Using Problem-based Learning to Teach Concepts for Ecological Restoration

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ABSTRACT

The uncertainty that characterizes ecological restoration presents a challenge for both instructors and practitioners. There are uncertainties arising from unknown synergistic effects between organisms and their environment. There are more uncertainties due to insufficient data about the physical and biological features of an area and how it became degraded. These complexities are compounded by multiple perspectives involved in establishing appropriate restoration targets, identifying relevant reference ecosystems, and exploring potential novel ecosystems. In contrast to one-way knowledge dissemination common in most university settings, problem-based learning allows students to develop technical and problem-solving skills that we believe provide a valuable approach to working with the uncertainties and complexities inherent in ecological restoration. Problem-based learning promotes a better understanding of problems and teaches students to find their own solutions to restoring degraded environments and to expect uncertainty. We can also use problem-based learning to clarify the meaning and application of adaptive management as a process to reduce uncertainty. The three case studies we present to illustrate our point and the ecological concepts relevant to ecological restoration they represent are: 1) reductions in biodiversity on gulf islands; prey suppression, trophic cascades; 2) nitrogen fertilizer impacts on moles; prey switching, peripheral populations, invasive species, novel ecosystems; and 3) interspecific competition between squirrels; commensalism, niche width.

Keywords: adaptive management, case studies, education, restoration concepts

Problem-based learning (PBL) is an instructional method in which students learn both content and thinking strategies through facilitated problem-solving exercises (Barrows 1996). There is evidence that PBL results in greater learning than traditional lectures (Wells et al. 2009, Barrett 2010). PBL originated in medical education and has been effective in training physicians for decades (Albanese and Mitchell 1993). Conceptually, restoring natural systems is similar to healing the human body with its complexities, synergisms, and thresholds (Schaefer 2006). In fact, restoring nature has been referred to as "helping the land heal" (BC Environmental Network 1999). We propose that the similarities between restoration ecology and medicine (Schaefer 2006) make PBL an effective approach to teaching restoration ecology as well.

The increased success of students involved in PBL is based on the ability of PBL to activate prior knowledge more effectively and to establish a context that resembles real-world situations (Jones 1996). PBL also supports and enhances student information gathering skills and retention through implementation of basic and clinical sciences, where student knowledge, interests, and motivation are increased (Finucane et al. 1998). In a review of the literature on problem-based learning Norman and Schmidt (1992) conclude that the technique does not improve skills in general, content-free situations. However, there is evidence that suggests that PBL enhances the transfer of concepts to new problems. It also fosters a better integration of basic science concepts into applied problems and clinical problems in the case of research. These lateral thinking skills of transferring concepts to new problems are important for students of ecological restoration to learn. They also result in students who are more scientifically literate and understand overarching core concepts such as systems, structure and function, pathways and transformation of energy and matter, evolution, and information flow and exchange (AAAS 2011).

Ecological restoration involves reintroducing elements lost in disturbed ecosystems and setting in motion the negative feedback loops such as predator-prey relationships that maintain ecosystem resilience (van Andel and Aronson 2012). Species and processes interact in complex ways that can be difficult to predict. This complexity is overlooked by some practitioners who apply general approaches without considering underlying causes of ecosystem degradation or testing areas of uncertainty to improve understanding (Frissell and Nawa 1992). Other practitioners may become paralyzed by uncertainty (Cranor 2001, Ascher

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2004). The inaction from uncertainty can interfere with timely interventions necessary for ecological restoration.

Although often misinterpreted to mean *ad hoc* trial and error, adaptive management is, in fact, a structured, iterative process that can reduce uncertainty over time through the use of experimental (management) trials and monitoring (Williams 2011). The feedback between learning and decision-making is a defining feature of adaptive management. Restoration activities contribute to learning through interventions that inform ecological processes and the impacts of management. Restoration activities can be viewed as experimental "treatments" that are implemented according to a management design, with the resultant learning seen as a means to an end, namely effective management, and not an end in itself (Walters 1997).

Problem-based learning presents an opportunity to clarify the term "adaptive management" for future restoration practitioners through their application of structured problem-solving to ecological problems. By researching and identifying the uncertainties inherent in the PBL problems as hypotheses, students can more clearly envision the adaptive management trials that will reduce uncertainty.

