Ecosystem Services Valuation as an Opportunity for Inquiry Learning

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ABSTRACT

Teaching ecosystem services provides an ideal opportunity to use inquiry-based learning to help students make connections between ecological, geological, and social systems. The idea of ecosystem services, or the benefits nature provides to society, has emerged as a key concept in a host of environmental fields and is just beginning to gain attention within the geosciences. Although the concept has the potential to positively affect policy decisions by quantifying the economic value of ecosystem services, it has been criticized for commodifying nature and having limited engagement with geoscience perspectives. To teach ecosystem services to the next generation of geoscientists, we developed two variations of an inquiry-based learning exercise in which students used the ecosystem services approach to assign a monetary value to eight different ecosystem services generated by four ecosystems. One version of the exercise had students make these valuations in the field, whereas one was completed solely in the classroom. In both cases, the students scored significantly better on a postexercise assessment, demonstrated a deeper understanding of the ecosystem services approach, and reported that the exercise was preferable to a traditional lecture. Our data and observations also suggest that this exercise offers a great deal of flexibility and can be used in many learning environments. Geoscientists should be especially interested in integrating the concept of ecosystem services into their courses so that the next generation of geoscientists is well positioned to contribute to the interdisciplinary field of ecosystem services. [DOI: 10.5408/15-138.1]

Key words: ecosystem services, pedagogy, inquiry learning, environmental science

INTRODUCTION

The concept of ecosystem services has become a salient topic across a number of fields, including environmental science, the geosciences, ecology, sustainability science, and ecological economics. In this context, an *ecosystem* includes both the biotic and abiotic components of a given area, and *ecosystem services* are the benefits society gains from ecosystem processes (Costanza et al., 1997). For example, when viewed through the lens of ecosystem services, a forest yields numerous benefits to humans, including timber and other forest products, habitat for plant and animal species, climate regulation from carbon sequestration, water quantity and quality regulation, erosion control, among others. Each of these services can be assigned an economic value as a method of quantifying the benefits humans receive from ecosystems.

As pointed out by Field et al. (2015, 2016), many ecosystem services are produced by exclusively geologic processes or processes that have significant geologic components. For this reason, it is critical that discussions of ecosystem services include geoscientists. Field et al. (2015, 2016) also suggest that these contributions will be most valuable if a critical-zone perspective is employed. Because this zone includes everything from the top of the tree canopy to the deepest groundwater, it is clear that an understanding of the myriad of interconnected systems that operate within this zone will help researchers better assess the production and value of ecosystem services. For geoscientists to collaborate effectively with the ecosystem-services community, it is vital that the idea of ecosystem services becomes integrated into geology and earth science courses so that young geoscientists are exposed to this critical concept.

In addition to its importance within the scientific, economics, and policy communities, the idea of ecosystem services provides an excellent inquiry-based learning opportunity for students to observe ecosystem function, assign values to those functions, and consider the implications of applying those values in the real world. Inquiry activities, in which students follow methods similar to those of scientists to create knowledge (Pedaste et al., 2015), have been shown to not only to maintain higher levels of student interest in science as a whole (Swarat et al., 2012) but also to increase student understanding (Edelson, 2001; Bell et al., 2010). In addition, inquiry learning helps students apply their knowledge to real-world applications (Edelson, 2001). Because this exercise is designed to be completed by small groups, students will also benefit from collaborative learning (Prince, 2004).

In this article, we present a framework for a short, flexible class or field inquiry–based activity with these objectives: (1) to provide students an opportunity to observe and think critically about ecosystems, ecosystem processes, and ecosystem services; (2) to have students learn and apply one technique used to value ecosystem services; (3) to engage students in evaluating the strengths and limitations of the ecosystem-service concept and the application of instrumental values to nature.

Why Teach Ecosystem Services?

Attention to the concept of ecosystem services has burgeoned during the past decade and has become an important part of the discourse on diverse environmental issues ranging from climate change to wildlife-habitat

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conservation to the protection of water resources (Millennium Ecosystem Assessment, 2005; Brauman et al., 2007; Nelson et al., 2008). Many governmental agencies (e.g., the U.S. Forest Service) and environmental conservation organizations (e.g., The Nature Conservancy) have adopted the concept as a key lens through which they frame their work. Monetary valuation of ecosystem services is one tool agencies and organizations are using to analyze and communicate their efforts to stakeholders and, in some cases, monetize these benefits through direct payment programs (Daily et al., 2000, 2009; Jack et al., 2008; Gomez-Baggethun and Ruiz-Perez, 2011). Although there are several approaches to the valuation of ecosystem services, the method known as *benefit transfer* is one of the most commonly used (e.g., Fisher et al., 2015). The benefit-transfer approach synthesizes results from other valuation studies conducted in specific geographic locations to estimate a range of values for ecosystem services in a different location (e.g., Costanza et al., 1997). For example, a benefit-transfer study of riparian forests in Oregon's McKenzie River watershed synthesized results from studies that value the flood control services of riparian forests in California, as well as habitat, pollination, and other services in other locations to provide an overall estimate of ecosystem services provided by riparian forests in the McKenzie River watershed (Schmidt and Batker, 2012).

