Science of the Total Environment 627 (2018) 480–493

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Ecological-economic assessment of the effects of freshwater flow in the Florida Everglades on recreational fisheries

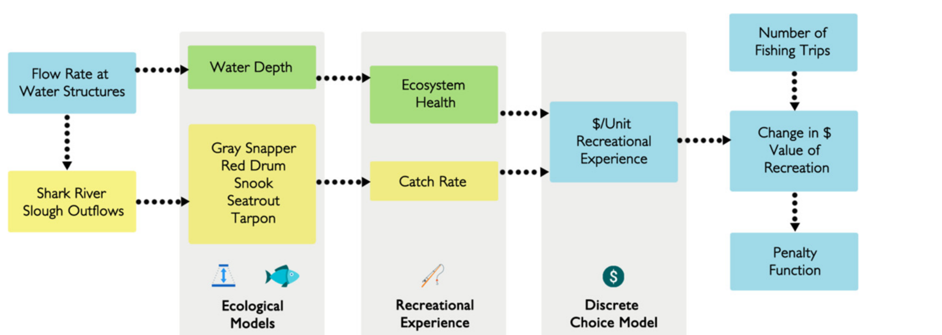
Christina Estela Brown [a], Mahadev G. Bhat [a,*], Jennifer S. Rehage [a], Ali Mirchi [b], Ross Boucek [c], Victor Engel [d], Jerald S. Ault [e], Pallab Mozumder [a], David Watkins [f], Michael Sukop [a]

[a] Florida International University, Miami, FL, United States
[b] University of Texas at El Paso, El Paso, TX, United States
[c] Florida Fish and Wildlife Research Institute, St. Petersburg, FL, United States
[d] U.S. Forest Service, Fort Collins, CO, United States
[e] University of Miami, Miami, FL, United States
[f] Michigan Technological University, Houghton, MI, United States

HIGHLIGHTS

- Develops an integrated methodology linking Everglades hydrology to economic values
- First ever estimate of anglers' willingness to pay for Everglades recreational experience
- Estimates losses in economic welfare due to missing freshwater delivery targets and implicit price of water use for recreation at \$41.54 AF^{-1}
- Relevant applications to management, restoration, and climate scenario analysis

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 July 2017
Received in revised form 14 December 2017
Accepted 5 January 2018
Available online xxxx

Keywords:
Penalty function
Ecosystem service valuation
Everglades
Recreational fishery
Discrete choice model

ABSTRACT

This research develops an integrated methodology to determine the economic value to anglers of recreational fishery ecosystem services in Everglades National Park that could result from different water management scenarios. The study first used bio-hydrological models to link managed freshwater inflows to indicators of fishery productivity and ecosystem health, then link those models to anglers' willingness-to-pay for various attributes of the recreational fishing experience and monthly fishing effort. This approach allowed us to estimate the foregone economic benefits of failing to meet monthly freshwater delivery targets. The study found that the managed freshwater delivery to the Park had declined substantially over the years and had fallen short of management targets. This shortage in the flow resulted in the decline of biological productivity of recreational fisheries in downstream coastal areas. This decline had in turn contributed to reductions in the overall economic value of recreational ecosystem services enjoyed by anglers. The study estimated the annual value of lost recreational services at \$68.81 million. The losses were greater in the months of dry season when the water shortage was higher and the number of anglers fishing also was higher than the levels in wet season. The study also developed conservative estimates of implicit price of water for recreation, which ranged from \$11.88 per AF in November to \$112.11 per AF in April. The annual average price was \$41.54 per AF. Linking anglers' recreational preference directly to a decision variable such as water delivery is a powerful and effective way to make management decision.

* Corresponding author.
E-mail addresses: cebrown@fiu.edu (C.E. Brown), bhatm@fiu.edu (M.G. Bhat), rehagej@fiu.edu (J.S. Rehage), amirchi@utep.edu (A. Mirchi), ross.boucek@myfwc.com (R. Boucek), engel.vic@gmail.com (V. Engel), jault@rsmas.miami.edu (J.S. Ault), mozumder@fiu.edu (P. Mozumder), dwatkins@mtu.edu (D. Watkins), sukopm@fiu.edu (M. Sukop).

https://doi.org/10.1016/j.scitotenv.2018.01.038

This methodology has relevant applications to water resource management, serving as useful decision-support metrics, as well as for policy and restoration scenario analysis.

1. Introduction

Everglades National Park (ENP), at the southern end of the Florida peninsula at 1.5 million acres, comprises the largest subtropical upland to marine ecosystem in North America. ENP contains a range of freshwater sloughs, seasonally flooded marl prairies, tropical hardwood hammocks, pine rocklands, and mangrove and seagrass-dominated estuarine habitats (Gunderson, 1994; Richardson, 2010; Saha et al., 2012). The Everglades, as an important migratory corridor, provides breeding and foraging habitats for over 400 species of birds, but also water storage and recharge for the Biscayne aquifer, the principal source of freshwater for regional human consumption (Lorenz, 2014; Saha et al., 2012).

South Florida's regional ecosystem is characterized by two distinct seasons, a wet season (generally from May–October) and a dry season (generally from November–April) (Saha et al., 2012; Brandt et al., 2012). While the average annual rainfall exceeds 60 in., variation in tropical weather systems may result in wide seasonal variation and large year-to-year fluctuations (1901–2000 standard deviation of 11 in. in the Miami-Dade area) (Abtew and Huebner, 2001; National Park Service, 2009). Brandt et al. (2012) report that approximately 77% of the total annual rainfall occurs during the wet season, and remaining 23% during the dry season.

