Global Ecology and Conservation 7 (2016) 107–121

Contents lists available at ScienceDirect

Global Ecology and Conservation

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

Original research article

Mapping potential freshwater services, and their representation within Protected Areas (PAs), under conditions of sparse data. Pilot implementation for Cambodia

Leonardo Sáenz[a,*], Tracy Farrell[b], Annette Olsson[c], Will Turner[a], Mark Mulligan[d], Natalia Acero[a], Rachel Neugarten[a], Max Wright[a], Madeleine McKinnon[a], Cesar Ruiz[e], Jairo Guerrero[e]

[a] Betty and Gordon Moore Center for Science, Conservation International, 2011 Crystal Drive, Suite 500, Arlington, VA 22202, USA

[b] Greater Mekong Program, Conservation International, Street 95 Sangkat Boeung Trabek, Khna Chamkar Morn, Phnom Penh, P.O. Box 1356, Cambodia

[c] Asia-Pacific Regional Office, 318 Tanglin Road, #01-30, Block B, Singapore 247979, Singapore

[d] Earth and Environmental Dynamics Research Group, Department of Geography, King's College London, Strand, London, WC2R 2LS, UK

[e] Conservation International Colombia, Carrera 13 No. 71-41, Bogotá DC, Colombia

HIGHLIGHTS

- Protected Areas represent better Freshwater regulation than provisioning services.
- Due to Freshwater regulation importance The Prey Lang forest, should be protected.
- Riparian forests around Mekong's deep water pools should be better protected.
- Freshwater metrics framework proposed suitable for sparse data regions.

ARTICLE INFO

Article history:
Received 21 September 2015
Received in revised form 2 April 2016
Accepted 31 May 2016
Available online 16 June 2016

Keywords:
Freshwater
Metrics
Ecosystem Services
Protected Areas
Cambodia
Mekong River
Tonle Sap

ABSTRACT

Freshwater is arguably one of Earth's most threatened natural resources, on which more than 7 billion people depend. Pressures on freshwater resources from infrastructure, resource development, agricultural pollution and deforestation are mounting, particularly in developing countries. To date, conservation responses such as Protected Areas (PAs) have not typically targeted freshwater ecosystems and their services, and thus little is known about the effectiveness of these efforts in protecting them. This paper proposes and pilots an innovative freshwater services metrics framework to quantify the representation of potential freshwater services in PAs under conditions of scarce data, with a pilot application for Cambodia. Our results indicate that conservation actions have more effectively represented potential freshwater regulation services than potential freshwater provisioning services, with major rivers remaining generally unprotected. Results from the framework are then used to propose a series of context and region specific management options to improve the conservation of freshwater services in Cambodia. There is an acute need for such management options, as the country's food security depends largely on important freshwater ecosystems such as the Tonle Sap Lake and the deep water pools systems of the Mekong River. The framework proposed can be applied in other countries

* Corresponding author. Tel.: +1 703 341 2784.
E-mail address: lsaenz@conservation.org (L. Sáenz).

http://dx.doi.org/10.1016/j.gecco.2016.05.007

or large river basins to explore the degree of representation of freshwater services within PAs systems, under conditions of sparse data.

1. Introduction

Freshwater is one of the most threatened resources sustaining human populations (Addams et al., 2009; Bourza, 2013; Foster et al., 2013; Lawford et al., 2013). Watershed and river degradation through deforestation, wetland degradation, river fragmentation, urbanization and pollution, are among the threats affecting the supply of this valuable resource (Vörösmarty et al., 2010; Hill et al., 2013; Winemiller et al., 2016). State-specific freshwater management strategies, including headwaters conservation through Protected Areas (PAs), have been proposed to more sustainably manage the supply of freshwater services (Vörösmarty et al., 2010; Green et al., 2015).

