Ecological Indicators 45 (2014) 148–159

Contents lists available at ScienceDirect

Ecological Indicators

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

Development of new indicators to evaluate river fragmentation and flow regulation at large scales: A case study for the Mekong River Basin

Günther Grill[a,*], Camille Ouellet Dallaire[a], Etienne Fluet Chouinard[a], Nikolai Sindorf[b], Bernhard Lehner[a]

[a] Department of Geography, McGill University, 805 Sherbrooke Street West, Montreal, Quebec H3A 0B9, Canada
[b] Conservation Science Program, World Wildlife Fund, 1250 24th Street NW, Washington, DC 20037, USA

ARTICLE INFO

Article history:
Received 20 August 2013
Received in revised form 18 March 2014
Accepted 20 March 2014

Keywords:
Dams
River network routing
Hydrological connectivity
Flow regulation
Geographic Information Systems
Mekong River

ABSTRACT

Large hydropower schemes have recently gained renewed interest as a provider of efficient and renewable energy, particularly in developing countries. However, some dams may have widespread effects on hydrological and ecosystem integrity, which reach beyond the scales addressed by typical environmental impact assessments. In this paper we address two main ecological impacts—reduced river connectivity and changes in the natural flow regime—at the scale of the entire Mekong River Basin as an important component of dam evaluations. The goal is to improve our understanding of the effect of individual dams as well as clusters of dams at a very large scale. We introduce two new indices, the River Connectivity Index (RCI) as a tool to measure network connectivity, and the River Regulation Index (RRI) as a measure of flow alteration, and calculate the individual and cumulative impact of 81 proposed dams using HydroROUT, a graph-theory based river routing model. Furthermore, we demonstrate how quantitative weighting, e.g. based on river habitat characterizations or species distribution models, may be included in dam impact assessments.

A global comparison of large rivers shows that the Mekong would experience strong deterioration in the fragmentation and flow regulation indices if all dams that are currently under consideration in the basin were built, placing it among other heavily impounded rivers in the world. The results illustrate the importance of considering the location of dams, both relative in the network and relative to other already existing dams. Our approach may be used as an index-based ranking system for individual dams, or to compare basin-wide development scenarios, with the goal of providing guidance for decision makers wishing to select locations for future dams with less environmental impacts and to identify and develop potential mitigation strategies.

1. Introduction

Dams have played a key role in regional development in recent history in many parts of the world by providing a source of renewable energy, water for irrigation and human consumption, and by protecting human settlements against floods and droughts. In addition to these intended and desirable effects of dams, numerous studies have also documented adverse, often unwanted consequences both locally and regionally (World Commission On Dams, 2000), including effects on hydrological connectivity (Vörösmarty et al., 2010), flow regulation (Lehner et al., 2011), sediment delivery (Syvitski et al., 2009), and biodiversity (Reidy Liermann et al., 2012). Dam construction and reservoirs have caused the displacement of millions of people worldwide and altered the livelihoods of river dependent societies (Richter et al., 2010).

A prominent example of the challenging trade-offs between benefits and risks related to dam construction is apparent in the Mekong River Basin (MRB). On the one hand, the international conservation community pays close attention to developments affecting the MRB as currently the river is widely considered "free-flowing" due to the fact that the entire lower portion of the main stem is unobstructed by dams. As a result, the Mekong's hydrological flow pattern has largely remained unchanged from its natural dynamics causing distinct seasonal patterns of discharge and flooding throughout the region. The natural flow regime is a main trigger of the migration of numerous fish species either

* Corresponding author. Tel.: +1 514 398 8794; fax: +1 514 398 7437.
E-mail address: guenther.grill@mail.mcgill.ca (G. Grill).

http://dx.doi.org/10.1016/j.ecolind.2014.03.026
1470-160X/

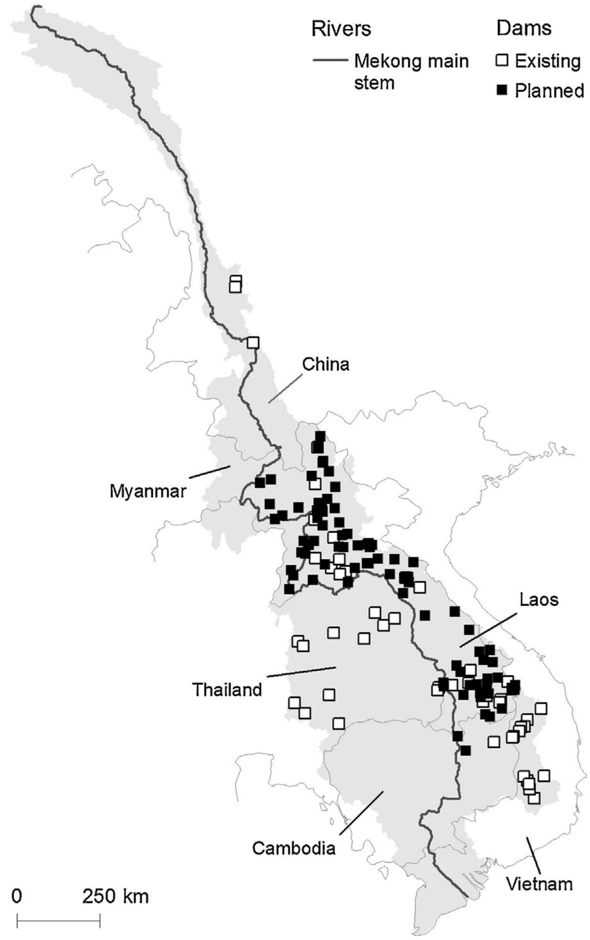

Fig. 1. Overview of the Mekong River Basin with existing and planned dams.

