that reflect system-level functions, structures, or processes that provide suitable habitat for freshwater mussels; and applicable in an efficient manner.
- *Question* (Step 3)—How will different USACE ecosystem restoration activities affect not only the mussel species but also other sensitive species in the region?
- *Alternatives* (Step 4)—The alternatives were assessed by how the habitat suitability index (HSI) increases or decreases with changes in the individual variable HSI ratings.
- *Scenarios* (Step 5)—Scenarios were decided on during the workshop and included different environmental parameters. This step includes the substeps below:
    - *Narratives about the system*—This system is an important aquatic habitat for fish and some species of federally endangered freshwater mussels.
    - *System components*—The main components of interest in this system were aquatic cover, substrate, temperature for both adult mussels and juvenile mussels, flow regime, connectivity, and fish species richness (number of fish species in the area).
    - *System dynamics*—Each component was considered an important dynamic in the system because each component contributed to suitable or unsuitable habitats for both fish and mussel species.
    - *Futures in scenarios*—Potential scenarios included increasing the different components to create a more suitable habitat for mussel species.
    - *Future scenarios with management actions*—Scenarios were linked to achieving obtainable habitat suitability by measures such as increasing connectivity between waterbodies (for example, removing dams upstream), adding suitable substrate, increasing the number of fish species to act as hosts, and increasing aquatic cover (that is, increasing the shade over the water or adding stumps to the streambed to act as fish and mussel gathering areas).
    - *Built a qualitative or semiqualitative model*—A quantitative model was developed as a result of the workshop that could test multiple different scenarios and cast predictions for the lifetime of the project (50 years).
- *Potential outcomes* (Step 6)—Potential outcomes were derived from communication among the workshop participants as ranges in HSI that would be considered acceptable for a proposed ecosystem restoration
- *Evaluation*—Evaluation is to be completed after the model has been completed and the total HSI has been evaluated.

The freshwater mussel model (Figure 3) was conceptualized during a workshop between members of ERDC and USACE mussel experts to be general enough to be applied for a wide variety of projects located throughout the range of freshwater mussels, including lentic and lotic systems. The parameters chosen during the workshop (connectivity, diversity, structure, water, and function, Figure 3) are critically important for freshwater mussel species and would be influenced by the implementation of proposed restoration plans.

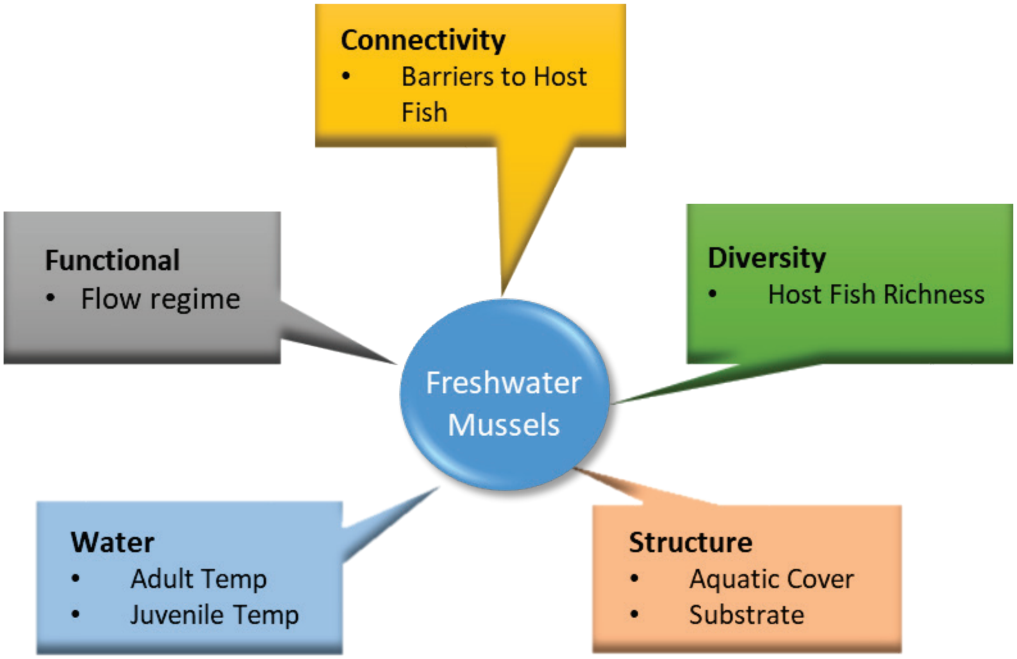

Figure 3. Freshwater mussel conceptual model showing parameters chosen for the implementation of the numerical freshwater mussel model.

