An Inquiry-based Case Study for Conservation Biology

Nathaniel P. Hitt
Brian R. Murphy

Case studies provide an important tool for inquiry-based science education but require careful consideration of how class activities promote specific learning objectives. Here, we present a case study of the implementation of the Clean Water Act in Stroubles Creek, Virginia. In contrast to a lecture format, our approach achieves learning objectives by requiring students to ask and answer a series of questions related to the case study. First, we present a "teaching case" to be distributed to students. Second, we provide "teaching notes" for instructors to facilitate student activities. Third, we report on our use of this case study during a 50-minute session for an undergraduate course in conservation biology.

Introduction

Case studies offer an important strategy for inquiry-based science education by requiring students to be active participants in addressing a current problem or issue. Unlike traditional lectures, course content in case study teaching stems from the case study itself (Herreid, 1994). This approach implements a constructivist educational strategy by focusing on student integration of new information into an existing framework (Bransford & Brown, 1999) in support of the National Science Education Standard for "inquiry-based" science education (NRC, 2006). In this article, we (1) present an "appraisal" case study (Herreid, 1994) to facilitate student inquiry into the normative and scientific aspects of conservation biology and (2) emphasize the methods for implementing an inquiry-based educational strategy (Prince & Felder, 2007).

This case study addresses the normative basis of environmental law, the scientific basis of implementing environmental law, and how these concepts interact. Implementation of the Clean Water Act (CWA) in Stroubles Creek, Virginia, USA provides the setting for this case study. The goal of this case study is to understand the conceptual basis of the "biological integrity" mandate of the CWA and how this mandate is implemented in scientific surveys of streams and rivers (i.e., bioassessments). Learning objectives are for students to:

- Distinguish between scientific and normative aspects of the CWA's "biological integrity" mandate;
- Understand the role of reference conditions in measuring biological integrity;
- Recognize how biological traits can affect pollution tolerance in streams; and
- Recognize some critical uncertainties in CWA implementation.

First, we present a "teaching case" to be distributed to students prior to class. Second, we present "teaching notes" for instructors to facilitate classroom activities. Third, we report on our use of this case study at Virginia Tech. Although this case study is designed for a class in conservation biology, modifications could make it appropriate for courses in freshwater biology, fisheries management, non-point source pollution modeling, or environmental law.

Teaching case

> *When asked why anyone should care that the Environmental Protection Agency put Stroubles Creek on its list of impaired streams in 1998, Llyn Sharp didn't say anything for several seconds. "I'm stunned anyone would ask that question," she said. "Our freshwater resources are societal treasures."*
>
> *Roanoke Times*, April 16, 2005. "Stroubles Creek water Plan needs volunteers"
>
> *More than two dozen people turned out for Wednesday night's meeting about cleaning up Stroubles Creek. Unfortunately, most of them represented state or local governments or Virginia Tech, and the effort to clean Stroubles is supposed to be dominated by regular residents, not officials. The intent, Tech researcher Gene Yagow said, "is to be driven by local people, local stakeholders."*
>
> *Roanoke Times*, June 3, 2005. "Decade-long effort commences to clean Stroubles Creek"

The policy

The Clean Water Act (CWA) of 1972 is one of the Nation's most important environmental laws. The Act was created "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This is the only federal law requiring conservation of the "biological integrity" of ecosystems. Although this law provides important conservation opportunities, defining and implementing concepts of biological integrity present significant challenges for conservation biology.

Here, we focus on section 303d of the CWA. This section requires states to identify specific stream segments that are impaired and report these to the U.S. Environmental Protection Agency (USEPA) on a biannual basis. Once a stream is listed as "impaired," state agencies must then conduct a Total Maximum Daily Load (TMDL) study to identify the sources of pollution and establish allowable limits for pollution input (Yagow, et al., 2006). Nationwide, over 300,000 miles of rivers and shorelines are listed as "impaired," requiring over 40,000 separate TMDL analyses (NRC, 2001).

The CWA specifies that states must assess impairment based on the designated uses for a given water body. In Virginia, state law specifies a general standard for designated uses:

> "All state waters…are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of

> edible and marketable natural resources (e.g., fish and shellfish)." (Virginia Administrative Code, Title 9, Section 25-260-10; see http://leg1.state.va.us/)

The place and the problem

Stroubles Creek is a tributary of the New River in Montgomery County, Virginia (Figure 1). The stream headwaters originate in the town of Blacksburg and flow under the Virginia Tech campus and through several ponds (i.e., the "duck ponds"). From the duck ponds, the stream flows approximately 20 km through agricultural and forested areas to its confluence with the New River. The upper Stroubles Creek watershed consists mostly of urban and agricultural land uses.

