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Identifying cost-effective invasive species control to enhance endangered species populations in the Grand Canyon, USA

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ABSTRACT

Recovering endangered species populations when confronted with the threat of invasive species is an ongoing natural resource management challenge. While eradication of the invasive species is often the optimal economic solution, it may not be a feasible nor desirable management action in other cases. For example, when invasive species are desired in one area, but disperse into areas managed for endangered species, managers may be interested in persistent, but cost-effective means of managing dispersers rather than eradicating the source. In the Colorado River, a nonnative rainbow trout (*Oncorhynchus mykiss*) sport fishery is desired within Glen Canyon National Recreation Area, however, dispersal downriver into the Grand Canyon National Park is not desired as rainbow trout negatively affect endangered humpback chub (*Gila cypha*). Here, we developed a bioeconomic model incorporating population abundance goals and cost-effectiveness analyses to approximate the optimal control strategies for invasive rainbow trout conditional on achieving endangered humpback chub adult population abundance goals. Model results indicated that the most cost-effective approach to achieve target adult humpback chub abundance was a high level of rainbow trout control over moderately high rainbow trout population abundance. Adult humpback chub abundance goals were achieved at relatively low rainbow trout abundance and control measures were not cost-effective at relatively high rainbow trout abundance. Our model considered population level dynamics, species interaction and economic costs in a multi-objective decision framework to provide a preferred solution to long-run management of invasive and native species.

1. Introduction

Endangered species recovery efforts sometimes focus on the reduction or eradication of invasive species that negatively impact recovery (Wilcove et al., 1998). While eradication has been possible in some situations (e.g., in isolated areas like islands, Ebbert and Byrd, 2002), it may not be a feasible nor desirable management action in other cases. In particular, limited budgets and/or beneficial economic, social, and biological effects stemming from the invasive species may preclude eradication as an optimal management action (Schlaepfer et al., 2011; Lampert et al., 2014). For example, resource users may favor maintaining an invasive species in areas adjacent to an area intended for endangered species conservation, and resource managers may focus on limiting the number of dispersing individuals. In these cases, the endangered species may require ongoing threat reduction to sustain viable populations in the wild.

An important consideration in ongoing endangered species management is the allocation of resources over time to meet species recovery goals. Species conservation strategies involves trade-offs between short- and long-run management actions, along with the potential for the reallocation of resources to alternative conservation objectives with higher return on investment (Polasky, 2008). An effective way to explicitly incorporate trade-offs in conservation planning is through the inclusion of economic costs (Naidoo et al., 2006; Polasky, 2008). Economic information can convey the opportunity cost of conservation, or the foregone benefit of undertaking an alternative conservation action, allowing comparison among competing conservation priorities over the period of analysis. This is particularly important when the dynamics of invasive species management for endangered species recovery may include a series of competing or complementary

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management actions over time.

Cost-effectiveness analysis—i.e., assessing how a given objective can be achieved at the least possible cost—is a useful tool for allocating resources for meeting endangered species recovery goals (Moran et al., 2010; Rose et al., 2016). Conservation objectives are typically set in accordance with societal goals, often embodied in legal directives governing actions of resource management organizations (Murdoch et al., 2007). In this context, when implicit social or economic valuation occurs as legislative bodies or other governing organizations establish endangered species protection goals, the act of minimizing costs maximizes the return on investment. Further, in the context of population abundance goals, cost-effectiveness analysis must be inherently dynamic, i.e. focused on the optimal allocation of management resources over time.

Cost-effectiveness analysis also has the characteristic of shifting the focus in the decision framework from justifying conservation ends (e.g., economic value of a species) to the various management actions available to best achieve conservation goals (Sagoff, 2009). This is an important distinction when stakeholders have different objectives or may fundamentally reject attempts to economically value aspects of ecosystem resources. In addition, cost estimates in conservation may be easier to generate than estimates of benefits (Naidoo et al., 2006). Therefore, cost-effectiveness analysis can provide a more suitable approach to endangered species conservation planning than benefit-cost analysis (which requires a much more comprehensive assessment of the benefits generated by species).

In this paper we developed a bioeconomic model to identify the least-cost management strategy to control invasive rainbow trout (*Oncorhynchus mykiss*; hereafter, RBT) subject to achieving juvenile humpback chub (*Gila cypha*; hereafter, HBC) survival targets. We modified established population models for RBT and HBC and utilized management cost information generated from long-term monitoring and research at the Grand Canyon Monitoring and Research Center (GCMRC) (Korman et al., 2012, Yackulic et al., 2014, Yackulic et al., In Press). We identify the least-cost management action given juvenile HBC survival targets, which supports long-run viability of the adult population over time. Further, we explore the sensitivity of the model across assumptions regarding RBT population parameters and risk preferences, and discuss the potential environmental conditions that would affect fundamental model assumptions and results.

