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Review

A one hundred year review of the socioeconomic and ecological systems of Lake St. Clair, North America

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ABSTRACT

There is a growing concern about continued impairment of aquatic ecosystems resulting from increasing population size, land use, climate change, and the feedbacks that may harm human well-being. We describe a 100 year multi-disciplinary overview of changes in Lake St. Clair, North America to identify knowledge gaps and needs to build the foundation for creating coupled human and natural system models. Our historical analysis indicates that the socioeconomic dynamics are inextricably linked to the urban dynamics of the Detroit metropolitan area. Environmental degradation and human health issues led to the adoption of relevant policies, including construction of wastewater treatment facilities by the 1960s. Climate trends during the 100-year period indicate a wetter region, which is influencing lake levels. Since the mid-1980s and 90s invasive zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena rostriformis bugenis*) have significantly altered the ecological structure and function of the lake. Waterborne illnesses due to contaminated drinking water were once an issue but current human health risks have shifted to contaminated recreational waters and coastal pollution. Key research needs for building coupled models include geo-referencing socioeconomic and ecological data to accurately represent the processes occurring within the political and watershed boundaries; assessing ecosystem services for human well-being; and developing research hypotheses and management options regarding interactions among land use, people and the lake. Lake St. Clair has gone through extensive changes, both socioeconomically and ecologically over the last 100 years and we suggest that it serves as a useful case study for the larger Great Lakes region.

Contents

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Introduction

The Laurentian Great Lakes region has a legacy of over 100 years of water quality science and policy. The history of impairment and management in the Great Lakes can be instructive as we consider the future challenges of climate change and sustainability in freshwater ecosystems. The Great Lakes region serves as an excellent case study for interdisciplinary research on water quality by bringing together a diverse group of scientists and stakeholders. Many scientists, stakeholders and government agencies are already involved in research and management of the Great Lakes, and one benefit of the multitude of programs is the rich and ever-growing data sets on a variety of physical, chemical, biological and socioeconomic indicators. However, the basin suffers from organizational fragmentation and lack of coordination among programs which can be a significant obstacle to synthesis and integration in support of environmental protection and restoration (US Government Accountability Office, 2003). The Laurentian Great Lakes and their connecting channels provide essential ecosystem services to citizens in the basin, such as providing a source of drinking water (U.S. Army Corps of Engineers, 2004b), a sport fishery (Gewurtz et al., 2007; Leach, 1991), recreational uses of beaches (Song et al., 2010), and shipping and transportation (Great Lakes Commission, 2006). The basin is also threatened by stressors common across the globe, such as land use change, pollution from human activities and their interactions with climate change (Allan et al., 2012). In light of these challenges, there is a need to synthesize and integrate available data in ways that advance scientific understanding and provide useful information for managers, decision-makers, and the public.

One approach to synthesizing data is to use the coupled human and natural systems (CHANS) framework that requires scientists to move beyond the methodological barriers of their discipline and develop integrative frameworks and models for analysis of environmental issues (An and López-Carr, 2012; Kotchen and Young, 2007; Liu et al., 2007). At an operational level, the CHANS approach links sub-models of human and natural systems and identifies the key parameters, interactions and feedbacks to develop better policies for tackling environmental issues with respect to sustainability (Carpenter et al., 2009). Defining sustainability remains a controversial issue among and within the various academic disciplines (Neumayer, 2010), and we support the notion that attaining sustainability requires the maintenance of functions and processes of natural systems that provide society with goods and services (e.g. natural resources, human health) (Bithas, 2008; Bithas and Nikjamp, 2006; Ekins et al., 2003).

A challenge to CHANS models is that natural and social sciences, having mainly worked in isolation in the past, use different scales of analysis to approach many environmental issues (Cumming et al., 2006; Ostrom, 2009; Pickett et al., 2005). The CHANS framework, with linkages between socioeconomic and ecological systems, has been used extensively in the last decade to better understand specific case studies (Haynie and Pfeiffer, 2012; Hopkins et al., 2012; Hufnagl-Eichiner et al., 2011; Liu et al., 2007). Liu et al. (2007) presented five case studies within the CHANS framework and highlighted the ability of integrated studies to capture systems dimensions that were previously not well understood. For example, in Wisconsin, ecological condition of lakes attracts tourism but economic development and touristic activities impact the ecological condition and in turn the attractiveness of the area. A study about the social–ecological coupling between agriculture in the Mississippi River Basin and hypoxia in the northern Gulf of Mexico found a mismatch between where the highest nutrient runoff occurs and the investment of socioeconomic resources that would help reduce hypoxia (Hufnagl-Eichiner et al., 2011). The usefulness of thinking in terms of systems' couplings has also inspired the development of a systems approach to define sustainable patterns of socioeconomic development for eighteen coastal systems in the European region (Hopkins et al., 2012).

Long-term data sets and historical analyses are needed to identify key components and couplings among humans and ecological systems to plan for sustainability (Carpenter et al., 2009; Swetnam et al., 1999). We explored data on climate, human population dynamics, land use, lake ecology and human health over Lake St. Clair's past 100 years (1900–2010). We mainly focused on the USA side because of the higher human population density and the available data, but we recognize that Canada's activities and policies are also important for this ecosystem. Our goal was to use the CHANS approach to identify data, research needs and to set the stage for further assessment (e.g. feedbacks, time lags, surprises, sensu Liu et al., 2007) on how the socioeconomic system and the aquatic ecosystem have interacted and changed through time.

Methods

The study system

Lake St. Clair (LSC), a shallow transboundary system in the Laurentian Great Lakes (Leach, 1991) (Fig. 1), connects Lakes Huron and Erie via the St. Clair River to the north and the Detroit River to the south. It is part of the Huron-Erie corridor. Lake St. Clair may seem small compared to the other Great Lakes, but it is the 11th largest lake in surface area in the continental USA (Herdendorf, 1982; Hunter and Simons, 2004). It also has about 1000 km of shoreline perimeter (Fig. 1). The LSC connecting channel contains three Areas of Concern as listed by the Great Lakes Water Quality Agreement, which are located in the St. Clair River, the Detroit River, and the Clinton River with a portion of the western lake shoreline (United States Environmental Protection Agency, access date 2 April 2012, http://www.epa.gov/glnpo/aoc/).

The aggregate area of the local watersheds that drain to LSC (excluding the watershed of Lake Huron and other upper Great Lakes) is 15,305 km^2, with 59% of this area (8988 km^2) on the Canadian side, and the remainder (6317 km^2) on the USA side (Fig. 1). The USA and Canadian portions of the LSC watershed differ greatly in terms of land use according to recent satellite-derived land cover data. On the USA