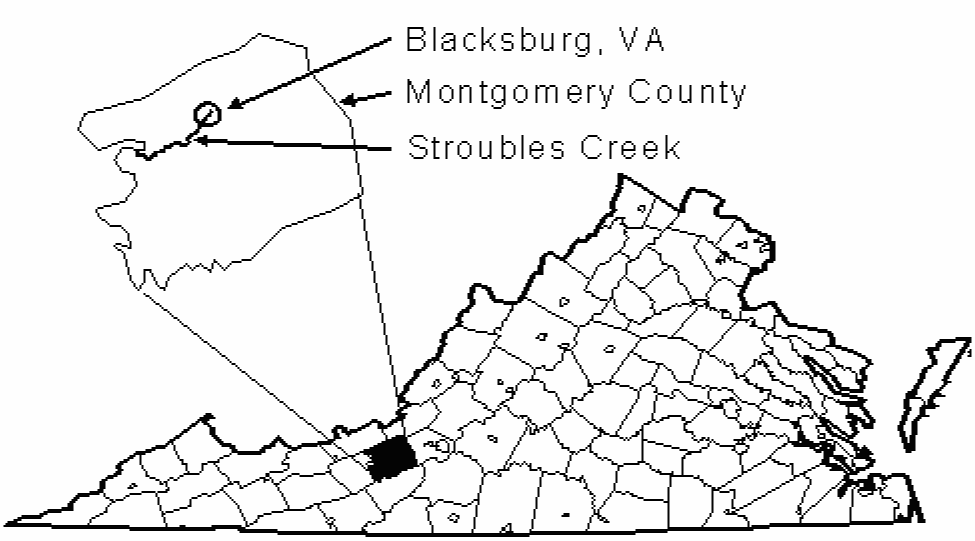

Figure 1. Location of Stroubles Creek in Montgomery County, Virginia.

In 1998, the USEPA and the Virginia Department of Environmental Quality (VDEQ) listed Stroubles Creek as an "impaired water body" based on 5 years of benthic macroinvertebrate data (Benham, et al., 2003). VDEQ determined that the taxonomic diversity of benthic macroinvertebrates was lower than expected and the abundance of net-spinning caddisflies was higher than expected, based on comparisons to a nearby reference site (Tom's Creek). The designated "impaired" section of Stroubles Creek begins on the Virginia Tech campus and extends approximately eight kilometers downstream.

A TMDL study was then initiated to identify the specific pollutants that caused the observed problems in the benthic macroinvertebrate community. The TMDL study analyzed chemical water quality data collected from a site located eight km downstream from the benthic macroinvertebrate sampling area. The study identified organic matter, nutrients, and sediment as possible stressors, but chose sedimentation as a focal stressor for mitigation (Benham, et al., 2003). In this analysis, sedimentation was estimated with the Generalized Watershed Loading Function (GWLF) and land use data. GWLF does not consider the spatial configuration of land uses (i.e., proximity to streams) but instead averages land uses upstream of analysis areas.

Public meetings, field trips, and working groups were used to develop an Implementation Plan for the TMDL. The TMDL Implementation Plan aims for a 77% reduction in agricultural sediment inputs and a 54% reduction from urban sources (Yagow, et al., 2003). Specific objectives of the TMDL Implementation Plan involve Best Management Practices for the agricultural areas and storm water reductions for the urbanized areas (Benham, et al., 2003; Yagow, et al., 2003). Successful restoration of the stream (and delisting from the CWA) will require the cooperation of many stakeholders, including landowners, Virginia Tech, the town of Blacksburg, and natural resource agencies. Although the TMDL establishes a legal limit for pollution in Stroubles Creek, landowner implementation of the TMDL is voluntary. As such, it remains to be seen whether or not the current implementation of the CWA will be successful in restoring the stream.

Teaching notes

Class activities

Students should read the "teaching case" prior to class. In class, the instructor should first introduce the case study by explaining the importance of the CWA and the specific learning objectives for the class session (see USEPA [2007] for an introduction to the CWA). Following the discussion format of Herreid (1994), we recommend a series of rapid brainstorming exercises to help students achieve the learning objectives listed above. For each exercise, we provide specific objectives for class discussion and recommend time allocations for using this case study in a 50-minute class session.

