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Valuation of fish production services in river basins: A case study of the Columbia River

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ABSTRACT

This study uses a bio-economic model to assess the capacity of the Columbia River to provide a selection of four ecosystem services and estimates the actual use of those services in terms of net economic welfare. Our findings reinforce the observation that Columbia River habitat supports production of valuable fish species that provide: (i) food production from commercial fishing, (ii) recreational fishing, (iii) tribal subsistence fishing, and (iv) nutrient cycling services. Relative to the status quo, a 10% greater prioritization of salmon conservation via shifts in the flow regime would generate an increase of $4.8 million/yr in the net economic benefit from these services. A return to pristine flow conditions would raise this value to $19.5 million/yr. Re-prioritizing hydropower production to average 1976–1980 flow levels would result in a $3.5 million/yr loss of net economic benefits. Recreational fishing is the most important ecosystem service we assessed. Under some scenarios, this sector generates twice the value of the next largest sector (commercial fishing). Although managers have placed greater emphasis on fish conservation in recent decades, opportunities for gains in economic welfare from fish production in the Columbia River may not be fully exploited, particularly considering that our conservation scenario only minimally alters the flow regime relative to the hydropower priority scenario.

1. Introduction

The world's rivers provide numerous benefits to society commonly referred to as "ecosystem services". Capturing the total economic value (TEV) of these benefits can be a complex and uncertain task, but is nevertheless advocated by various researchers and can be used as a decision tool by resource managers (Pearce and Turner, 1990). The TEV of an environmental resource or ecosystem is the sum of its use and non-use values[1]. Non-use values are intrinsic to the resource and arise from the value people place on its existence. Use values arise from activities such as resource extraction, harvest, and recreation and more indirectly from various ecosystem services such as nutrient cycling, watershed protection or groundwater recharge. For example, rivers support fish populations, which are valued for use (e.g. commercial fishing, subsistence fishing, recreational fishing, nutrient cycling) and non-use (e.g. existence, cultural and spiritual) purposes (Daily, 1997).

In addition to fish production, river systems provide other services such as aesthetics, water supply for domestic and agricultural uses, water quality regulation, natural flood control (wetlands), opportunities for shipping and transportation, opportunities for recreation, and natural features that permit the construction of dams for hydroelectric power production and engineered flood control. Many of these uses compete with fish production systems, especially in larger rivers, and create tradeoffs among the various services that comprise the TEV of these rivers. For example, prioritizing hydropower development may cause fish production benefits to decline due to habitat degradation from blocked migration routes, or a less favorable flow regime. Hydropower is particularly relevant as it is increasingly attractive in many basins as a means to reduce greenhouse gas (GHG) emissions.

It is challenging for resource managers to assess such tradeoffs without some measure of value for each service. The total value of fish production services is particularly complicated to evaluate due to the range of non-use and use values as well as the need to

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[1] Many researchers also use the classification of ecosystem services according to the Millennium Ecosystem Assessment (2005), including provisioning, regulating, supporting, and cultural services. We chose to adopt the TEV framework instead.

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measure changes in production resulting from changes in habitat quality.

To support river managers' decision-making, we develop an approach for valuing several ecosystem services associated with fish production in any river basin where the natural hydrograph is significantly altered from its natural state by dams. As a case study, we use the production of Pacific Salmon (*Onocorhynchus* spp.) in the Columbia River Basin in the Pacific Northwest region of North America. We consider how changes in river management for hydropower production and salmon conservation affect: (i) productivity of Columbia River salmon populations, and (ii) resulting economic welfare implications for commercial fishing, subsistence fishing, recreational fishing and fish-related nutrient cycling.

Valuation of ecosystem services is a widely supported practice (Arrow et al., 1993), although standardized valuation of the full range of ecosystem services has proven difficult. Few studies focus on changes to net (rather than gross) economic welfare from fish production (Grantham and Rudd, 2015), including those caused by dam operations. Analyses that consider the impacts of hydropower production on fish production tend focus on only one or two ecosystem services provided by fish production (e.g. recreational fishing), and/or do not incorporate biological relationships linking salmon populations and altered flow regimes (Loomis, 1996; Douglas and Taylor, 1999; Layton et al., 1999).