The increasing adoption of the ecosystem-services concept and valuation of these services is not without controversy. Those who advocate for a focus on ecosystem services argue that this approach makes explicit the relevance that nature has to people and will thus help spur efforts by individuals, business, and governments to take actions that support these benefits through environmental conservation (e.g., Daily et al., 2009; Fisher et al., 2015). For example, Daily et al. (2009: 27) argued that if scientists and policy makers could appropriately price ecosystem services "everyday behavior and decisions will be channeled toward a future in which nature is no longer seen as a luxury we cannot afford, but as something essential for sustaining and improving human well-being everywhere." Others argue that ecosystem services in general and valuation methods in particular represent inappropriate commodifications of nature, that instrumental rationales for nature conservation are unlikely to succeed (Norgaard, 2010; Vatn, 2010), and that conservation arguments should be based on the intrinsic values of nature (Vucetich et al., 2015).

Given the prominence of ecosystem services in current environmental science and policy debates, students pursuing environmental and geoscience careers need to be prepared to engage with this topic, which is likely to remain salient for the foreseeable future. Our objective with this exercise was to directly engage students with the concept through an exercise that required them to identify relevant ecosystem services and to determine a value for them using a simplified benefit-transfer methodology. Through the synthesis questions and subsequent classroom discussion, we also sought to engage the students in current ethical and policy debates about the appropriateness and trade-offs inherent in ecosystem-service valuation.

Applicable Courses

In this article, we present data on student learning from two variations of our exercise implemented in two different courses: an introductory environmental science course at a small liberal arts school, and a sustainability class at a large land-grant university. The field-based activity was part of the environmental science class because of the availability of a laboratory period and immediate access to several ecosystem types. The sustainability class completed the in-class version of the activity because of logistical and time constraints. We selected these classes for study based on availability; however, because of their differing sizes and demographics, they offered the chance to implement two different versions of the exercise with two different student populations in dramatically different learning environments.

In the environmental science class, the ecosystem services unit comprised most of a single 50-min class period that consisted of a brief presentation on the basics of ecosystem services and a discussion of the Radiolab podcast (described below) and the Costanza et al. (1997) article, followed by a 2-h laboratory period in which students completed the field-based version of the exercise. In the sustainability course, the ecosystem services unit consisted of two 50-min class periods. The first period consisted of a lecture on ecosystem services to give the students a background for the exercise, which they completed during the second class.

The field version of the activity was a laboratory activity for the environmental science class. Each laboratory section had 15 students and a 2-h class period. Of the 31 students in the class, 25 were environmental science majors. The class contained 15 men and 16 women and had the following class breakdown: 12 freshman, 10 sophomores, 7 juniors, and 2 seniors. The in-class version of the exercise was used in a course on sustainability with 82 enrolled students from numerous majors spanning the campus (e.g., majors included geology, philosophy, engineering, forestry, apparel design, communications, among many others) and was roughly evenly divided among men and women. The course fulfilled the general education requirement, and students had to have junior or senior standing to enroll. The course met 3 d/wk for 50-min lecture sessions.

Although we used the exercise in our environmental science and sustainability courses, it could be applicable to other courses. The concept of ecosystem services fits well into a variety of classes, such as environmental geology, natural resource management, soil science, ecological economics, applied ecology, and similar topics. As evidenced by our implementation in courses with widely differing enrollments, distribution of majors, class length, and access to fieldwork opportunities, this exercise is versatile and can be adapted to suit a wide variety of classroom and other learning environments.

THE EXERCISE

Background

Before the exercise, students were given background information on the concept and application of ecosystem services. In addition to a brief, in-class introduction to the topic, students were also instructed to read the article by Costanza et al. (1997). We have also found that the episode "How Do You Put a Price Tag on Nature?" from the National Public Radio show Radiolab (http://radiolab.org) is an excellent primer for the exercise, which brings the real-world debate and ethical implications of the ecosystem-

TABLE I: Values of ecosystem services from the literature.