Problem-based Learning for Ecological Restoration

There are multiple perspectives in setting appropriate restoration targets, identifying reference ecosystems, and determining potential novel ecosystems. These multiple perspectives combined with uncertainties in our knowledge of natural ecosystems make teaching ecological restoration a challenge. We were motivated to use problem-based learning as one approach to address this challenge. We developed case studies that would illustrate the complexities inherent in understanding ecological relationships and appropriate restoration actions. Students studying ecological restoration come from a variety of backgrounds and we were looking for a direct, effective way to teach the subject to a broad audience.

Students also sometimes tended to propose simplistic restoration targets. They would focus on the superficial aspects of a problem and overlook underlying principles. For example, students may assume that all you need for a restoration target was the appropriate reference ecosystem or to determine the climax community for an area from terrestrial ecosystem mapping. However, neither approach provides appropriate restoration targets in certain situations, especially in permanently altered conditions as found in cities. The problem-solving skills needed to promote a better understanding of a particular situation and to solve open-ended real-world problems can be developed through the discussion-oriented learning environment of problem-based learning (Singer and Bonvillian 2013).

One of the best practices in education that fosters a better understanding of material is using Backward Design (Wiggins and McTighe 2005). The idea is to start with an outcome, what we want the student to achieve, and work backwards. This flips the traditional curriculum development process and works well for teaching ecological restoration. With ecological restoration, the outcome is to engage with the complexity of the natural world and the case study in which problem-based learning is used becomes the final third stage of Backward Design, the instructional activity. The first two stages of Backward Design would be to clearly articulate learning goals and to identify how assessment demonstrates student knowledge/skills.

We presented one or more of the three case studies described in this article to three classes in the Restoration of Natural Systems (RNS) Diploma Program and the Native Species and Natural Processes (NSNP) Certificate programs at the University of Victoria, British Columbia. RNS Diploma courses are at the 3rd and 4th year undergraduate level and can be applied to a BSc but the Diploma is also taken by people with degrees to improve their applied skills. The NSNP Certificate has a prerequisite of a BSc and is usually taken by practitioners for professional development.

For each problem we provided the students with: 1) the observation that was the problem to be solved; 2) a handout with background and supplementary information; and 3) some primary references. Students were encouraged to conduct further research using Google Scholar. Students were first asked to develop at least one hypothesis to explain the mechanism behind the observation. Given their understanding of the situation, students then deliberated on a proposal for a potential solution to restore the disturbed ecosystem. They worked in the classroom in groups of 3–4 for one hour to explore possible scenarios. The class then reconvened as a whole to discuss the results of the group work. Students were not evaluated at the time of the exercise. Instead, they were required to write a major essay on their final exam that involved evaluating their skill in integrating science concepts into an applied problem, and a significant component of their major course project involved articulating and addressing uncertainty in a restoration project.

In this article, in addition to describing the student activities, we also provide some ecological principles illustrated by the problem that we as instructors used for discussion at the end of the problem-solving process.

Problem 1: What happened to the birds in paradise?

For students

Observation: Islands and islets in the Salish Sea archipelago are experiencing a loss of avian biodiversity, even though they are federally protected.

Background: The Salish Sea archipelago, spanning the BC, Canada-Washington, USA border, is a mix of private and protected lands. It contains beautiful islands with high ecological integrity and rare ecosystems. First Nations used some islands for seasonal camps and camas harvest (MacDougall et al. 2004). The biggest islands, such as the Southern Gulf islands in Canada and the San Juan Islands in the United States, suffer the greatest human impacts because they had trees large and straight enough for logging, soils deep enough for agriculture, or meadows large enough for grazing. In 2003, Gulf Islands National Park Reserve became the 39th park in the Canadian national park system. The lands for the national park were previously provincial parks, ecological reserves, and private land.

The islands of the national park vary in plant composition. Some are dominated by invasive grasses and others have a simplified forest structure. The smallest islands retain some of the highest proportions of native species, although overall they have fewer species than large islands. It is likely that the abundance of native species has been declining for some time; however, declines have been noticeable in the past two decades.