There is general agreement among hydropower, flood control and conservation managers in the Columbia Basin that the altered flow regimes of the mainstem and major tributaries have had a substantive negative impact on salmon productivity (NPCC, 2014). However, to understand the resulting change in economic benefit from fish production, it is first necessary to establish a relationship between salmon survival and flow regimes at different stages of hydropower development. Our analysis draws on methods introduced by Knowler et al. (2003), including: (i) use of bio-economic modeling to estimate net economic benefits that are consistent with economic theory, rather than measuring only changes in revenue; (ii) estimation of general stock-recruitment relationships for basin-wide aggregate salmon populations (i.e. not just local streams and sub-populations); and, (iii) incorporation of habitat quality into the stock-recruitment relationship.

In this paper we estimate the value of the Columbia River salmon production system under four development scenarios that emphasize hydropower production and salmon conservation to different degrees. The primary objective of our evaluation is to assess how net economic benefits derived from Columbia River salmon change when habitat quality is altered to accommodate different management objectives and associated flow regimes[2]. We conclude with a discussion of results and potential improvements for future efforts.

2. Study area

The Columbia River is a large river in the Pacific Northwest region of North America that flows 2000 km from Canadian Rocky Mountains to the Pacific Ocean. It is the fourth largest river in the United States by volume and collects runoff from a drainage basin roughly the size of France (~671,000 km^2), spanning portions of seven American states (Washington, Oregon, Idaho, Montana, Wyoming, Utah, Nevada) and one Canadian province (British Columbia) (Muckleston, 2003).

The river's annual cycles are driven by thawing/melting of snowpack. Daily discharge at the river mouth averages 7504 m^3/s (265,000 cfs) but can be as high as 15,744 m^3/s (556,000 cfs) during peak floods in May/June[3] (FPC, 2015).

The Columbia Basin holds one of the most engineered river networks in the world with over 300 publicly and privately owned dams that provide flood control, irrigation, hydropower production, navigation, and recreation opportunities. Fourteen of these dams are located directly on the river's mainstem. A key location on the Columbia is The Dalles, Oregon, which is the standard reference point for mainstem flow measurements dating as far back as 1878 and is the focal point for measuring habitat quality in this study (see Fig. 1).

3. Methods

In this section we detail the methods used to produce our valuation results when habitat quality is altered to accommodate different management objectives and flow regimes.

3.1. Scenario development

We focus on impacts of hydropower and flood control as the primary sources of development affecting salmon production in the Columbia River It should be noted however that Huppert et al. (2004) concluded that there might be "some negative effects on fisheries and passive use values tied to salmon and steelhead runs" (p. viii) if water diversions for domestic and agricultural water supply were to increase. We select four indicator services for evaluation based on the following criteria: (i) expected economic significance; (ii) data availability; and, (iii) feasibility in terms of available valuation methods. The services thus selected include commercial fishing, subsistence fishing, recreational fishing and salmon-related nutrient cycling.

We also assume economic welfare changes are associated with change in the primary sector only and we do not consider post-harvest processing or related downstream industry impacts. We adapt the approach from Knowler et al. (2003), which is consistent with welfare measurement, where habitat quality is an input to production, and where our model is based on stock estimates for a fishery managed for constant adult spawner exploitation and escapement. Applying these assumptions, we begin with an initial level of habitat quality and salmon survival under status quo flow conditions (scenario 1) then vary the level of environmental quality in three additional scenarios (Table 1). Differences in net economic benefit provided by salmon across scenarios provide measures of social gain or loss associated with the modeled changes.

3.2. Modeling fish population dynamics with an environmental influence

We develop a biological model linking changes in habitat quality to changes in fish productivity. By varying the level of environmental quality in the biological model according to our development scenarios, we determine salmon abundance (and total harvest in the case of fishery uses). Derivation of the habitat quality parameters for each scenario is described below, followed

[2] We refer to changes in "net economic benefit" to capture changes in consumer and/or producer's surplus resulting from changes in management or policy. Note that care is needed in interpreting "net economic benefit" as specific to fish production. Welfare gains stemming from increased hydropower production and/or other valued components are not considered here. We discuss the implications of this intentional omission in the Discussion and Conclusion sections.

[3] Maximum daily average of hourly flow measurements 1980–2015 (i.e. after hydropower and flood control development).