Ecosystem Service	Value ($/acre/y) in 2009 U.S. Dollars
Timber and forest products	$80 for forests[1]
Recreation	$491 for wetlands/floodplains[1]
	$38 for forests[1]
	$1 for rangeland[1]
Climate regulation	$381 for urban forests[2]
	$28 for other forests[2]
	$6 for rangeland[3]
Water quantity and quality regulation	$8,196 for urban and suburban forested wetland[2]
	$4,635 for rural forested wetland[2]
	$1,728 for riparian, nonwetland[2]
	$7 for nonriparian, nonwetland forest[2]
Soil formation and stability	$7 for rangeland[3]
	$69 for forests[3]
Habitat/refugia	$223 for forests with abundant rare species[2]
	$0 for forests with few rare species[2]
Pollination	$184 for nonwetland/riparian forests[2]
	$30 for rangeland[1]
Aesthetic, cultural, and passive use	$74 for forests[1]
	$1 for nonforest[1]

[1]Represents values taken from Costanza et al. (1997) adjusted for inflation.
[2]Represents values taken from Moore et al. (2011).
[3]Represents values take from Liu et al. (2010) adjusted for inflation.

services concept to life in an accessible and entertaining fashion. We also supplied each student with a handout detailing the following ecosystem services: water quantity and quality regulation, soil formation and stability, climate regulation, habitat/refugia, pollination, timber and forest products, recreation, and aesthetic, cultural, and passive use (available in the online journal and at <http:dx.doi.org/10.5408/15-138s1>).

Data Collection

In the field version of the exercise, we divided the students into groups, and they worked through the process of assigning values for eight ecosystem services in four different ecosystems. Students were taken to a location with easy access to a mixed hardwood and pine forest, a pine plantation, a wetland, and a hayfield. Before dealing with the issue of valuation, students established a 5-m × 5-m plot in each ecosystem and wrote down their observations about the different ecosystems, ongoing ecosystem processes, and ecosystem-service production. After observing each ecosystem, the students used a table containing monetary values for each of the ecosystem services taken from the literature (Costanza et al., 1997; Liu et al., 2010; Moore et al., 2011) (Table I) and determined the value for the eight ecosystem services in each of the four ecosystems. Finally, the students added those values together to produce an estimate of the total value of the annual ecosystem services generated in each ecosystem.

In the classroom variant of the exercise, students were divided into groups of four and were presented with an aerial image of a local property that contained a variety of ecosystems. On the image, areas of wetlands, riparian forests, coniferous forests, and agricultural fields were outlined. Students were asked to look at the aerial images and list the ecosystem services that were likely provided by each ecosystem and to determine whether those services primarily benefit people locally (e.g., soil formation and stability), regionally (e.g., water quantity and quality), or globally (e.g., climate regulation). After listing the relevant services and the spatial distribution of their benefits, students used the methodology described above to assign monetary values to the identified ecosystem services for each ecosystem type.

Synthesis

After tabulating their data, the students answered the following questions in a few sentences to provide a foundation for a facilitated classroom discussion:

(1) Why are some of the ecosystem types missing estimated economic values for certain ecosystem services? Do you think these ecosystems do not have value?
(2) Why are the ecosystem services worth more if located in an urban area? Remember the definition of "ecosystem services."
(3) Which ecosystem services benefit people locally and which benefit people globally?
(4) Identify at least two approaches you could use to develop policies that would protect ecosystem services.
(5) What is an ethical dilemma of valuing ecosystem services? Do you think the benefit of valuing them outweighs this dilemma?

RESULTS

Observations

While implementing this exercise, we observed several themes common to both the field and in-class versions. In particular, many students never thought about the benefits that nature provides to people in such an explicit way. As one student commented, "Before this exercise, I had no idea that ecosystem services existed. Well I knew they existed, but I didn't realize they had a name." Others were surprised to realize that many ecosystems provided several of the services included in the exercise and that the value of those services often differed dramatically among the ecosystems. This realization provided the opportunity to challenge students to consider the underlying ecosystem processes as well as the human context that might be driving the differences in value. For example, several students commented on the stark differences in climate regulation provided by urban forests, other forests, and rangeland. Although the amount of carbon sequestered (i.e., the ecosystem process) differs significantly between forests and rangeland ecosystems, that does not fully account for the much higher value of urban forests, which provide additional climate-regulating services (e.g., microclimate impacts from shade and humidity) because of their proximity to substantially more people (i.e., the human context).

