# Best Practices for the Development and Application of Quantitative Models for the Conservation and Management of Fish and Wildlife Species

Quantitative models of species population dynamics and species distributions have been widely applied in the management of fish and wildlife species in North America. Certain quantitative modeling approaches, including population viability analyses (PVAs), species distribution models (SDMs), climate vulnerability assessments, and climate-envelope models, are increasingly viewed as useful tools for addressing certain questions relevant to the management and conservation of rare and declining fish and wildlife species, including estimating species population trajectories, current and future geographic distributions, and responses to climatic changes. New modeling techniques and approaches continue to proliferate with rapid advances in analytical tools and availability of geospatial data at higher resolutions. At the same time, there has also been a corresponding increase in the number of organizations, academic institutions, and government agencies expressing interest in providing modeling expertise to fish and wildlife managers. With the increased interest in modeling population trajectories and distributions of species, the Science and Research Committee of the Association of Fish and Wildlife Agencies has developed the following set of best practices and principles for state fish and wildlife agencies to consider when deciding how and whether to apply these models to their species conservation and management efforts.

## PROBLEM DEFINITION AND SELECTION OF MODELING APPROACH

Identify and clearly state the problem or question that needs to be addressed, including identifying the species or populations involved as well as the geography and spatial/temporal scale of the problem.

Review available modeling approaches which may be suitable for addressing the particular problem or question, and identify the underlying assumptions, data requirements, and potential limitations of each approach.

Compare the biological needs of the species with the available geospatial data to determine whether a model is even possible, and to identify shortcomings of any potential modeling effort. Determine what degree of certainty is needed to adequately address the specific problem or question, and the relevant timeframe by which information is needed.

Determine whether a quantitative modeling approach is appropriate for addressing the particular problem or question. Are there alternative approaches (e.g. non-quantitative models or expert input) which could address the question or problem at hand? Is a quantitative model even needed, and, if the answer is yes, are suitable quantitative modeling approaches available?

Identify whether the datasets needed for a proposed modeling approach are available, or whether they can be obtained within the available temporal and financial constraints.

If a quantitative model is needed, determine what modeling approach(es) will help to address the question at hand. Work with modeling experts to choose modeling methods and data that will be appropriate for the species, geography, and spatiotemporal scale of the problem or question. Engage biometricians and statisticians as appropriate. Consider how different modeling approaches and modeling structures may affect the outcomes of modeling exercises. Comparison of outputs from multiple models may be necessary, especially in cases of particular uncertainty.

Review the underlying assumptions inherent in the available modeling approaches, translating mathematical relationships in the models into statements about species biology, in order to identify inherent shortcomings and limitations of the potential modeling approaches before modeling begins.

## PROCESS OF MODEL DEVELOPMENT

Use collaborative processes that engage species experts and modeling experts when selecting modeling approaches, designing models, reviewing and select data sources, and interpreting results.

Engage relevant species experts early and continually throughout the process of model development to ensure models reflect the biological realities of the system of interest.

Engage modeling experts who have appropriate training and expertise in the modeling approach that has been selected.

Identify other key groups and stakeholders who have relevant expertise or knowledge regarding the species and should be involved in some or all aspects of model development and interpretation.

Account for, document, and carefully consider how to manage potential biases among the members of the modeling team, particularly if organizations or individuals involved in the effort have a vested outcome in particular outcomes or results.

Be aware of assumptions built into the model, how the data may violate those assumptions, and how violating assumptions can affect ecological inference.

Carefully document all data sources, hypotheses, processes, models, methods, model outputs, and results for future reference, review, and replication. Consult with information technology and data management personnel regarding reproducibility and archiving of relevant data and analyses.

## DATA SELECTION

Identify best available data sources for use in the model. Review literature, contact species experts, contact regional and local GIS experts to identify potential data sources. Carefully review available data sources for relevance and appropriateness. It is highly unlikely that any one source will have all relevant data. From the available data sources, select datasets that are appropriate for the particular modeling approach which has been selected, and which will help to address the question(s) at hand at a biologically meaningful and relevant spatial scale.

Clearly document which of the model inputs are empirical data, which are derived from other models, and which are based on expert judgment.  For empirical datasets, document precision, accuracy, and variance from sampling and from natural processes.

