Science of the Total Environment 651 (2019) 1796–1809

Contents lists available at ScienceDirect

Science of the Total Environment

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

Land conservation can mitigate freshwater ecosystem services degradation due to climate change in a semiarid catchment: The case of the Portneuf River catchment, Idaho, USA

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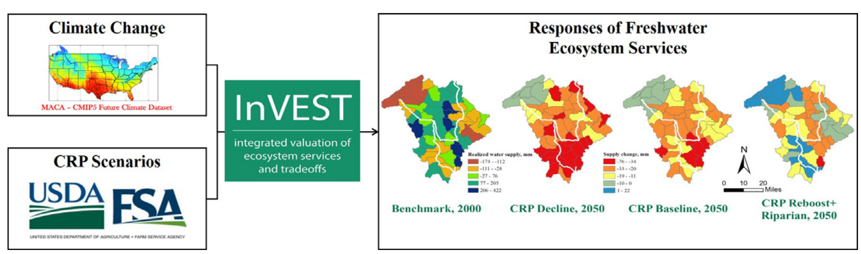
HIGHLIGHTS

- Freshwater ecosystem services (ES) under climate change and conservation assessed
- Degradation of freshwater ES is expected as a result of climate change.
- Increasing agricultural land conservation would offset the degradation.
- Model outputs are sensitive to the parameters of major land cover types.
- This study has potential implications for other semiarid catchments.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 July 2018
Received in revised form 20 September 2018
Accepted 20 September 2018
Available online 24 September 2018

Editor: Sergi Sabater

Keywords:
Climate change mitigation
Conservation Reserve Program (CRP)
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)
Portneuf River
Scenario analysis
Freshwater ecosystem services

ABSTRACT

There is increasing evidence of environmental change impacts on freshwater ecosystem services especially through land use and climate change. However, little is known about how land conservation could help mitigate adverse water-sustainability impacts. In this paper, we utilized the InVEST tool and the Residual Trends method to assess the joint effects and relative contributions of climate change and land conservation on freshwater ecosystem services in the Portneuf River catchment in Idaho, USA. We developed five hypothesized scenarios regarding gain and loss in the enrollment of Conservation Reserve Program (CRP), the largest agricultural land-retirement program in the U.S., plus riparian buffer and assessed their interactions with climate change. Results suggest that the realized water yield in the Portneuf River catchment would possibly be 56% less due to climate change and 24% less due to the decline of CRP enrollment. On the contrary, if CRP enrollment is promoted by ~30% and riparian buffer protection is implemented, the water supply reduction in the year 2050 could be changed from 56% to 26%, the total phosphorus (TP) and total nitrogen (TN) export would be reduced by 10% and 11%, and the total suspended sediment (TSS) reduced by 17%. This study suggests that increasing implementation of the CRP would likely preserve key freshwater ecosystem services and assist proactive mitigation, especially for semiarid regions vulnerable to changing climate conditions.

1. Introduction

Freshwater ecosystems are responsible for the provision of a variety of services to humanity. The ecosystem services (ES) involve not only direct benefits to society, such as the supply of drinking water,

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http://dx.doi.org/10.1016/j.scitotenv.2018.09.260

hydropower, industrial and agricultural water usage, water purification, and erosion control, but also indirect impacts on human health, recreation and culture (De Groot et al., 2010; Keeler et al., 2012). The provisioning and functionality of freshwater ES are projected to be severely impacted by global climate change (Boithias et al., 2014; Brauman et al., 2007; Field et al., 2014; Foley et al., 2005; Pronk, 2002). Specifically, the impacts of climate change on semiarid regions are more evident given their climatological characteristics of low annual precipitation with high spatial variability, high potential evapotranspiration, and low annual runoff (Branson et al., 1981; Terrado et al., 2014). Current trends indicate that a warming climate will impact semiarid regions by concentrating the rainfall period during the year and causing more extended droughts (Brown et al., 2012).

Besides changing climate, anthropogenic changes, e.g., urbanization, population growth, and agriculture, are also major stressors for freshwater ES (Dodds et al., 2013; Foley et al., 2005; Zimmerman et al., 2008). In the anthropogenic changes, agricultural production is the largest consumer of freshwater. Land use change induced by agricultural intensification will likely increase water demand and lead to more pesticide and fertilizer use, and thus potentially cause water scarcity and deteriorate water quality (Boithias et al., 2014; Hamel et al., 2015; Secchi et al., 2011). To mitigate the possible negative impacts, solutions such as land conservation have been used to target the environmentally sensitive land and remove crops from production (Foley et al., 2011; Kovacs et al., 2013; Polasky et al., 2011). However, few empirical studies have either integrated land conservation with the two stressors of climate change and agriculture or explored the mitigating potential of agricultural land conservation practices under global change (Gleason et al., 2011; Johnson et al., 2016; Runting et al., 2017).