Students were also challenged to address the ambiguity in the classification scheme that was intentionally built into the exercise. For example, the ecosystems that the students observed did not perfectly match the ecosystem types provided in Table I. After letting students struggle with this ambiguity for several minutes, we then confirmed their sentiments that the classification scheme was not perfect and instructed them to use their own judgment and decide as a group on how best to proceed and to justify their decisions by documenting the logic used to reach their conclusions. This led some groups to choose values for one ecosystem type over others, based on their judgment that this ecosystem was the closest to the one they were observing. Other groups, however, decided to average values of some ecosystem types because the ecosystems they observed seemed to fit between the ecosystem types provided in Table I (e.g., observed ecosystems were not entirely rural or urban but more ex-urban). This ambiguity forced students to use higher-level critical-thinking skills and to discuss and build consensus with their group members. Reflecting on this challenge, one student commented, "The one idea that really impacted me about the [exercise] was that everybody ranked each environment with a different value. This would make it extremely hard if not impossible to assign a dollar figure to a service."

The exercise also helped illuminate the strengths and limitations of the ecosystem services concept for many students. Some observed that if ecosystems are not valued, then they are essentially treated as having no value in many public policy decisions. For instance, a student who completed the in-class version of the exercise commented, "People should value ecosystem services because it can help people to make economic decisions, policies, etc. People should consider ecosystem services when they make any big decisions." Others, however, struggled with the ethical implications of assigning economic values to ecological processes that are intrinsically valuable. After completing the field version of the exercise, one student wrote, "It is not a good idea to price nature because it adds more value to some species/habitats while completely devaluing others. In this sense some of nature is useful and indispensable, while other features are useless and dispensable." Finally, others felt the exercise illustrated the advantages and disadvantages of valuing ecosystem services. One student expressed this view by stating, "I feel like the activity put price and value of ecosystem services into perspective. The [assignments before] showed both sides of the ecosystem service topic... and show services that are difficult to measure (like bees pollinating plants) along with the items that are easier to measure."

In addition to the common themes observed in both the field and in-class versions of the exercise, we also observed several differences. Students participating in the field version were able to make direct observations of relevant ecosystem properties, such as biodiversity, and ecosystem processes, such as insects pollinating crops. As suggested by the literature (Pedaste et al., 2015), this hands-on component helped students make connections between these processes and their related services. The field-based exercise also created an environment for place-based learning (Gautreau and Binns, 2012), which allowed students to connect with their local environment and their own experiences in that environment.

Conversely, students participating in the in-class version had a harder time making those connections and required more guidance from the instructor. Although the in-class version was limited in providing opportunities for direct observations, it was easily implemented and could be augmented in the future with photos and/or short videos of each ecosystem type.

Assessment

We conducted a preassessment and postassessment tests of the student's knowledge of ecosystem services to gauge the effect of the exercise on student learning. We developed the assessment to gauge learning around the three objectives for the exercise as outlined in the "Introduction." The assessment consisted of several multiple choice and true/false questions. In the postassessment study, we also asked students to rate their enjoyment and the perceived effectiveness of the exercise using a Likert scale and to provide feedback on what they liked and disliked about the exercise in a short-answer format. We had a colleague who is an interdisciplinary scientist with some experience with ecosystem services provide feedback on an early draft of the assessments. The preassessment test was administered after the students read the Costanza et al. (1997) and listened to the Radiolab podcast, and the postassessment test was administered at the conclusion of the exercise. In the multiple choice and true/false portion of the postassessment test, students scored higher on nearly every question (students completing the field exercise scores decreased by 6% on one question from the preassessment to the post-assessment) (Table II). Table III presents the mean scores of the field and in-class groups on the preassessment and postassessment studies. A paired *t*-test showed that students scored significantly higher on the test after completing the exercise, moving from an average score of 59% (field) and 58% (in-class) on the pretest to an average score of 72% (field) and 71% (in-class) on the posttest. When asked to reflect on the exercise, most students agreed (61% field, 60% in-class) or strongly agreed (29% field, 4% in-class) that the exercise was an effective way to learn about ecosystem services (Table IV). A plurality of students also agreed (29%) or strongly agreed (15%) that the in-class exercise was more enjoyable than a traditional lecture on ecosystem services (Table IV). The field-based exercise was rated even more highly; 32% and 45% of students agreed and strongly agreed, respectively, that the exercise was preferable to a traditional lecture.

DISCUSSION

Strengths of the Exercise

According to our preassessment and postassessment data, this exercise accomplished its primary goal of increasing student knowledge of ecosystem services and student engagement. In addition to improvement on the multiple choice and true/false portion of the assessment, students' answers to the synthesis questions suggested that they moved beyond a simple understanding of the benefit-transfer approach to considering the challenges and risks of valuing nature and thinking about the implications of policy based on assigning monetary values to ecosystem services.

TABLE II: Preassessment and postassessment results.