Question #1: What is "biological integrity?"

When asked to define integrity, students may invoke concepts of health, stability, naturalness, wholeness, functionality, and diversity. The instructor should ask follow-up questions to demonstrate that (a) naturalness is a normative concept, (b) organisms can be "healthy" whereas ecosystems cannot, (c) stability can be non-natural in some cases (e.g., dams reducing downstream flow variability), and (d) assessing "integrity" requires a standard for comparison (i.e., reference conditions). For example, the instructor may wish to ask students "what is pollution?" to illustrate that their established notions of "pollution" invoke a normative basis of naturalness and require a baseline for comparison.

The primary objective for this brainstorming exercise is to illustrate that the CWA's biological integrity mandate includes normative concepts (i.e., integrity is good) as well as scientific concepts (i.e., role of reference conditions) (Policansky, 1998). The reference site concept leads into the next brainstorming exercise. The desired outcome of this exercise is for students to identify their own questions related to the concept of reference conditions in assessing environmental quality (e.g., "how does Stroubles Creek compare to reference conditions?"). For a 50-minute class, this exercise and discussion should take approximately 15 minutes.

Question #2: Why were net-spinning caddisflies more abundant in Stroubles Creek than in the reference stream?

The primary objective for this exercise is for students to hypothesize mechanistic links between water quality and biological responses. Students may or may not be familiar with the biology of net-spinning caddisflies (family Hydropsychidae). In either case, students should generate a list of hypotheses to explain why net-spinning caddisflies (or any benthic macroinvertebrate taxon) would be more abundant in a degraded stream than a pristine stream. To accomplish this, instructors may wish to show a brief video clip from *Freshwaters Illustrated* showing feeding behavior of Hydropsychid caddisflies. This video clip is available on-line (*www.freshwatersillustrated.org*) but requires membership for a nominal fee.

In this video, students will see that net-spinning caddisflies feed by collecting suspended particles from the water column in the net they create. As such, net-spinner abundances have been shown to increase in streams with high nutrient concentrations (Voshell, 2002), suggesting a "bottom-up" mechanism controlling local abundances. For example, increased nutrients can permit growth of algae that becomes food for net-spinning caddisflies. Other hypotheses may involve the exclusion of competitors or predators (i.e., "top-down" mechanisms controlling local abundances). The desired outcome for this exercise is for students to generate testable questions about how caddisflies may respond to land use, nutrient loads, and suspended particles in streams. For a 50-minute class, this exercise and discussion should take approximately 15 minutes.

Question #3: What actions should the TMDL implement to achieve "biological integrity" in Stroubles Creek?

The final exercise is intended to help students synthesize concepts from this case study and recognize key uncertainties in TMDL implementation. From the previous brainstorming exercise, students should recognize that the increased abundance of net-spinning caddisflies suggests a nutrient enrichment problem, but the TMDL targets were developed for sedimentation, not nutrient enrichment (Yagow, et al., 2003). It is therefore uncertain whether the targets established by the TMDL will achieve biological recovery of Stroubles Creek. However, students should also recognize that some best management practices could reduce both nutrient and sediment problems (e.g., fencing livestock out of the stream, restoring riparian zone vegetation).

Students should also recognize that continued biological monitoring is essential for TMDL implementation (Yagow, et al., 2006) and that both Stroubles Creek and the reference stream (Toms Creek) must be sampled. The key uncertainty in this analysis will relate to how natural variability in benthic macroinvertebrate populations could confound differences between the Stroubles Creek and the references stream. In addition, subsequent degradation of the reference stream would lower the standards for recovery in Stroubles Creek. Finally, students may conclude that social and economic factors will ultimately determine the success of TMDL implementation in Stroubles Creek.

Application

We used this case study during a 50-minute class session in Conservation Biology (FIW 4314) at Virginia Tech in 2006. We present results from informal surveys of students conducted during the class session. Prior to this case study, most students in this class were familiar with Stroubles Creek in some way, but few students were aware that the stream was listed as "impaired" under the CWA. Furthermore, no students indicated an *a priori* understanding of the TMDL program or the "biological integrity" mandate of the CWA.

