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

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ABSTRACT

Large-scale aquatic ecosystem restoration is increasing and is often controversial because of the economic costs involved, with the focus of the controversies gravitating to the modeling of fish responses. We present a scheme for best practices in selecting, implementing, interpreting, and reporting of fish modeling designed to assess the effects of restoration actions on fish populations and aquatic food webs. Previous best practice schemes that tended to be more general are summarized, and they form the foundation for our scheme that is specifically tailored for fish and restoration. We then present a 31-step scheme, with supporting text and narrative for each step, which goes from understanding how the results will be used through post-auditing to ensure the approach is used effectively in subsequent applications. We also describe 13 concepts that need to be considered in parallel to these best practice steps. Examples of these concepts include: life cycles and strategies; variability and uncertainty; nonequilibrium theory; biological, temporal, and spatial scaling; explicit versus implicit representation of processes; and model validation. These concepts are often not considered or not explicitly stated and casual treatment of them leads to mis-communication and mis-understandings, which in turn, often underlie the resulting controversies. We illustrate a subset of these steps, and their associated concepts, using the three case studies of Glen Canyon Dam on the Colorado River, the wetlands of coastal Louisiana, and the Everglades. Use of our proposed scheme will require investment of additional time and effort (and dollars) to be done effectively. We argue that such an investment is well worth it and will more than pay back in the long run in effective and efficient restoration actions and likely avoided controversies and legal proceedings.

1. Introduction

Large-scale aquatic ecosystem restoration is increasingly being used to offset or compensate for impacts made to the environment (Bullock et al., 2011; Suding, 2011). Prominent examples include the removal of dams on the Klamath River to enhance salmon populations (US DOI, 2012), ensuring sufficient freshwater flows for biota in the Everglades (NRC, 2012a) and the California Delta (NRC, 2012b), reducing nutrient loadings to improve water quality in the Chesapeake Bay (NRC, 2011), and offsetting the losses of wetlands in coastal Louisiana (Peyronnin et al., 2013). Because of the large magnitude of the restoration actions needed and their broad spatial extent, these large-scale projects are considered expensive and often controversial. Recent restoration plans are estimated at about 25 billion dollars over the 50 years for the California Delta (CADWR, 2013), 13 to 15 billion dollars to Maryland alone for the Chesapeake Bay (Gray, 2013), and 20 to 50 billion dollars for the Louisiana coast-wide plan (Peyronnin et al., 2013). Actions as part of the recovering the Delta smelt, a U.S. Federally endangered species,

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in the California Delta have been debated in Federal court (McKinley et al., 2011) as a result of the uncertainty in the effectiveness of restoration actions and their high monetary costs associated with restoration resulting in limitations on water exports for human and agricultural use (NRC, 2010).

An extreme case of a modeling melt-down was the salmon life cycle population analyses done for evaluating the removal of the dams on the Klamath River (US DOI, 2012). One of the population models was removed from consideration just before a peer review panel meeting (Atkins, 2011), how the conclusions of a review panel were subsequently reported by a federal agency was reviewed by another panel (Atkins, 2012), and staff scientists in a Federal agency litigated against their supervisor based on their involvement with a salmon population model (Nature Newsblog, January 9, 2013).

While there are many aspects to restoring the ecosystem services of these restoration projects, the focus often gravitates to the responses of fish and shellfish (referred to as fish here). This is because of the recreational and commercial value of some of the fish species, their listing as endangered under the Endangered Species Act, and because trends in fish abundances (often indices) are visible to the interested public. The controversy arises because fish species have complex life cycles and can be difficult to monitor, and thus predicting their responses using modeling is necessary but also highly uncertain (Rose, 2000). Often, only certain life stages are within the influence of the restoration actions so that long-term trends in abundances can be greatly influenced by factors outside of the influence of the restoration. Also, many restoration projects result in changes to the environment that have multiple effects on the vital rates of the fish. For example, restoring hydrology can affect the water quality, productivity of the food base, access to certain habitats, and changes to physical habitat that provide shelter. These changes to the habitat and food can, in turn, have a complex mixture of effects on fish via affecting their growth, mortality, reproduction, and movement. In addition, restoration actions often occur in a subset of the habitats inhabited by the organisms.