longitudinally (up- and downstream) or laterally (river-floodplain) (Baran, 2006), some of which can travel several hundred kilometers up and down the Mekong.

On the other hand, at least 81 different proposals for dam development are currently under consideration for the lower Mekong region, of which 11 are located on the main stem (MRC, 2009; Fig. 1). Facing poverty, population pressure and rising energy demands, the main stakeholder countries of the MRB, i.e. Laos, Vietnam, Cambodia, Thailand, and China, plan to tap into the large hydropower potential of the Mekong River (MRC, 2010) to accelerate their economic development. However, if dams were built on the main stem, migratory fish populations are expected to decline, resulting in a significant loss in fish catch and consequently leading to reduced income and food supplies upon which the majority of the basin's population rely either directly or indirectly (Baran, 2010; Dugan et al., 2010; Hortle, 2009; Orr et al., 2012).

As both the plans for economic development and the goal to conserve the ecological integrity of the river system are implemented on large scales, a sustainable hydropower strategy is needed for the MRB in which the risks of dam developments are assessed for the entire basin. While most studies, such as environmental impact assessments for individual dams, focus on isolated, small scale impacts around the site of a dam or in its close downstream vicinity, only very few studies have attempted to estimate combined effects of multiple dam developments on ecosystems at larger scales. For example, the strategic environmental assessment carried out for the Lower Mekong River Basin in 2010 (ICEM, 2010) includes a number of development scenarios for pre-defined sets of dams, but as the approach is not spatially explicit it does not allow decision makers to evaluate individual dams regarding their specific role in the network.

Recently, new approaches have emerged that seek to "optimize" the development, distribution and operation of dams by assessing and prioritizing them based on their geospatial location. A more holistic 'river network mindset' is required for this approach and river basin development and management plans should take advantage of newly available data resources and computer software tools to reveal the cumulative effects of dams on the entire river system, helping to identify important linkages and critical thresholds (Lehner et al., 2011). Such prioritization efforts could also indicate dams where changes in release patterns and operation schemes, or technical interventions such as fish bypass facilities, would be most likely to improve environmental flows and/or ecosystem services.

The goal of this study is to explore some of these "optimization" strategies for the specific setting of the MRB and to report on the feasibility of applying these methods in more detail in the future. We present a model that is based on two major groups of effects: (i) the effect of dams on longitudinal connectivity, which includes barrier effects and cut-offs between rivers, floodplains and wetlands. And (ii) the effect of dams on the natural flow regime through water storage and retention, which includes changes in the magnitude and timing of flows, as well as associated changes in water quality. We examine both groups of effects in a single framework and can thus improve our understanding of trade-offs between different types of dams in relation to their societal benefit, which in the MRB is typically related to energy production.

The intention of our research is to provide scientific and methodological advances toward the inclusion of quantitative measures and expert knowledge into a common framework to support integrated dam assessments. In particular, we believe that our approach has the potential to improve decision making processes by adding perspectives from a larger scale context. It should be emphasized, however, that by no means our methodology is supposed to substitute or replace local environmental impact assessments, but to expand our understanding by adding the large scale as an explicit new layer of consideration. A second goal of our study is to design indicators that can be derived rapidly as a first-order proxy even in data-poor settings, and to provide a proof-of-concept that the methodology is feasible. While the described framework is, in theory, capable of providing individual dam evaluations, the choices and weights of our data and derived indicators will need critical review and validation by local experts before being reliable for political discussions and decision making. Given this current lack of local validation, it is not within the scope of this study to provide final results for immediate use in policy planning. For this reason we refrain from referring to explicit future dams and their names throughout this report.

2. Theoretical background

2.1. River fragmentation

Connectivity—or inversely fragmentation—has been estimated in the past using increasingly complex methods (Fullerton et al., 2010). Basic indicator methods have been applied in global and large scale studies. Those include the number of dams within a watershed (dam density), the total length of a river (in km) upstream from each dam, the proportion of the river network inaccessible from the sea, or the total length of swimmable distance from each point of the network (Anderson et al., 2008; Lassalle et al., 2009; Nilsson et al., 2005; Vörösmarty et al., 2010). In an attempt to capture the obstruction of large river systems by dams, Reidy Liermann et al. (2012) measured the length of the longest