Input data will affect model results.  Carefully review and evaluate all input data to avoid common modeling problems and issues. Practices that will help to avoid such problems include:

- Include available biologically relevant data layers for the species of interest and use caution in including data layers which do not have clear biological relevance.
- Minimize chronological mismatch between datasets (e.g., old species data points and current land cover data).
- Minimize scale and resolution mismatch (e.g., comparison of high-resolution point data with land cover polygons mapped at coarser scales).
- Perform adequate quality assurance/quality control checks on input data.
- Conduct robust data discovery efforts to identify available data from all available sources and avoid sole sourcing of data; this is a particular issue with species occurrence data but certainly applies to other forms of data as well.
- Consider other common attributes often inherent in rare species data, including:
    - Small sample sizes and small number of sites sampled.
    - Short or non-continuous time series.
    - Incomplete or inadequate sampling, especially during the first pilot year of a new sampling regime, and biased sampling.
    - Failure to distinguish between detection-non-detection and detection-only species occurrence data.
    - Spatial autocorrelation, which can result in spurious covariate effects.
    - Tendency of rare species experts to focus their sampling on the highest-quality sites in surveys.  Through natural processes (e.g. vegetation succession) these sites often will become lower in quality over time. Declines at well-sampled sites may not reflect population trends for the species overall.
- Account for variance and covariance in model-input datasets, including:
    - Separate sampling variance from variance due to natural processes.
    - Account for random and/or natural fluctuations in abiotic and biotic factors through time.
    - Recognize and account for spatial and temporal autocorrelation among variables.

## REVIEW OF FINDINGS

Review modeling outputs collaboratively, engaging species experts and modelers in joint discussions.  Ask if the model outputs make sense, given what we know about the species' biology and distribution.

Subject the modeling process and model outputs to independent peer review by individuals with relevant expertise to assess the robustness and validity of the modeling effort.

As time and resources permit, perform and report sensitivity analyses and appropriate statistical tests to determine the robustness of model results and provide error estimates and confidence intervals for all key modeled values and outputs.  Particularly test the sensitivity of modeled results to certain input values such as those based on expert judgment, early values in time series, and other inputs likely to be associated with higher degrees of uncertainty.

As part of the review of the model outputs, consider differences between types of data (e.g., presence-absence and presence-only species occurrence data) and what that means for model interpretation. Collaborate with statistical experts to understand inferential differences and biases associated with alternative modeling approaches.

As time and resources permit, conduct validation studies and tests (e.g. additional field surveys) to determine model accuracy.

## APPLICATIONS OF MODEL RESULTS

Communicating model results to appropriate audiences is a critical step and will likely require careful guidance in interpretation of model results, understanding sources and degrees of uncertainty, and appropriate methods for representing and applying model results in decision-making.

Be creative and learn to communicate complex model results in a simple and efficient manner. Often target audiences are not as concerned about the minutiae of the modeling process as they are in a well-crafted summary of the key findings and results.

Be prepared to defend the modeling process and model results against uninformed or misguided critiques. Be prepared to acknowledge limitations and areas of uncertainty inherent in the model, modeling process, and results.

Model outputs are not determinative. Remember the famous quote from George E. P. Box: “All models are wrong, some models are useful.” Models and their outputs can differ from reality for many different reasons, even in cases when the model indicates a high probability of a certain outcome. Therefore, it is important to avoid making decisions solely on the basis of "the model tells us so." Models can help inform decisions through structured decision-making processes, but models and modeled outputs should not be the only source of information for a particular decision.

Models can be dynamic; as new data are collected and data sources with greater spatial/temporal resolution become available, data can be reanalyzed, allowing for adaptability in the modeling process. Adaptively managing the process of modeling can help to facilitate risk assessment, improve monitoring programs, and evaluate conservation and management alternatives.

Take into account all other relevant data in addition to the model outputs when making a decision, including other information and conclusions found in the peer-reviewed scientific literature, other published and unpublished data and assessments, external expert judgments and reviews, and also economics and other socio-political factors as appropriate. Encourage the presentation of model outputs in formats that allow the use of models in subsequent analysis. (e.g., retain full raster files (.img, .tif), after jpegs are produced for publication, and include metadata).