Given the complexity of the situation, a common approach is to use habitat suitability indices (HSI) to assess restoration effects on fish (e.g., Fuller et al., 2008; Nyman et al., 2013). HSI modeling has many advantages but also some key weaknesses (Ahmadi-Nedushan et al., 2006; Draugelis-Dale, 2008; Elith and Burgman, 2003; Gore and Nestler, 1988; Roloff and Kernohan, 1999). The main advantage to a habitat-based approach is that one avoids the challenges in modeling fish population and community dynamics, which is subject to debate about the model formulation, is data-intensive, and can be highly uncertain. Habitat is critical to healthy and productive fish populations, and so determining how “restoration actions” will affect habitat relative to “no action” is an important step toward quantifying the ecological benefits to fish of restoration actions. HSI models are also relatively easy to understand and explain. The major disadvantage to habitat-based approaches is simply that they quantify habitat, which may or may not be directly correlated to fish abundance and provides little information beyond changes in habitat capacity for certain life stages.

In some situations, there is pressure from stakeholders and others to go beyond habitat suitability to predicting the abundance and biomass responses of fish species in order to justify the restoration actions (i.e., changes in habitat capacity from HSI are not sufficient). Models of fish population and community dynamics can, in theory, be used to assess the net population responses by attempting to account for the full life cycles and the complex suite of effects on certain life stages and in certain areas (Rose et al., 2009). How fish models that are used to assess the large-scale effects of restoration are selected, implemented, interpreted, and reported therefore becomes especially critical to ensure the credibility of the restoration decisions that rely on the modeling results.

One challenge is that fish modeling is a scientific process that involves the judgment of the modeler. While this is true of all modeling, it is particularly apparent with fish and ecological modeling. Other modeling disciplines also involve judgment but usually the judgment is more focused on the details. For example, statistical modeling uses data to determine which model is best, and debates gravitate to details on which data transformation to use and determining outlier points. All hydrodynamics models solve the same basic set of fundamental physics equations (i.e., conservation of mass and continuity of momentum), and the major judgment decisions are how to set up the model grid and how to deal with subgrid scale processes (e.g., turbulence). Fish modeling often does not have sufficient data to identify the optimal model formulation, and fish modeling does not have fundamental equations like hydrodynamics. Thus, decisions about the level of detail of processes to include in fish models get pushed more toward the judgment of the modeler (i.e., “the art of modeling”). The strong role of the modeler’s judgment in fish modeling does not weaken the power and utility of fish modeling, but does make model selection and implementation more challenging to document and justify.

In this paper, we present a scheme of best practices for using models to assess fish responses to restoration actions. While there have been multiple “best practice” schemes proposed for ecological modeling in general (e.g., Jakeman et al., 2006), our experience is that none of them alone are sufficiently tailored for use with fish and restoration. We first summarize previously proposed modeling best practice schemes as a basis, and then present our version for fish modeling applied to restoration projects. We also describe a set of concepts about fish modeling that are often at the center of misunderstanding and controversy. We propose that combining our version of the modeling steps with these concepts would build consensus about the fish modeling and thereby lead to more effective and less controversial restoration decisions. We illustrate several of the key steps and concepts using our experience with coastal Louisiana, Florida Everglades, and the Colorado River. While our focus is predicting the effects of restoration on fish, these steps can be easily applied to other taxa and ecological modeling that deals with evaluating future scenarios. We conclude with a discussion of the importance of using best practices, and some additional advice about how to implement the best practices framework.

2. Steps in best modeling practices

2.1. Previously proposed schemes

The idea of specifying a series of steps that would promote and encourage successful and informative ecological and environmental modeling has a long history. Often, the way ecological and fish model analyses are presented can create the appearance that the model was selected arbitrarily or in an ad hoc manner. Furthermore, usually only the final model structure, and a subset of the results of the final model, are presented. The analysis is then viewed in isolation, without the benefit of knowing how and why the particular model, from the many possible models, was selected and how decisions were made about its implementation and interpretation. Despite the appearances, models used by experienced modelers are never arbitrarily selected. There is a careful evaluation and thought process involved in selecting a model, implementing it, and reporting the results. However, this thought process and decision making is rarely sufficiently documented.

A variety of best practices schemes have been proposed. Schmolke et al. (2010) discussed ecological models supporting environmental decision making. They summarized from the literature the elements of good modeling practice: inclusion of stakeholders; clear formulation of objectives; development of a