Review

To manage inland fisheries is to manage at the social-ecological watershed scale

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ABSTRACT

Approaches to managing inland fisheries vary between systems and regions but are often based on large-scale marine fisheries principles and thus limited and outdated. Rarely do they adopt holistic approaches that consider the complex interplay among humans, fish, and the environment. We argue that there is an urgent need for a shift in inland fisheries management towards holistic and transdisciplinary approaches that embrace the principles of social-ecological systems at the watershed scale. The interconnectedness of inland fisheries with their associated watershed (biotic, abiotic, and humans) make them extremely complex and challenging to manage and protect. For this reason, the watershed is a logical management unit. To assist management at this scale, we propose a framework that integrates disparate concepts and management paradigms to facilitate inland fisheries management and sustainability. We contend that inland fisheries need to be managed as social-ecological watershed system (SEWS). The framework supports watershed-scale and transboundary governance to manage inland fisheries, and trans-disciplinary projects and teams to ensure relevant and applicable monitoring and research. We discuss concepts of social-ecological feedback and interactions of multiple stressors and factors within/between the social-ecological systems. Moreover, we emphasize that management, monitoring, and research on inland fisheries at the watershed scale are needed to ensure long-term sustainable and resilient fisheries.

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1. Introduction

Inland fish and fisheries serve important nutritional, economic, cultural, and recreational roles in human society (reviewed in Lynch et al., 2016). Found in freshwater above mean tide levels, inland fish are a major source of protein, essential fats and oils, and micronutrients for hundreds of millions of people worldwide with potential to improve human health and combat malnutrition (Roos et al., 2007; Youn et al., 2014). More than 60 million people in developing countries rely on inland fisheries as a source of livelihood and as a 'safety net' for food security and income (Welcomme et al., 2010; FAO, 2014). In the lower Mekong basin alone, inland fisheries provide roughly 60% of the animal protein intake of inhabitants and economic benefits of about US$17 billion (Nam et al., 2016). Inland fisheries also provide cultural and recreational services that contribute to human health, social benefits, and well-being (Holmlund and Hammer, 1999; Lynch et al., 2016).

While fishing is often the largest anthropogenic influence on marine fisheries (e.g., Jackson et al., 2001; Mullon et al., 2005), inland fisheries are often impacted by other societal needs and uses of inland water resources, particularly competition for freshwater for agricultural production, municipal use consumption, waste disposal, and power generation (Cooke et al., 2014). Freshwater ecosystems and their intimate connection with their watersheds make them receptors of a number of stressors and threats – in other words, the "stream is a reflection of its valley" (Hynes, 1975). The vulnerability of freshwaters to numerous, often multiple, threats, including extraction, damming, habitat degradation, pollution, and nutrient enrichment (Malmqvist and Rundle, 2002; Dudgeon et al., 2006) increases pressures on the productivity and sustainability of the ecosystem services they deliver. This in turn puts inland fish and fisheries at risk of population declines, biodiversity loss, and extinction (e.g., Maitland, 1995; Duncan and Lockwood, 2001).

Inland fisheries do not often receive the same degree of attention relative to other sectors of freshwater and related watershed usage (e.g., hydropower, agriculture, and transportation; Cooke et al., 2013), perhaps because inland fisheries assessment data is so poor that it is often disregarded. Inland fisheries have generally been a low priority for researchers and regulators, putting the livelihoods and food security of many communities at risk (Beard et al., 2011; Cooke et al., 2016). However, there is increasing acknowledgement among scientists and managers that to manage inland fish and fisheries is to manage for the broader environment (Welcomme et al., 2010; Cooke et al., 2016). It is argued that we must consider the activities from the entire watershed because whatever happens in a watershed will directly and indirectly affect the quality and quantity of water, productivity of resident biota, including fishes, and ultimately people (Baron et al., 2002; Collares-Pereira and Cowx, 2004).

The challenge of conserving fish populations and communities, and maintaining fisheries production is enormous, especially when considering the numerous freshwater users and system stressors (e.g. Dudgeon et al., 2006; Vörösmarty et al., 2010). This paper proposes a framework that unites disparate concepts from the literature with the goal of reorienting how we, as inland fisheries researchers and managers, think about the complexity of inland fisheries, and by extension how they are researched and managed. To do this, we contend that inland fisheries needs to be evaluated and managed as a *social-ecological watershed system* to inform effective fisheries management and maintain watershed resilience.

2. Managing inland fisheries as a social-ecological watershed system (SEWS)

While inland fishes do not recognize socio-political jurisdictions, they do respect watershed boundaries. 'Watershed' (also commonly referred to as catchment or drainage basin) refers to the geographic boundary within which rainfall drains into a particular river, stream, or waterbody (Borre et al., 2001). Whatever happens within these watershed boundaries influences these water bodies; thus, the watershed is an appropriate management unit for inland fisheries as it encompasses the ecological barriers to the system, the terrestrial influences, and resource gradients, particularly for lotic systems (Hynes, 1975; Vannote et al., 1980; Ward, 1989). Watersheds are also complex social ecological systems (SES), which are systems that illustrate the interplay between humans and natural environments and the powerful reciprocal feedbacks between them (Berkes and Ross, 2013). Therefore, with the intimate connection of inland waters to their watershed, management of inland fisheries ought to be viewed as a SES at a watershed scale (Baron et al., 2002). We thus argue that inland waters and the services they provide are nested in social-ecological watershed systems (SEWS, Fig. 1); a holistic and transdisciplinary framework that integrates watershed and SES principles (see Ostrom, 2009). With that in mind, inland fisheries research and management ought to be approached at an SEWS scale. Doing so requires understanding the interactions among human and ecological components of watersheds, how both the watershed and its inhabitants respond to changes, what trade-offs exist between social and ecological needs (or decisions), and how to optimize those trade-offs.

Although these ideas are not necessarily new, globally, they appear to not be widely adopted in inland fisheries research and management. To date, there are many proposed frameworks, management approaches, and concepts that are potentially relevant for addressing the long-term sustainability of inland fisheries, such as ecosystem services approaches, ecosystem-based