Questions to consider: What may be the impact of invasive plant species on bird populations and how can mobile species moving in and out of protected areas have an impact on avian biodiversity in the protected areas and habitat degradation of winter ranges for migratory species?

Supplementary information:

1. Bigger isn't better? Island biogeography predicts that large islands close to the mainland will have more native species than small isolated islands. However, within the Southern Gulf Islands, the small, isolated islands have the greatest abundance of native species.
2. Where did all the flowers go? One reason for the species-area relationship is the greater diversity of plants and habitat for wildlife on larger islands. Yet there are some moderately sized islands where forest structure is simplified (a lack of understory) and invasive grasses predominate in non-forested areas. Songbird diversity is also lower on these islands.

For Instructors

Martin et al. (2011) found that the density of alien fallow deer (*Dama dama*) or native black-tailed deer (*Odocoileus hemionus columbianus*) was associated with the loss of habitat for songbirds on islands in the Salish Sea. As deer densities increased, forest structure became simplified. In particular, forest understory was lost creating a visible "browse line". Increasing simplification in a landscape is correlated with reduced species richness (Gagné and Fahrig, 2011, Winqvist et. al. 2011, Jones et al. 2012, Shimelis et al. 2013).

In the past three decades rising deer populations have had negative impacts on ecosystems, economics, and human health (Côté et al. 2004). Under optimal conditions, deer populations double every two years (Alverson et al. 1988). With the loss of top carnivores in most of southern Canada, hunters are the primary agents that reduce deer populations (Brown et al. 2000). Suburban and protected areas are refuges from hunting, resulting in deer densities that exceed ecological carrying capacity (Rooney and Waller 2003). In some eastern North America parks, hyperabundant deer caused the disappearance of over half of all plant species, plus birds and other species that relied on those plants in just a few decades (Rooney and Waller 2003). Similarly, deer have extirpated native plants and facilitated the invasion of alien grasses in the west coast's endangered Garry oak ecosystems (Gonzales and Arcese 2008, Gonzales and Clements 2010).

The average deer eats nearly 500 kg of vegetation annually (Verme and Ullrey 1984). Deer have a diverse diet and consume a wide variety of plants. However, they have favourite foods they eat first. In Garry oak ecosystems, deer favour certain wildflowers and avoid alien annual grasses (Gonzales 2008). This selective herbivory can create the "illusion" that annual grasses are outcompeting native plants when the shift toward grasses is instead the result of the indirect effects of herbivory. This example underscores the importance of testing hypotheses to understand the causes, and not just the symptoms, of declining biodiversity.

Restoration Concepts

Prey Suppression. Damage on a vulnerable prey species can occur where predator populations are bolstered by alternate prey in high abundance. If one prey species is abundant it can maintain a continuously high predator density. The abundant predator might eliminate a second prey species. For example, caribou declined in the late 1930's and 1940's in BC after moose (*Alces alces*) expanded their range and wolves (*Canis lupus*) increased with this increasing prey source (Bergerud and Elliot 1986). Wolves can survive without caribou, but moose maintain wolf populations higher than caribou populations can tolerate. A similar phenomenon occurs with plants. In our example, deer do not need wildflowers to survive because they eat a variety of other plants and are protected from hunting in the park. The seasonal wildflowers, however, are a favourite prey for deer and suffer when deer densities are high.

Trophic Cascades. A trophic cascade is typically triggered by the addition or removal of species at upper trophic levels that result in descending changes in populations at lower trophic levels. Trophic cascades due to hyperabundant deer have been observed in a number of other protected areas (Martin et al. 2011). Other species at higher, lower and equivalent trophic levels may also potentially be affected by increased deer populations. In Gwaii Haanas

National Park Reserve, the diversity of songbirds (Allombert et al. 2005a) and invertebrates (Allombert et al., 2005b) declined as a result of introduced black-tailed deer. Black bears on Parc National d'Anticosti (Côté 2005) were extirpated by the indirect effects of deer browsing; bears were unable to secure enough food for hibernation.

Problem 2: Why would fertilizing a pasture reduce mole populations?

For Students

Observation: Nitrogen fertilizer reduces digging activity of moles.