The first inquiry required students to define "biological integrity" in the CWA. The purpose of this exercise was to illustrate the distinction between normative and scientific aspects of the CWA. Initial student responses to this question included concepts of "naturalness", "wholeness", and "functionality." We then responded with follow-up questions to illustrate that concepts of naturalness imply a normative premise and rely on reference (i.e., relatively pristine) conditions. To describe how normative and scientific concepts interact, we used the analogy of a compass: a compass can show you north (i.e., realm of science) but it can't tell you which direction to go (i.e., realm of normative claims). In this case study, biological integrity was the normative goal, and bioassessment was the scientific tool for achieving that goal.

The second inquiry required students to brainstorm the potential causal links between biological indicators and environmental quality. Some students in this class had experience in entomology and were able to hypothesize why net-spinning caddisflies were more abundant in Stroubles Creek than in the reference site (i.e., nutrient enrichment). However, most students had very limited entomology experience and therefore developed more general causal links. We found that it was useful to organize the brainstormed list of concepts in two columns on the chalkboard: biotic traits and environmental conditions. We further organized the biotic traits according to a hierarchy of organismal, population, and community attributes. We then drew lines between columns to illustrate possible causal links to environmental conditions. We explained which links were more plausible than others and that all of these potential relationships comprise testable hypotheses.

The third inquiry required students to integrate concepts from this case study to illustrate the forms of uncertainty in CWA applications. One student commented that changes in the reference condition (i.e., Toms Creek) could bias interferences about recovery in Stoubles Creek. During follow-up questions, we asked the student to explain how this bias could contribute to either type I or type II errors based on sampling methodologies as well as changes in the reference site. One student commented that the greatest source of uncertainty for recovery of Stroubles Creek was not within the realm of science, but instead the realm of politics. During follow-up questions, we encouraged the student to define a hierarchy of political decisions most relevant for Stroubles Creek and how scientific investigations could inform political decisions at each level.

Conclusion

The Stroubles Creek case study provides an opportunity to implement inquiry-based science education in conservation biology. Here, we have provided a "teaching case" to be distributed to students and "teaching notes" which provide general recommendations for instructors to use this case study. We found that this case study approach was useful for engaging students and addressing specific learning objectives. As such, we believe that case studies may contribute to inquiry-based strategies for science education (Prince & Felder, 2007). Additional background on the Stroubles Creek TMDL may be found at www.vwrrc.vt.edu/stroubles/watershed/watershed.html.

References

Benham, B., Brannan, K., Dillaha, T., Mostaghimi, S., Wagner, R., Wynn, J., et al. (2003). Benthic TMDL for Stroubles Creek in Montgomery County, Virginia. Retrieved July 13, 2007 from http://www.deq.virginia.gov/tmdl/apptmdls/newrvr/stroub.pdf

Bransford, J.D., & Brown, A.L., (Eds.). (1999). *How people learn: Brain, mind, experience, school*. Washington, DC: National Academy Press.

Herreid, C.F. (1994). Case studies in science-a novel method of science education. *Journal of College Science Teaching*, 23, 221-229.

National Research Council (NRC). (2001). Assessing the TMDL Approach to Water Quality Management. Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction, Water Science and Technology Board, National Research Council. Washington, DC: National Academy Press.

National Research Council (NRC). (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

Policansky, D. (1998). Science and decision making for water resources. *Ecological Applications*, 8, 610-618.

Prince, M., & Felder, R. (2007). The many faces of inductive teaching and learning. *Journal of College Science Teaching*, 36, 14-20.

United States Environmental Protection Agency (USEPA). (2007). *Introduction to the Clean Water Act*. Retrieved July 13, 2007 from http://www.epa.gov/watertrain/cwa

Voshell, R. (2002). *A Guide to Freshwater Invertebrates of North America*. Virginia: McDonald & Woodward Publishing Company.

Yagow, G., Wilson, B., Srivastava, P., & Obropta, C.C. (2006). Use of biological indicators in TMDL assessment and implementation. *Transactions of the American Society of Agricultural and Biological Engineers*, 49, 1023-1032.

Yagow, G., et al. (2003). Upper Stroubles Creek watershed TMDL Implementation Plan, Montgomery County, Virginia. Retrieved July 13, 2007 from http://www.deq.virginia.gov/tmdl/implans/stroubip.pdf

Nathaniel P. Hitt is a Research Associate with the Department of Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University in Blacksburg, VA. He can be reached via email, than@vt.edu.

Brian R. Murphy is Professor of Fisheries Science with the Department of Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University in Blacksburg, VA.