The Conservation Reserve Program (CRP) administered by the U.S. Department of Agriculture (USDA) has provided critical ES. Rooted in practices implemented in the 1950s and formalized in 1985, the CRP specifically targets the retirement of highly ecologically sensitive cropland and pasture to achieve water quality improvement (Johnson et al., 2016), wildlife habitat enhancement (Hiller et al., 2015), greenhouse gas emission reduction (Gelfand et al., 2011), soil erosion and nutrient load reduction (Gleason et al., 2011), and flood damage reduction (Todhunter and Rundquist, 2008). The CRP has an annual expenditure of about $2 billion and a long enrollment period from 10 to 15 years of contract for conserved land (Farm Service Agency, 2017; Stubbs, 2014). Even though the CRP provides more ES benefits than its rental payment (Hansen, 2007; Johnson et al., 2016), the program's cap, namely, the statutory limit of the maximum allowable acreage based on the Agricultural Act, has declined from its peak of 32 million acres in financial year (FY) 2007 to 24 million acres in FY2018 after the reauthorization of the Agricultural Act of 2014 (2014 farm bill hereafter, P.L. 113-79). The CRP enrollment has also declined from its peak of 36.8 million acres in 2007 to 23.4 million acres in 2017 due to the decreased cap, high commodity prices, and low rental rates (Chen and Khanna, 2014; Hellerstein, 2017; Newton, 2017; Stubbs, 2014). An additional 7.8 million acres on contracts will expire between 2018 and 2022 (Farm Service Agency, 2017). Thus, more research is needed to assess how the fluctuation and alternative scenarios of the CRP will affect freshwater ES in regions where the enrollment is evident.

In this study, we aim to comprehensively assess the relative contributions and joint effects of climate change and land conservation through CRP on freshwater ES in the Portneuf River catchment in Idaho, USA. The Portneuf River catchment is a semiarid basin troubled with water scarcity and water quality problems due largely to irrigation and fertilizer applications in agricultural production (Bechtold et al., 2012; Hopkins et al., 2011; IDEQ, 2010; Marcarelli et al., 2010; Minshall and Andrews, 1973). We used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool to model the services of water supply, water purification, and sediment retention under different climate change and conservation scenarios (Sharp et al., 2014). We address the following questions: (a) If current land use and management practices persist, how will freshwater ES likely respond to climate change? (b) To what extent will land conservation, such as the CRP, help offset the adverse effects of climate change? (c) Given the spatially explicit results from InVEST, what are the implications for policy making to maintain current freshwater ES? We hypothesize that climate change and declining CRP enrollment will negatively affect the freshwater ES, whereas increasing CRP enrollment will partially offset the degradation and even counteract the impacts due to climate change.

2. Material and methods

2.1. Study area

The Portneuf River in southeastern Idaho, USA, is a fifth order river that drains 3500 km^2 (Fig. 1). The catchment is characterized by a semiarid climate with low annual precipitation, ranging from 330 mm at Pocatello city to 760 mm in the mountains (Minshall and Andrews, 1973), and high potential evapotranspiration, as large as 1550 mm in lower Portneuf valley (Welhan, 2006). The largest urbanized city in the region is Pocatello (population 54255 based on the 2010 census). Land use cover in the catchment is dominated by rangelands (60% of total area, with 41% as shrublands and 19% as grasslands; 28% is grazed), followed by croplands (14%), forest (13%), urban area (1%), and water (1%). About 8% of the catchment area is irrigated, and 85% of the irrigation withdrawal is from surface water (Marcarelli et al., 2010). The CRP land covers 11% of the catchment (NRCS, 2007). Among the three major counties in the catchment, Bannock County ranks 78th in terms of CRP enrollment, and Bingham County and Caribou County rank in the top 250 (118th and 245th) among 2511 participating counties in 2017 (Farm Service Agency, 2017).

The river is listed as ecologically impaired with respect to several of the criteria regulated under the federal Clean Water Act, including excess sediment and nutrients (N and P), as well as low flows and low dissolved oxygen in its downstream segments (IDEQ, 1999, 2010). The water consumption by irrigation accounts for 94.5% of the total consumptive use in the catchment (Solley et al., 1998). The consumptive use lowers discharge during summer by 70% compared to if the river were unregulated (Marcarelli et al., 2010). The catchment is also troubled with high concentrations of nitrogen, phosphorus, and turbidity from suspended sediments (Hopkins et al., 2011). The high nitrogen concentration and turbidity are mainly associated with agricultural practices and fertilizer application, whereas the high phosphorus concentration is related to the phosphorus processing complex located downstream of Pocatello (Baldwin et al., 2004). Marsh Creek is the largest tributary to the Portneuf River, which significantly contributes to the high nutrient and suspended sediment loads due largely to intensive agricultural activities within the drainage area (Layhee et al., 2015; Marcarelli et al., 2009). The river has its headwaters and outlet on the Fort Hall Reservation of the Shoshone-Bannock Tribes, adding additional jurisdictional complexity to and impetus for sustaining river-related ES.

2.2. Scenario building and modeling using InVEST

We modeled hypothesized scenarios to assess the joint and individual effects of climate change and CRP enrollment changes on freshwater services (Fig. 2). We used an InVEST model for each of our primary ES response variables: water yield, nutrient retention, and sediment retention (Appendix A). The InVEST tool is easily accessible and widely used in modeling ES change caused by climate and land use changes (Boithias et al., 2014; Fu et al., 2017; Hoyer and Chang, 2014; Pan et al., 2015). It is based on ecological production functions parameterized on land use management, aiming to cope with study area as large as a nation or as small as an individual catchment (Redhead et al., 2016; Sharps et al., 2017). It focuses on scenario comparisons via a first-order assessment rather than accurate prediction (Guswa et al., 2014; Hamel et al.,