Background: In Greater Vancouver, the pastures used by dairy cattle are excellent habitat for the native coast moles. They are entirely fossorial and Glendenning (1959) determined that 93% of their diet is comprised of earthworms (*Lumbricus terrestris*). Coast moles excavate tunnel networks and produce molehills in the process. The hills reduce the amount of feed available for livestock. The earth dulls the blades of harvesting equipment, adding to maintenance costs for farmers. Collapsed tunnels are a hazard to livestock. There are few methods available to control moles. Trapping is time-consuming and largely ineffective. Folklore suggests putting mothballs in the tunnels or burying bottles and is not effective. Although cats occasionally catch them, moles have no natural predators.

European moles (*Talpa europaea*) are similar in size to coast moles with a diet of 100% earthworms. They are pests for the same reasons as coast moles. Ennik (1967) noted that European moles declined in fields treated with nitrogen fertilizer. Although the mechanism was not understood, nitrogen fertilizer was recommended as a treatment to control moles in Europe.

Questions to consider: How might nitrogen fertilizer affect the population numbers of a small mammal and how can agriculture be incorporated into ecological restoration plans?

Supplementary information:

1. The coast mole has the wrong smile. Despite almost identical diets, the dentition of coast moles and European moles differ dramatically (Schaefer 1984). Coast mole teeth are typical of other insectivores like shrews that primarily eat adult insects and their larvae. European moles have dentition typical of carnivores.
2. The endangered Townsend's mole (*Scapanus townsendii*) is one of the rarest mammals in Canada. It occurs within a 20 km² range on the Canada-US border, about 100 km east of Vancouver. Its teeth and diet are similar to that of the coast mole. Townsend's moles are abundant in the United States where they are considered a pest.

For Instructors

Schaefer and Sadleir (1981) hypothesized that nitrogen fertilizer indirectly reduced the digging activity of moles by reducing the abundance of their primary food source, earthworms. Mole activity (measured as the number of hills) was significantly positively correlated with earthworm biomass (Schaefer 1979). Nitrogen fertilizer lowered the pH of the soil and the increased acidity significantly reduced earthworm biomass (Schaefer and Sadleir 1981).

Restoration Concepts

Prey Switching. Ecosystems change over historical time creating conditions that are different trophically and abiotically than the imagined reference ecosystem. *Lumbricus terrestris* is an alien invasive species brought to North America in the late 1700s in the earth ballasts of ships from Europe (Eisenhauer et al. 2007). It spread with agriculture and spread west where native earthworms were rare (Bohlen et al. 2004). With earthworms now abundant, moles switched from their insect diet. The nitrogen fertilizer increased soil acidity reducing earthworm biomass. Therefore, reducing prey abundance controlled predator abundance.

Peripheral Populations. Although Townsend's moles are not threatened globally, the Canadian population is endangered. Abundant in the USA, some Canadian species at risk are protected in Canada because these populations are at the northern-most end of their geographic range. Gene pools of these peripheral populations may be more heterogeneous than populations at the core of a range (Lesica and Allendorf 1995). This heterogeneity could provide resilience to the species in light of climate change, threats from invasive species, and other disturbances.

Invasive Species and Novel Ecosystems. Alien invasive earthworms have created novel ecosystems (Frelich et al. 2006). Since their introduction, the duff layer in eastern forests has been reduced and woodland wildflowers and amphibians have lost their preferred habitat (Bohlen et al. 2004). Townsend's moles have prospered in a novel ecosystem with a habitat of pastureland and new diet of alien earthworms (Pedersen 1963). Prior to European contact the pastureland was a forest of western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) or floodplain forests of black cottonwood (*Populus trichocarpa*) and trembling aspen (*P. tremuloides*).

Problem 3: A tale of two squirrels in BC: Are alien squirrels displacing native squirrels?

For students

Observation: Alien eastern gray squirrels (*Sciurus carolinensis*) have flourished and spread throughout Greater Vancouver, British Columbia.

