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Analysis

An Integrative Methodological Framework for Setting Environmental Criteria: Evaluation of Public Preferences

Maryam Ramin[a], Vincent Y.S. Cheng[a], Dong-Kyun Kim[a], Felicity J. Ni[a], Aisha Javed[a], Noreen E. Kelly[a], Cindy Yang[a], Sarah Midlane-Jones[b], Shan Mugalingam[b], George B. Arhonditsis[a,*]

[a] Ecological Modelling Laboratory, Department of Physical & Environmental Sciences, University of Toronto, Toronto, Ontario M1C1A4, Canada
[b] Lower Trent Conservation, Trenton, Ontario K8V 5P4, Canada

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ABSTRACT

The main objective of the present study is to introduce public preferences into the development of water-quality criteria that effectively balance environmental concerns and socioeconomic values. A novel feature of our research is the analysis of subjective public judgments with Bayesian inference techniques, which are ultimately connected with environmental conditions through mathematical modeling. Our case study is the Bay of Quinte, Ontario, Canada; an embayment at the northeastern end of Lake Ontario with a long history of eutrophication, characterized by frequent and spatially extensive algal blooms and predominance of toxic cyanobacteria. In this study, we present a major survey to determine public opinions on water quality in the area. Our survey was conducted among a random sample of 1527 local residents and tourists during the summers of 2013 and 2014. The key findings of the survey were: (*i*) fishing (29%) and beauty of the area (20%) were the main reasons for public use of the Bay of Quinte; (*ii*) among different water-quality problems, the public chose the algal scums (26%) and the integrity of fish populations (22%) as the main issues; (*iii*) only 30% of the returning visitors noticed that the clarity of water is better now relative to the prevailing conditions five years ago; (*iv*) there is a dramatic change in public sentiment between the beginning and end of the summer season; and (*v*) a substantial portion of local residents were willing to contribute financially towards the restoration of the bay. Our modeling analysis suggests that the likelihood of public satisfaction increases significantly when the total phosphorus concentrations fall below the critical levels of 20–25 $\mu g\, L^{-1}$, which however is a difficult target to achieve even under significantly reduced nutrient-loading conditions. Other biological variables such as chlorophyll *a* concentrations, harmful algal blooms, and toxin levels in locations frequently used by the public appear to more closely influence their satisfaction level.

1. Introduction

In 1987, the International Joint Commission (IJC) amended the Great Lakes Water Quality Agreement (GLWQA), a binational treaty between the United States and Canada, to effectively address the ongoing pollution issues threatening the physical, chemical, and biological integrity of the Great Lakes (Krantzberg, 2012a). The growing appreciation of the complex policy decisions required to restore and maintain the ecological integrity against the cumulative effects of a multitude of tightly intertwined stressors has also brought about a shift towards an holistic ecosystem management (Zhang and Arhonditsis, 2008; Krantzberg, 2012a). The GLWQA provided the framework to guide the management of 43 severely degraded waterbodies, referred to as Areas of Concern (AOCs), and restore beneficial uses that have been impaired, known collectively as Beneficial Use Impairments, or BUIs (Sproule-Jones, 1999; George and Boyd, 2007). Generally, BUIs reflect poor ecological status, in terms of water and sediment quality, habitat degradation, and/or impairments that might adversely affect human health (George and Boyd, 2007).

Remedial Action Plans (RAPs) have been developed and implemented to streamline the ecosystem management process as follows: initial designation of a site as an AOC and identification of BUIs; establishment of desirable (or "delisting") environmental goals, objectives and actions towards ecosystem restoration; final assessment of the progress until all metrics have been met, and the system is ready to be delisted as an AOC (George and Boyd, 2007). RAPs have been based on

* Corresponding author.
E-mail address: georgea@utsc.utoronto.ca (G.B. Arhonditsis).

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a variety of stakeholders from a range of sectors, including but not limited to governmental organizations, academia, industry, agriculture, and conservation agencies (Krantzberg, 2012b), with several AOCs encouraging active participation from local community members. To date, seven out of 43 AOCs have been delisted through this process (White Lake, Deer Lake, Presque Isle Bay, Oswego River, Collingwood Harbor, Severn Sound, Wheatley Harbor), while two other AOCs are "in recovery" status (Jackfish Bay, Spanish Harbor); the latter classification implies that all RAP actions to restore water quality and ecosystem health have been completed, but more time is needed for the environment to recover and for environmental quality objectives to be achieved. The GLWQA marks a novel approach in environmental governance through the incorporation of citizen participation into transboundary environmental protection between Canada and the United States (Krantzberg, 2012a). Community participation provides valuable experiential knowledge, deeper understanding of facts, recognition of natural variability and uncertainty, and incorporation of human values and beliefs (Perkins, 2011; Dietz, 2013). Including citizens in the decision making process also helps legitimize decisions and promotes funding (Krantzberg, 2003). A characteristic example of public consultation was the Ashtabula River and Harbor (Ohio, US), where local citizens not only accepted taxation to support the clean-up of the local AOC, but also formed a successful partnership with governmental bodies that facilitated the local remediation efforts (Lichtkoppler and Blaine, 1999).

