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Research article

Attributes of successful actions to restore lakes and estuaries degraded by nutrient pollution

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ABSTRACT

As more success is achieved in restoring lakes and estuaries from the impacts of nutrient pollution, there is increased opportunity to evaluate the scientific, social, and policy factors associated with achieving restoration goals. We examined case studies where deliberate actions to reduce nutrient pollution and restore ecosystems resulted in ecological recovery. Prospective cases were identified from scientific literature and technical documents for lakes and estuaries with: (1) scientific evidence of nutrient pollution; (2) restoration actions taken to mitigate nutrient pollution; and (3) documented ecological improvement. Using these criteria, we identified 9 estuaries and 7 lakes spanning countries, climatic regions, physical types, depths, and watershed areas. Among 16 case studies ultimately included, 8 achieved improvements short of stated restoration goals. Five more were successful initially, but condition subsequently declined. Three of the case studies achieved their goals fully and are currently managing to maintain the restored condition. We examined each case to identify both common attributes of nutrient management, grouped into 'themes', and variations on those attributes, which were coded into categorical variables based on thorough review of documents associated with each case. The themes and variables were organized into a broad conceptual model illustrating how they relate to each other and to nutrient management outcomes. We then explored relationships among the themes and variables using multiple correspondence analysis (MCA). Results of the MCA suggested that the attributes most associated with achieving restoration goals include: (1) leadership by a dedicated watershed management agency; (2) governance through a bottom-up collaborative process; (3) a strategy that set numeric targets based on a specific ecological goal; and (4) actions to reduce nutrient loads from all sources. While our study did not provide a comprehensive road map to successful nutrient management, it suggested attributes that could be emulated in future efforts. The quantitative approach that was applied could be used to provide ongoing analysis as new examples of nutrient management success emerge.

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1. Introduction

Nutrient pollution of aquatic ecosystems accelerated globally starting in the 1950s, reflecting a variety of causes associated with growing human population and the necessary increased provision of developed land, food, and energy (Davidson et al., 2012). Extensively documented negative water quality responses often include harmful algal blooms, hypoxia, habitat degradation, and adverse changes in aquatic food webs (National Research Council, 2000). Significant efforts have been undertaken in some cases to reduce loading of nutrients to lakes or estuaries, or to otherwise mitigate the impacts of nutrient pollution. As these efforts have matured, the number of cases in which management actions have achieved some success has increased, enabling examination of the ecological patterns and processes associated with recovery and restoration (Borja et al., 2010; Duarte et al., 2009; Jeppesen et al., 2005; Kemp et al., 2009; Verdonschot et al., 2013). Examples of successful restoration also present the opportunity to evaluate what scientific, social, and policy factors are associated with successful restoration, with the idea that this information could inform new or ongoing programs that seek to restore lakes and estuaries

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from nutrient pollution.

Papers examining policy, planning, and management of natural resources in general, and water resources in particular, have identified a variety of relevant issues and concepts. These include studies of the 'focusing events' that lead to new policy initiatives (Birkland, 1996; Prokopy et al., 2014), the antecedents to forming managing partnerships (Selin and Chavez, 1995; Waddock, 1989) and the effectiveness of partnerships in terms of their implementation of plans and satisfaction of stakeholders (Koontz and Newig, 2014; Leach and Pelkey, 2001). Some studies have begun with examples of policy efforts, then evaluated factors associated with achieving the policy objectives, whatever those may be. For example, Ansell and Gash (2008) examined cases of collaborative governance to identify factors associated with successful collaboration. In their study, successful collaboration was defined by having generated the desired governance process, not necessarily by achieving the desired environmental outcomes, which until recently have been relatively uncommon. Similarly, Leach and Pelkey (2001) defined a successful watershed partnership in organizational terms or "capacity building," while acknowledging that watershed managers would generally focus on ecological outcomes.

As more remedial actions are implemented, research – often utilizing the results of long-term monitoring data – has documented ecosystem responses to these actions. This includes reviews and comparative studies of recovery from various stressors, including nutrient enrichment in rivers, lakes, estuaries, and coastal systems (Borja et al., 2010; Jeppesen et al., 2005; Verdonschot et al., 2013). Many concepts in restoration ecology have been defined and explored, such as recovery, resistance, and resilience (Elliott et al., 2007), hysteresis and shifting baselines (Duarte et al., 2009), passive and active restoration (Simenstad et al., 2006), adaptive management (Rist et al., 2013; Williams, 2011), and integrated environmental management (Margerum and Born, 1995). These restoration concepts are relevant to nutrient management.