Freshwater services include the supply and regulation of freshwater in quantity and quality, which are fundamental for the survival of humans and biodiversity (Vörösmarty et al., 2005, 2010). However, we know little about the effectiveness of PAs in safeguarding freshwater services (Neil et al., 2009; Farrell et al., 2010). This is, in part, due to lack of appropriate methods, data and metrics to examine and monitor the cause–effect relationships between conservation policies and the state of freshwater services and their supplying ecosystems (Juwana et al., 2012; Hill et al., 2013; Ferraro and Hanauer, 2015). The evidence base that is needed to more adequately represent freshwater services in conservation plans is generally lacking (Neil et al., 2009).

However, part of the complication in deriving the evidence needed to better represent freshwater services in conservation programs may reside in our perception of what freshwater services are. According to the Millennium Ecosystem Assessment (MEA) freshwater is treated as a service as well as a system that supports other services (Vörösmarty et al., 2005). Indeed, freshwater can support, for instance, purification processes such as pollutants dilution in river streams; or it can support nutrient recycling processes, such as those that ensure healthy fisheries in the Mekong River basin (MEA, 2005; MRC 2013). Nevertheless, freshwater is also a final service that results from the interaction of several intermediary services working together (Mulligan et al., 2010). For instance, according to the MEA, forests, wetlands, lakes, flood plains and ground water aquifers are natural storages that help regulate the quantity and quality of the freshwater flowing out of watersheds (MEA, 2005). In contrast, rivers, lakes and other aquatic ecosystems are natural networks that provide access to gravity-driven freshwater flows for human consumption and biodiversity (Jones, 2011).

Due to these complexities in disentangling final from intermediate freshwater services, the literature has often categorized freshwater only in terms of its quantity, especially in global analysis of water resources (Vörösmarty et al., 2005), paying less attention to freshwater regulation and quality dimensions (Mulligan et al., 2010; Juwana et al., 2012; Hill et al., 2013). This knowledge gap in freshwater conservation requires attention in order to improve the design and planning of PAs, given that biodiversity and people are highly sensitive to changes in both the quality and the pulse of freshwater flows (Wallace, 2007; Constanza, 2008; Mulligan et al., 2010). Thus, before defining freshwater conservation priorities we must develop a clear understanding of (1) what type of freshwater services we are interested in protecting, (2) where and how those services are generated, (3) who receives the benefits, and (4) what types of indicators and safeguards are needed to diagnose and improve their status and track conservation progress (Thieme et al., 2007; Neil et al., 2009).

In this manuscript we take these perspectives forward to propose an innovative freshwater services metrics framework to quantify the representation of freshwater services in PAs, which can serve as a tool to help better inform conservation planning programs for freshwater at national or large river basin scales. The framework was designed to distinguish between the role of PAs in the regulation and provision of freshwater, both in quality and quantity. The distinction between these different freshwater services is important to make because their importance for people or biodiversity may vary between regions and can be context specific. Moreover, their effective management, conservation and monitoring may be service specific.

In this study we focus only on potential services (services irrespective of their use by humans) (Turner et al., 2013) and not on realized services. This choice of focus was made because the assessment of realized services requires additional analysis, especially at national scales, to effectively connect freshwater services with the corresponding set of service users, which was beyond the scope of the present study. Nevertheless, we believe that the analytical steps to assess potential services proposed in this study establish an adequate foundation for a subsequent assessment of realized freshwater services and their economic value. From now onward, when we use the term freshwater services we are referring to potential freshwater services and not realized freshwater services.

To develop the set of physical indicators that constitute the framework, we use a process-based eco-hydrological modeling approach implemented with the WaterWorld policy support system (http://www.policysupport.org/). Results are summarized spatially using a sub-watersheds hydrological network, according to Lehner and Grill (2013), to prioritize areas and river reaches important for freshwater service supply.

Finally, we applied the framework in the data-scarce context of Cambodia. We chose Cambodia because the Mekong River was one of the least modified in the world, until recently, and many fish species and human communities have evolved