2. Methods

2.1. Study area

This study is focused on the HBC habitat in the lower Little Colorado River (LCR) and its confluence with the mainstem of the Colorado River (mainstem) in Grand Canyon National Park (GCNP) (Fig. 1). HBC were widely dispersed in the mainstem prior to construction of dams and the introduction of invasive species (USFWS, 1994). Most HBC in LCR aggregation spawn in the lower 13.6 km of the LCR and a large portion of juvenile HBC disperse into and rear in the mainstem, with the majority of dispersal occurring between July and October (Yackulic et al., 2014). A variety of factors, including both biotic (i.e., interspecific and intraspecific interactions, food availability, etc.) and physical factors (temperature, turbidity, etc.) determine how many juvenile HBC survive into larger size classes (Yackulic et al., In Press); however, the roles of temperature (positive) and RBT (negative) have typically been the focus of management debate.

Glen Canyon Dam (GCD) impounded the Colorado River in 1963 for the primary purposes of water storage, flood control, and hydroelectric power generation (Bureau of Reclamation, 1995). Construction of GCD substantially altered the temperature, turbidity and flow regime of the mainstem (Schmidt et al., 1989). Following dam construction, RBT were introduced immediately downstream, creating a clear, cold-water sport fishery in an approximately 26 km reach of Glen Canyon, often referred to as Lees Ferry. Rainbow trout recruitment in the tailwater of the GCD (i.e., Glen Canyon reach) is driven by many factors, including within-day, seasonal and annual variation in flows from the GCD, and a proportion of RBT move downstream (Korman et al., 2012; Korman et al., 2015). Rainbow trout that move downstream along the mainstem to the LCR confluence prey on, and compete with, HBC (Yard et al., 2011) and increased RBT abundances are associated with lower survival of juvenile HBC (Yackulic et al., In Press).

In an effort to reverse declining HBC abundance, mechanical removal of RBT was performed from 2003 to 2006 and in 2009 (Interior, 2016). Mechanical removal involves boat electrofishing for RBT, which are subsequently processed (e.g., cleaned, frozen) for beneficial use outside of GCNP.[1] Humpback chub abundance appeared to increase following RBT removals; however, these increases coincided with two favorable changes in the environment from the perspective of HBC: warming mainstem temperatures and declining RBT numbers systemwide (Coggins Jr. et al., 2011). The GCMRC has continued to monitor and collect data on RBT and HBC, along with environmental conditions, since RBT removals began in the 2000s. Concerted juvenile HBC research beginning in 2009 allowed us to develop an empirically-grounded model to explore the ability of RBT removals to meet HBC long-run population recovery goals under historically demarcated periods of cold and warm mainstem temperatures. The bioeconomic model modified recent approaches to modeling HBC and RBT demographics and utilized existing empirical data to inform parameter estimates, as summarized in the Long-Term Experimental and Management Plan Final Environmental Impact Statement (LTEMP FEIS) (Interior, 2016).

2.2. Model framework

In our model, the manager's hypothetical objective is to identify the least-cost management strategy that reduces downstream RBT abundance to maintain long-term adult HBC (200 mm+) abundance. Since HBC have complex population dynamics and relatively slow growth in the colder mainstem, we used our understanding of HBC life history to translate this adult HBC abundance goal into a shorter-term annual juvenile HBC survival target. Specifically, we determined the annual juvenile HBC (40–100 mm total length) survival target required to maintain a long-term adult abundance of 7000 or greater (see below for specifics). Estimated abundance of adult HBC in the LCR aggregation has ranged from 5 to 11 thousand in the last several decades (Interior, 2016). We developed the bioeconomic framework by integrating HBC and RBT population dynamics with RBT control actions, where RBT populations are determined by stochastic recruitment in the tailwater of GCD and the manager's choice of up to 6 control actions in a year is a function of RBT abundance in the Juvenile Chub Monitoring (JCM) reach. The control action is comprised of mechanical removal to reduce RBT abundance from river kilometer 116.5 to 147.1 of the mainstem, near the JCM reach. Complete eradication of RBT in Lees Ferry is not considered given the undesirable loss of upstream recreational fishing. The RBT fishery has an estimated $2.6 million annual economic value (Bair et al., 2016), considerably greater than the cost of proposed RBT control actions. The population model schematic appears in Table 1 and population and management variable definitions and parameters are specified in Table 2 (See Appendix A for bioeconomic model code (R Core Team, 2016)).

2.2.1. Population model

The population model depicts the stylized dynamics, or simplified configuration of empirical findings, of RBT and HBC along a ~130-

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[1] Beneficial use is a mitigation action established during federal consultation with Native American tribes to address the live removal of fish during management actions in the Grand Canyon (Reclamation 2011). An example is the use of removed rainbow trout in the Pueblo of Zuni aviary.