Each parameter has its own set of equations to determine the individual HSI. As the ecosystem becomes more suitable for mussel populations, the overall HSI will get closer and closer to 1. The Meramac River in Missouri was used as a case study to run scenario analysis. The baseline input for parameters was determined to be the conditions that currently exist in the area, year 0 of analysis. The two scenarios that were tested were a future without project (FWOP) and future with project (FWP). Scenarios were evaluated over a 50-year project horizon. Figures 4 and 5 are line graphs showing changes in HSI values (y-axis) over time (x-axis) for FWOP (Figure 4) and FWP (Figure 5) scenarios. The FWOP (Figure 4) consisted of doing no restoration to the area and allowing the environment to continue degrading and potentially resulting in complete loss of suitable habitat for mussels. The FWP (Figure 5) consisted of improving the habitat conditions by adding stumps in the streambed, removing dams to increase connectivity, and creating a more suitable substrate. Data for the baseline and future conditions for each model parameter were estimated by stakeholders during model workshops. Once parameterized, the model was run, and an overall HSI was calculated per time steps 0, 1, 5, 10, 25, and 50 years over the period of analysis. The FWP (Figure 5) has higher habitat suitability than the FWOP (Figure 4). The FWP

(Figure 4) option projects a gain in environmental benefits (for example, habitat suitability) and potentially an increase in ecosystem services such as biodiversity.

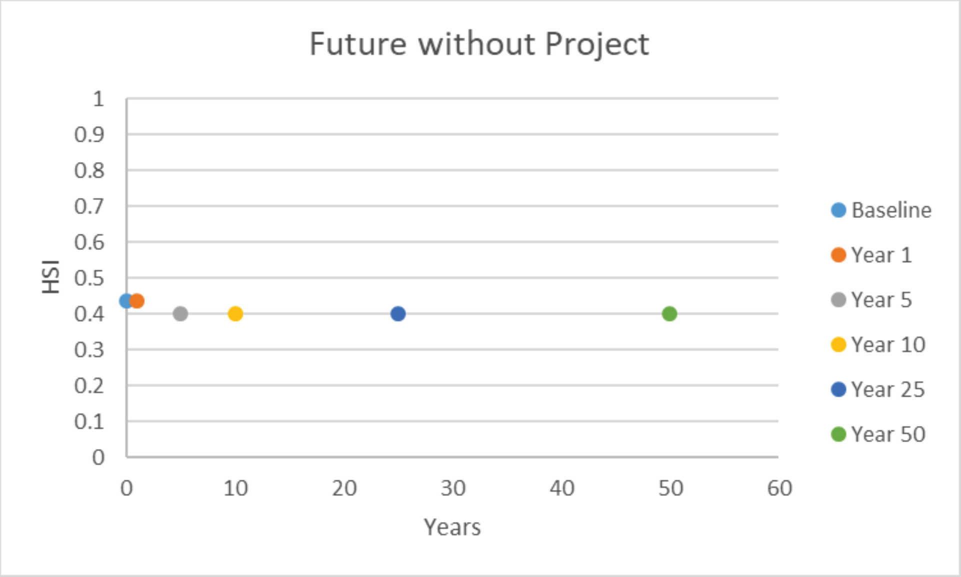

Figure 4. Future without project (FWOP) scenario for proposed ecosystem restoration for freshwater mussel habitat.