In this study, we examined case studies in which documented improvements in ecological condition of lakes and estuaries resulted from deliberate policy actions to manage and reduce nutrient pollution or its impacts. We define "success" with respect to such improvements and provide further clarification of our definition below. Because it is not possible to identify and fully understand the potentially numerous cases in which nutrient pollution effects are present but policy responses have not yet resulted in improved ecological outcomes, we did not evaluate cases of non-success. We did consider cases where success was qualified in some way (e.g., partial, temporary). Our hypothesis is that there are common themes present in examples of successful nutrient management in lakes and estuaries and that some variations of these themes are more commonly associated with unqualified or sustained management success.

2. Methods

Our overall approach can be characterized as having four steps. These include: (1) identifying case studies of ecological improvement, (2) identifying themes and variables related to nutrient management, organizing via a conceptual model, and categorizing each case study, (3) evaluating relationships among themes and variables using multiple correspondence analysis and (4) evaluating the resulting relationships to draw overall conclusions.

2.1. Case studies of ecological improvement

We identified prospective case studies from a survey of scientific literature and water resource agency documents for lakes and estuaries with: (1) scientific evidence of nutrient pollution; (2) restoration actions implemented to mitigate nutrient pollution and its effects; and (3) documented medium to long-term ecological improvement at the whole ecosystem scale. Examples of ecological improvements include reduction in harmful algal blooms (HABs), reduced abundance of nuisance macroalgae, increased submerged aquatic vegetation coverage (seagrass or freshwater macrophytes); increased coral abundance, and increased benthic faunal diversity and species richness. Water quality improvement alone, such as decreased extent of hypoxia, did not meet our criteria unless accompanied by a biotic response such as improved benthic community condition. Literature sources were initially drawn from reviews addressing ecological recovery (Borja et al., 2010; Jeppesen et al., 2005). Additional case studies were identified from the National Estuarine Eutrophication Assessment Update (Bricker et al., 2007), the European Union Freshwater Eutrophication Assessment (Lyche-Solheim et al., 2010), Australian Department of the Environment Water Quality Hotspots (Australian Department of the Environment), and the US Environmental Protection Agency Non-Point Source Success Stories (US Environmental Protection Agency). Additional cases were identified from literature associated with the case study reviews. Details of restoration actions were obtained directly from agency websites, technical documents, and from reports prepared by the respective management agencies and their reviewers.

2.2. Model of nutrient management themes

Once case studies were selected, general aspects of the nutrient management effort that were common to each case, but with different variations, were grouped into 'themes.' These themes were defined based on similar groups of factors from the public policy, natural resource management, and restoration ecology literature, and from published reviews of freshwater and estuarine restoration. Whenever possible, existing terms, definitions, and models were used to bridge the disciplines and ensure consistency with previous work. A conceptual model was developed using the resulting themes, and was then applied to each case of successful nutrient management.

To evaluate the cases, the restoration actions that local researchers and other experts believed were most responsible for ecological improvements (e.g. improved sewage treatment, agricultural controls, wetland restoration, etc.) were identified based on their peer reviewed publications and other technical documents. Other initiatives that local experts did not believe were a significant factor in the recovery (as expressed in reviewed documents) were not considered. Information related to each theme was gathered from the literature, and then the variations in each theme were coded into categorical variables to enable a systematic, reproducible analysis of the information (e.g. Biddle and Koontz, 2014; Leach and Pelkey, 2001). The resulting mutually exclusive variables were determined for each case, then added to the conceptual model. Useful details illustrating application of theme variables to our case studies are presented in the Supplementary Material including supplementary tables (Table S1, Table S2, Table S3).

2.3. Multiple correspondence analysis

Relationships among themes and the theme variables that characterized each case study were explored using multiple correspondence analysis (MCA). MCA is an ordination technique applied to reduce the dimensionality of the data when observations (i.e. case studies) are described by multiple categorical variables (Le