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Trade-offs between socioeconomic and conservation management objectives in stock enhancement of marine recreational fisheries

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ABSTRACT

We used an integrated bio-economic model to explore the nature of tradeoffs between conservation of fisheries resources and their use for socioeconomic benefit, as realized through the stock enhancement of recreational fisheries. The model explicitly accounted for the dynamics of wild, stocked, and naturally recruited hatchery-type fish population components, angler responses to stocking, and alternative functional relationships that defined conservation and socioeconomic objectives. The model was set up to represent Florida's red drum (*Sciaenops ocellatus*) fishery as a case study. Stock enhancement produced strong trade-offs characterized by frontiers indicating that maximizing socioeconomic objectives could only be achieved at great losses to conservation objectives when the latter were based exclusively on abundance of wild-type fish. When naturally recruited hatchery-type fish were considered equivalent to wild fish in conservation value, this tradeoff was alleviated. Frontier shapes were sensitive to alternative assumptions regarding how conservation objectives were formulated, differential harvesting of stocked and wild-type fish, and potential inherent stakeholder satisfaction from the act of stocking. These findings make more explicit the likely opportunity costs associated with recreational stock enhancement and highlight the utility of trade-off frontiers for evaluating management actions.

1. Introduction

Management of recreational fisheries, like for most natural resources, is characterized by both conservation and socioeconomic objectives (Shea, 1998; Mardle and Pascoe, 2002; Walters and Martell, 2004). Conservation objectives might include valuing abundance of wild fish populations for inherent reasons (e.g., endangered species) or future benefits, including sustained harvests or yet-unrealized benefits (Cowx et al., 2010; Cooke et al., 2015). Alternatively, socioeconomic objectives commonly entail valuing a fish population for direct use—namely angler satisfaction related to catch or market activity related to fishing effort (McConnell and Sutinen, 1979; Propst and Gavrilis, 1987; Anderson, 1993). Over the long run these objectives are complimentary (Hilborn, 2007). In the short term they may conflict, since fish populations cannot be simultaneously maximally conserved and used (Sylvia and Cai, 1995; Koehn, 2010). This conflict can result in a present-time trade-off characterized by achieving short term socioeconomic objectives at the dissipation of the long term conservation objectives (Walters and Martell, 2004; Cheung and Sumaila, 2008). Selecting a satisfactory compromise between both objectives and identifying suitable management actions to realize it are thus the primary challenges of fisheries management (Walters and Martell, 2004). This challenge is acute in open access recreational fisheries. Here traditional management actions (e.g. size, bag limits) may be ineffective at controlling harvest or sustaining catch rates if captured and subsequently released fish are subject to substantial discard mortality (Coggins et al., 2007) or behavioral alterations (Camp et al., 2015). Direct control of fishing effort would be potentially effective, but is particularly unpopular with stakeholders and considered by managers to have a high socioeconomic cost (Sullivan, 2003; Dorow et al., 2010; McClenachan, 2013). To avoid these high costs while sustaining populations of fish, alternative management strategies are increasingly considered.

An alternative management strategy that restricts neither catch nor effort is stock enhancement: the release of hatchery-reared fish into waters containing wild populations of the same species (Lorenzen, 2005; Camp et al., 2014). Stock enhancement is widely used in the management of inland and increasingly, marine recreational fisheries (Richards and Rago, 1999; Halverson, 2008; Vega, 2011). The popularity of stock enhancement stems in part from the perception that this strategy can maintain or

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increase fish population abundance, catches, and fishing effort, and thereby alleviate trade-offs between conservation and socioeconomic objectives (Taylor et al., 2005). However, this should not be assumed (Lorenzen, 2014). Principally, trade-offs between conservation and socioeconomic objectives arise in stock enhancements because hatchery-reared fish may differ biologically from their wild conspecifics and may not be afforded the same conservation or utilitarian value as the latter. Biological interactions between hatchery-reared and wild fish may result in a reduction of the abundance of fish with wild characteristics, even when overall abundance of fish, catches and fishing effort are increased by the enhancement (Camp et al., 2014). To assess the nature of such tradeoffs requires considering at least three issues: (1) biological differences between wild fish, hatchery-reared fish and their naturally recruited offspring; (2) biological and fishing effort feedbacks by which stocking affects wild fish; and (3) the functional composition of socioeconomic and conservation objectives.