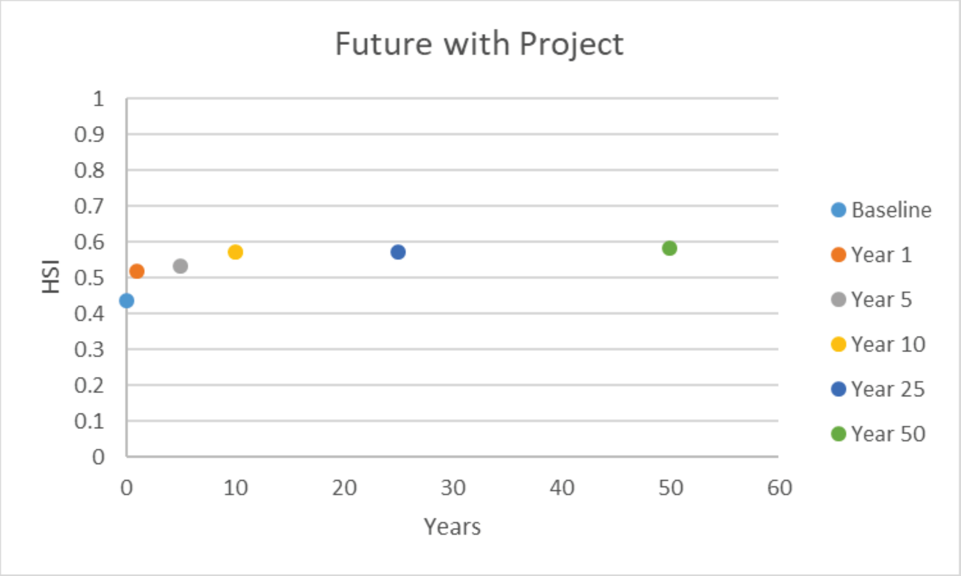

Figure 5. Future with project (FWP) scenario for proposed ecosystem restoration of the Meramac River for freshwater mussel habitat.

CONCLUSION: Scenario analyses compare potential project outcomes and aid the determination of future strategies and actions for different projects. Scenarios are potential changes in a system under a set of different anthropogenic (for example, restoration or conservation alternatives, urbanization) or natural alterations (for example, meteorological, geological, biological). A scenario analysis can provide an integrated and timely understanding of emergent conditions and help to avoid regret and belated action (Hamilton et al. 2013).

Scenario analyses can be conducted quantitatively, semiquantitatively, or qualitatively, but all must follow seven general steps. First, a focal (1) *problem* must be identified. All components in the system affected by the problem must then be (2) *assessed* and a guiding (3) *question* on the scenarios and alternatives evaluated must be formulated. Next, (4) *alternatives* on potential measures that can be taken to target the problem must be identified. Different (5) *scenarios* must then be constructed to represent changes in a system, and the possible (6) *outcomes* of these changes would look like must be identified. Finally, the potential scenario and alternative outcomes must be (7) *evaluated* to determine how they would affect the initial problem. It is important when doing these analyses to make sure the main problem to be tackled is what is being examined in different scenarios. Agreeing on the number of scenarios being tested, either agreed on by the customer or all stakeholders, in advance will give the best results. Following these seven steps will result in the best possible scenarios being chosen as a final decision in the overall project objective.

Scenario analysis allows us to make better sense of the system and make more informed decisions, but it has some challenges. The nature of our work in forecasting and making decisions using incomplete information will always include uncertainty. Our goal is to best understand that uncertainty and decide whether it alters the decisions we make (at least in feasibility). There is also a tendency to view scenarios as having equal probability, yet models with the appropriate data can show some scenarios have higher probabilities than others. Variable levels of uncertainty means scenarios with a spatial dimension require additional assumptions. Being transparent in communicating assumptions when building scenarios is imperative to others understanding and evaluating outcomes.

Many fields use scenario analysis to determine the best outcome for a certain problem. In this technical note, we briefly discussed the utility of scenario analysis in evaluating ecosystem services and socioecological systems; global scenarios under the effects of climate change; and different natural resources, land use, and biodiversity changes. We also demonstrated how scenario analysis can be used by USACE projects when evaluating ecological outcomes either semiqualitatively (that is, anadromous fish conceptual diagrams) or quantitatively (that is, using the HSI model for freshwater mussels) to plan future projects, evaluate alternatives and communicate with multiple stakeholders involved in the project life cycle.

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