Integrating stakeholder and public values with scientific evidence and cost–benefit analyses can be a challenging task, since decision making in environmental restoration projects involves inherent trade-offs among sociopolitical, environmental, ecological, and economic factors (Cangelosi, 2001; Nelson et al., 2009; De Groot et al., 2010; Wegner and Pascual, 2011). Stakeholder and public values can easily become intractable during the decision making process, as they cannot be translated easily into monetary values or quantitative terms (Kiker et al., 2005). Conversely, stakeholders and public have played a key role in encouraging governmental bodies to take more responsibility, as well as in minimizing the risk of future polarization (Krantzberg, 2012b). Public involvement may be as simple as having water users give feedback on the esthetic and water-quality changes of a waterbody (e.g., Carroll and Strang, 2014). Public participation is not unique to the Canadian or American AOCs in the Great Lakes area (e.g., Warriner et al., 1996; Irvin and Stansbury, 2004). For example, Papillion Creek (Nebraska, US), a heavily degraded watershed with flooding issues, is a case where public participation was unsuccessful, in part due to their limited power to forcefully guide the decision making process (Irvin and Stansbury, 2004). The Grand River watershed (Ontario, Canada) has elicited public consultation regarding issues of resource management, groundwater contamination, and urban development (Warriner et al., 1996). Comparative analysis of all of these issues provided a contextually rich account of the circumstances under which public consultation in watershed management can be beneficial for the local restoration efforts (Warriner et al., 1996). Along the same line of thinking, Warriner et al. (1996) highlighted the importance of giving community members an active role in the decision making process, arguing in favor of the notion that ecologically minded societies should embrace direct rather than representative democracy. The motivation for increased citizen participation is founded on the assumption that if citizens become active participants in the policy-making process, governance will become more democratic and effective. One more reason for citizen participation is that ecosystem services embody characteristics of public goods, so we need to employ methodologies that capture their collective character. As a result, policies will be developed with impartial consideration of citizen preferences, and the public will become more understanding of the challenges underlying the decisions made by government administrators (Irvin and Stansbury, 2004).

The objective of this paper is to present a Bayesian methodological framework that engages the perspective of the public on the criteria-setting process through the development of predictive linkages among measurable water-quality variables, such as total phosphorus (TP) and chlorophyll *a* (Chl*a*) levels, and the anticipated public response. The Bay of Quinte (Ontario, Canada) is used as a case study to understand the decision making process and the type of information contributed through citizen participation practices. Based on surveys of visitors and local residents of the Bay of Quinte, we attempt to elucidate the level of public satisfaction with the prevailing conditions in the system. Our framework addresses the urgent need for novel policy analysis tools that bring a shift towards a more democratic and effective governance through (*i*) the introduction of the preferences of primary users/consumers of ecosystem services, which has been a major oversight of the contemporary environmental management practices; and (*ii*) the ability to iteratively update our beliefs by accounting for the significant variability in space and time as well as the uncertainty with our knowledge of the ecosystem functioning.

2. Methods

2.1. Module 1: Public Survey

The first module of our framework involves the public survey to address questions pertinent to the Beneficial Uses of the Bay of Quinte AOC. We prepared a questionnaire to assess the perceptions of both local residents and tourists. The questionnaire comprised twenty-two (22) questions, surveying their preferential uses, their perceptions/concerns about the bay, and their demographic information (Please refer to our Supporting Information). All the representatives from the RAP technical team and the University of Toronto Research Ethics Committee reviewed the questionnaire (RIS Prod ID 00028997). Some modifications were also implemented based on public feedback. We visited the Bay of Quinte and conducted random surveys of local residents and tourists from May to September in 2013 and in 2014 (a total of 25 visits). Average survey length was approximately three minutes per person. A total of 721 individuals were surveyed in 2013 and 806 individuals in 2014 (N = 1527). The main sites were four towns in the upper (Trenton, Belleville, and Deseronto) and middle bay (Picton), where we could access high population numbers to facilitate our survey (Fig. 1).

2.2. Module 2: Bayesian Modeling of Public Perception

The second module aims to assess public perception of the prevailing water-quality conditions according to the socio-economic status (e.g., age, gender, education level and income) of the respondents at different locations and periods of the year. Public perception analysis focused on two important questions: (*i*) What is the level of public satisfaction with the current state of the Bay of Quinte? (*ii*) How does the socio-economic status of respondents relate to their satisfaction? To assess public satisfaction, we developed a multinomial model that quantifies the likelihood of a certain public sentiment/attitude in time and space. The governing equations are as follows:

$$Y_{ijk} \sim \text{Multinomial}_{(p_{ijk}, N_{ij})}$$

$$p_{ijk} = \phi_{ijk} / \sum \phi_{ijk}$$

$$ln(\phi_{ijk}) = \alpha_{ik} + \beta_{jk}$$

$$\sum \alpha_{ik}, \sum \beta_{jk} = 0$$

$$\alpha_{ik}, \beta_{jk} \sim N(0, 10000)$$

where Y_{ijk} is the number (counts) of public response for five satisfaction levels k; in group category j (age, amount willing to donate, education level, and gender) in different months (May to August) or locations i with a given sample size N_{ij}; p_{ijk} refers to the probability of the public