Background: In 1909, a small number of eastern gray squirrels were transported from New York to Vancouver's

Stanley Park (Gonzales 1999). The squirrels remained within Stanley Park until the 1970's. As eastern gray squirrels became a nuisance in residential properties neighbouring Stanley Park, they were relocated around Greater Vancouver (Gonzales 2000). They then became the most common and widespread squirrel in the region. There are two native squirrels, northern flying squirrel (*Glaucomys sabrinus*), which are rarely seen, and Douglas squirrel (*Tamiascirus douglasii*), which are locally common.

Questions to consider: How can urbanization differentially affect the food supplies of birds and mammals and how can competitive exclusion be distinguished from habitat impacts?

Supplementary information:

1. Pick on someone your own size. Douglas squirrels prefer conifer forest (Carey 1991) whereas eastern gray squirrels prefer deciduous trees (Riege 1991). Douglas squirrels are territorial and build middens from the discards of their conifer cones. Tree recruitment in middens is rare (Goheen and Swihart 2003). In contrast, eastern gray squirrels "scatter hoard". They bury nuts and then locate them again by smell. They maintain a home range but are not as territorial. Despite their smaller size, Douglas squirrels often chase eastern gray squirrels off their territories.
2. Tales of two squirrels elsewhere. Douglas squirrels occur from the west coast to the Cascade Mountains. Red squirrels (*Tamiascirus hudsonicus*) occupy a similar niche space as Douglas squirrels in the rest of North America. Niche segregation allows the co-existence of red squirrels and eastern gray squirrels in Ontario, where both species are native (Riege 1991). In Indiana, red squirrels are expanding their distribution and eastern gray squirrels are declining (Goheen and Swihart 2005). Due to decreased scatter hoarding, large nut bearing trees such as walnuts may decline with the loss of eastern gray squirrels (Goheen and Swihart 2003).

For Instructors

Using data from wildlife shelters about injured wildlife and land-use maps, Gonzales et al. (2008) explored whether the decline of native squirrels was related to eastern gray squirrels abundance or to urbanization. If alien squirrels replace native squirrels there should be a negative relationship between the abundances of the two squirrel species through time. If habitat change caused the decline, eastern gray squirrels should increase with urbanization whereas Douglas squirrels would decline.

The results supported the habitat change hypothesis. If alien squirrels were filling an "empty niche" in the urban landscape, we would expect to see a positive relationship between eastern gray squirrels and urbanization through time—and we do. In contrast, native squirrels were negatively correlated with the amount of urbanization (Gonzales et al. 2008). Further, the habitat change hypothesis predicts that the two squirrel species should co-exist as long as there is sufficient preferred habitat for both species. In fact, both squirrel species have co-existed in their preferred habitats in Stanley Park for over 100 years.

Restoration Concepts

Interspecific Competition. Interspecific competition is when two different species complete for the same resource. Exploitation competition is when resources used by one species are reduced and negatively affected by another species. Interference competition is when one species physically excludes another species from using a particular resource (Davis 2003).

Commensalism. Urban wildlife can have commensal relationships with people. Urbanization displaces natural habitats such as coniferous forests with those dominated by deciduous trees. The horticultural plant species, compost and garbage bins, and buildings of cities provide food and habitat for certain wildlife, also known as human commensal species. Squirrels do not benefit or harm human populations.

Niche Width. A species has a physical and functional space it occupies in an ecosystem. The fundamental niche is the space a species can occupy if limited solely by its own biology. Competition from other species can occupy some of the space of the fundamental niche. This reduced niche width is called the realized niche. In this example, *Tamiasciurus* spp. squirrels and gray squirrels co-exist in Stanley Park and Ontario, suggesting that they have sufficient niche space under those conditions.

Summary

Ecological restoration needs practitioners that can manage and communicate the level of uncertainty in our understanding of an ecosystem and predicting the results of a restoration project. The practitioners can then take steps to reduce uncertainty through adaptive management (Hilderbrand et al. 2005). To do so, our approach to teaching ecological restoration needs to encompass methods such as problem-based learning whereby students grapple with complexity and uncertainty.

It was a pleasant surprise to see how quickly the students engaged with the exercise and how animated they were in their groups. They quickly set themselves to the task, exchanged ideas and used the internet to bring new information into their discussions. They needed no prompting or help from the instructor. The ideas the students came up with were all on topic and they generated valuable discussion in the class.

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