Hatchery rearing influences the biology of stocked fish through developmental and genetic mechanisms and often results in fish that are less fit in natural environments than their wild conspecifics and may also differ in their genetic diversity or structure (Lorenzen et al., 2012). Therefore, released stocked fish and their offspring are not, in general, fully equivalent to wild fish (Araki et al., 2008; Fraser, 2008). Once released, stocked fish (and eventually their offspring) may interact biologically with wild fish through competition, predation and reproduction (Weiss and Schmutz, 1999; Ham and Pearsons, 2001; Bell et al., 2008). Interactions may be particularly strong and immediate if stocked fish are released at small sizes because density dependent mortality is strongest in the early juvenile stages of the fish life cycle (Lorenzen, 2008; Camp et al., 2014). Exposure to density dependent processes may cause stocked and wild fish to experience increased mortality and may result in partial displacement of wild by hatchery-reared fish (Lorenzen, 2005). Differences between hatchery-reared and wild fish are at least in part genetically based and replacement may therefore persist for multiple generations, though natural selection will tend to restore wild traits and levels of fitness within a several generations (Quinn et al., 2001). Replacement of wild fish by hatchery-reared fish and their offspring may take place with or without any associated increase in total population abundance (additive or non-additive effect of stocking) (Rogers et al., 2010). If stocked fish augment overall fish populations, stocking can potentially translate into greater socioeconomic objectives via increased catch rates and related angler utility (Anderson, 1993; Schuhmann, 1998; Anderson and Lee, 2013) or increased effort and greater regional market activity (Hilborn, 1998; Camp et al., 2013). Even if enhancement does successfully augment overall fish populations in open-access fisheries, angling effort may increase in response and lead to greater fishing related mortality on wild fish (Baer and Brinker, 2010), or prevent increases in catch rates from persisting (van Poorten et al., 2011; Camp et al., 2014). Where they occur, such negative impacts on wild populations can be considered conservation costs of improving socioeconomic objectives (Camp et al., 2014), depending on the definition of those objectives (Lackey 1998; Hilborn 2007).

The capacity for any management action, such as stock enhancement, to address trade-offs between socioeconomic and conservation objectives ultimately depends on the characteristics of those objectives (Lackey, 2004; Koehn, 2010). Objectives can be functionally characterized by the relationships between objective value and changes in measurable outcomes, such as catch rate or wild fish abundance (Hilborn, 2007; Koehn and Todd, 2012). These functional relationships can be strongly influenced by societal perceptions and preferences (Lackey, 2003; Arlinghaus, 2005). For example, the value of socioeconomic objectives achieved via enhancement depends on the functional relationship between catch-related satisfaction and marginal increase in catch rates (Camp et al., 2013), as well as the strength of any inherent stakeholder preferences for or against stocking as a management action (Baer and Brinker, 2010; Arlinghaus et al., 2014). Similarly, the conservation value associated with stock enhancement largely depends on how society views wild versus stocked fish (Myers et al., 2004; Olaussen and Liu, 2011; Anderson and Lee, 2013), but also on the marginal values of each unit of wild fish (Cooke et al., 2015)—i.e. the value of one unit of wild stock over a range of stock sizes, from unfished conditions to extinction. While some societal preferences have been well studied, such as marginal increases in angler satisfaction from additional catches (Arlinghaus et al., 2014; Beardmore et al., 2015), others have not been, such as inherent preferences for management strategies or marginal value of wild fish (Holling and Meffe, 1996; van Poorten et al., 2011; Arlinghaus et al., 2014). In fact, fundamental goals, clear objectives and explicit, quantitative targets are often not well defined for the socioeconomic and conservation management of many recreational fisheries (Lackey, 1998; Walters and Martell, 2004; Cooke et al., 2015). This creates a real challenge for assessing trade-offs between objectives realized under certain management strategies, like stock enhancement.

One approach to assess how potential management actions address trade-offs between even implicit objectives involves using trade-off frontiers to visualize the relative socioeconomic and conservation opportunity costs—that is, what is sacrificed from one objective to achieve some amount of the other (Possingham and Shea, 1999; Walters and Martell, 2004; McNie, 2007). Relative opportunity costs can be characterized for a given strategy (e.g., stock enhancement) by assessing the conservation and socioeconomic outcomes realized under a range of implementations (e.g., number and size of fish stocked). Plotting these anticipated outcomes against each other on a plane visualizes the conservation and socioeconomic outcomes possible with specific implementations of the given strategy (Walters and Martell, 2004). The Pareto-efficient implementation options comprising the outermost points represent the "frontier" for a strategy (Sylvia and Enriquez, 1994; Cheung and Sumaila, 2008; Lester et al., 2013 Cheung and Sumaila, 2008; Lester et al., 2013). The frontier shape reveals something of the nature of the trade-off and has management implications (Walters and Martell, 2004; Cheung and Sumaila, 2008). A concave down shape suggests an opportunity cost-efficient compromise is possible (e.g., a certain size and number of fish stocked provides high conservation and socioeconomic outcomes relative to alternative stocking implementation). Alternatively, a concave up shape would suggest high opportunity costs of a compromise, such that the most efficient implementations would focus on achieving only one objective (Walters and Martell, 2004). While assessment of trade-off frontiers is not uncommon (e.g., Figge, 2004; Sanchirico et al., 2008; Gaydon et al., 2012), it has rarely been completed for recreational fisheries management strategies, and to our knowledge never with stock enhancement.

The overall objective of this work was to explore how stock enhancement might be expected to address conservation-socioeconomic trade-offs common to recreational fisheries. Specifically, we evaluated the nature of the trade-off frontiers realized with stock enhancement, and how these frontier shapes might be sensitive to alternative assumptions regarding the composition of objectives and the possible use of differential harvesting of stocked and wild fish. To accomplish this we used an integrated bioeconomic model to systematically assess socioeconomic and conservation outcomes of alternative implementations of stock enhancement, and used these outcomes to depict stylized trade-off frontiers. The results provide insights into the efficacy of stocking programs to simultaneously achieve economic value while maintaining conservation value associated with healthy wild stocks.