Prior to the development of the large freshwater drainage system in South Florida in the early and mid-20th century, water flowed south from Lake Okeechobee into a broad, slow-moving, shallow river of water. In the post-development period, these flows are constrained by a dike and levy system and occupy less than half of their original areal extent, relegating the Everglades to part of a complex watershed management system regulated primarily for agriculture, flood control, and consumptive uses (Ogden et al., 2005a, b; Sklar et al., 2001, 2005). As a result, the flow of freshwater through ENP has been reduced, diverted, channelized and otherwise modified such that salinity regimes, biota, and a variety of ecosystem services in the coastal Everglades have dramatically changed (Perry, 2008; Rand and Bachman, 2008).

As a large, subtropical estuary averaging in depth from 6 to 9 ft, Florida Bay provides critical habitat for a variety of species, including seagrasses and coastal mangrove communities (Bachman and Rand, 2008). It serves as a nursery for larvae and juveniles of many critical species, including fish and wading birds (Lorenz, 2014).

The ENP, encompassing Whitewater Bay, Tarpon Bay, and Florida Bay, is renowned for its world-class recreational fisheries. Commercial fishing has been banned in Park waters. Recreational fishing in the Everglades generates more than $1.2 billion in annual economic activity, with largemouth bass, red drum, snook, Atlantic tarpon, gray snapper and bonefish providing the largest economic impact (Fedler, 2009). Timing, quantity, and quality of freshwater inflows can greatly affect salinity and water quality regimes in south Florida coastal bays (Wang et al., 2003). Freshwater flows are a key determinant of habitat and fisheries resource productivity (Rudnick et al., 2005; Stabenau et al., 2011; Walters et al., 1992), making the recreational fishing industry in the area a direct beneficiary of improved and sustained fishery habitat.

Surface water stage (water depth relative to a given datum) and salinity gradients are strongly influenced by the amount of freshwater released through water management structures along the northern boundary of ENP (Stabenau et al., 2011; Childers et al., 2005). These flows are regulated by the South Florida Water Management District (SFWMD) through massive canals and structures. The SFWMD determines monthly water delivery targets for the Everglades wetlands based on the historical water flow levels (South Florida Water Management District, 2014). However, in the recent years, average monthly deliveries have fallen short of these regulatory flow targets by >80% in some months. Managers are interested in understanding the potential ecological and economic impacts associated with water deliveries relative to the pressing demands of non-environmental sectors (e.g., agriculture, urban needs, etc.).

The goal of this paper was to develop a systems approach to systematically measure the economic impacts to changes in Everglades recreational ecosystem services relative to changes in freshwater management. We developed an integrated ecological-economic methodology by linking the Everglades hydrology to fisheries production and then modeled the effects of freshwater flows on several robust biological indicators. We quantified various attributes of the recreational fishing experience, and, finally, link the hydrology-influenced anglers' fishing experience to economic values.

Following Johnston et al. (2011, 2012), economic values are developed using a stated preference discrete choice experiment, taking care to provide respondents with the relevant ecological and hydrological knowledge essential for making informed choices to ensure valid willingness to pay estimates. At the end, this integrated methodology allows us to estimate losses in economic welfare due to missing monthly freshwater delivery targets in the Everglades. These welfare losses are simply the foregone benefit or penalty of failing to meet exogenously determined freshwater flow targets. These penalty estimates serve as useful decision-support metrics for water resource managers making regional water resource allocations. While the conceptual model of the penalty function has been used in hydro-economic optimization (Harou et al., 2009; Jenkins et al., 2004; Newlin et al., 2002), its application to ecosystem services in terms of recreational fisheries is novel. In particular, the flexibility of this approach lends itself to applications to management scenario analysis and evaluation of potential restoration projects. This study advances ecosystem services valuation methods through its integrated hydrological-ecological-economic model.

2. Methods

2.1. Delineation of the study area

The geographic focus of the study is the ENP watershed, in particular the Shark River Slough (SRS) (Fig. 1). Our goal is to assess the economic value of managing water through the Northern boundary of ENP. The relevant water structures involved in these flows are S12A-D, S333, and S334, located along Tamiami Trail (U.S. 41) at the northern boundary of ENP. The SRS region is bounded by state road U.S. 41 to the north, Gulf of Mexico to the southwest, Miami Rock Ridge to the east, and marl prairies to the west. The areal extent of the slough considered in this study is approximately 1700 km^2 (Saha et al., 2012). At the western end of the slough is an estuarine zone including mangrove forests that extends approximately 30 km inland from the Gulf of Mexico. On the northern end, a ridge and slough landscape dominates, with sawgrass marshes and tree islands along the ridges, and floating and submerged aquatic macrophytes in the sloughs (Saha et al., 2012; Price, 2008).

The majority of the inflow going through the above hydrological structure and into the ENP (70%) flows through Shark River Slough, with the remaining inflows reaching Taylor Slough to the southeast (Price et al., 2008). More than 90% of the flow through SRS region discharges into the Gulf of Mexico through five major rivers along the southwest coast (Levesque, 2004), corresponding to zones 4, 5, and 6 of ENP (Fig. 1). Lostmans River contributes 33% of mean annual