Question[1,2]	Field (%)			Classroom (%)		
	Pre-assessment	Post-assessment	Difference	Pre-assessment	Post-assessment	Difference
In comparison to the value of the global economy, ecosystem services globally are worth roughly ______________ global GDP.	39	65	26	24	71	47
A. 10% of						
B. 0% of						
C. **Twice as much as**						
D. The same as						
E. 10 times as much as						
Which of the following is not a type of ecosystem service?	0	35	35	9	16	7
A. Cultural values						
B. Outdoor recreation						
C. Climate regulation						
D. Wildlife habitat provision						
E. **Atmospheric processing**						
Which of the following is an ecosystem service?	19	13	−6	19	22	3
A. Cloud formation						
B. Water flowing in a river						
C. **A bee pollinating a crop**						
D. All of the above						
E. None of the above						
True or **False**: Ecosystem services are worth the same to everyone around the world.	84	94	10	76	89	13
True or False: Policies to protect ecosystem services are most easily implemented locally.	81	90	10	84	91	7
True or False: Valuing ecosystem services is a useful tool in helping society make decisions about natural resources.	97	97	0	97	98	1
True or False: It is impossible to truly value some ecosystem services.	65	87	23	59	80	21
True or **False**: There are no ethical dilemmas to valuing ecosystem services.	84	100	16	84	93	9
Which ecosystem service would be more challenging to develop a policy to protect?	61	65	3	71	75	4
A. Flood protection						
B. **Climate regulation**						
C. Water supply provision						
D. Habitat provision						
E. Erosion control						

[1]Correct answers are in bold.
[2]GDP = gross domestic product.

TABLE III: Mean score on preassessment and postassessment, difference, and paired *t*-test results.

Activity Type	Preassessment (%)	Postassessment (%)	Difference (%)	*t*-Test
Field ($n = 31$ students)	58.78	71.68	12.90	−2.88*
In-class (N = 82 students)	58.11	70.56	12.44	−2.62*

*$p < 0.05$

This nuanced understanding of ecosystem services requires a great deal of critical thinking, and the inquiry-learning exercise helped students arrive at these ideas on their own.

The exercise also had the benefit of encouraging meaningful collaboration among students. Each team of students had to work together to deal with an ambiguous, but realistic, classification scheme and then to reach a consensus. Dealing with issues of classification, especially with imperfect classification schemes, is a common challenge in science, and this exercise provided a practical example for the students. As part of this process, students made meaningful connections between ecological and social systems, a key component of thinking critically about environmental issues.

We also feel that one of the greatest strengths of the exercise was its ability to be implemented with minor modifications in a wide variety of learning environments. We have already shown that it can be easily adapted to small, laboratory settings, as well as large lecture classes. Although the field-based activity had slightly higher levels of student engagement than the in-class version, students greatly preferred the activity to a traditional lecture. In addition, the exercise could be simplified for younger students or made more detailed for an upper-division undergraduate course.

A unit on ecosystem services, which included this exercise, would also be easy to add into a course because it can fit it into any portion of the course. In the environmental science course, the ecosystem services unit came early in the semester, immediately after a discussion of ecosystem and ecosystems processes. In addition to providing a collaborative, field-based inquiry activity early in the semester to create a tone of student engagement, it gave students a more-nuanced perspective on the environmental issues discussed during the rest of the term. Although this was successful in this particular course, we also feel that this exercise would work well as a synthesis activity at the end of a course or as a bridge activity in the middle of the term to make connections among the many fields that contribute to ecosystem services.

TABLE IV: Postexercise survey results.

Question	Response	Field (%, $n = 31$)	Classroom (%, $n = 82$)
The activity was an effective way to learn about the value of ecosystem services.	Strongly disagree	6	5
	Disagree	0	4
	Neither agree nor disagree	3	27
	Agree	61	60
	Strongly agree	29	4
I enjoyed the activity more than a traditional lecture on ecosystem services.	Strongly disagree	6	4
	Disagree	3	15
	Neither agree nor disagree	13	38
	Agree	32	29
	Strongly agree	45	15

Limitations of the Exercise and the Evaluation

In reviewing the preassessment and postassessment results, we noted that, although students in both classes significantly improved their overall scores, we were surprised that only 13% of students who completed the field-based exercise answered the question "Which of the following is an ecosystem service" correctly on the postassessment test (6% fewer than on the preassessment test). Similarly, only 22% of students completing the in-class version answered the question correctly (3% more than on the preassessment study). So, although we feel the exercise did an excellent job at teaching multiple aspects related to valuing ecosystem services, students still struggled to distinguish ecosystem services from ecosystem processes or functions. Although this is a limitation of the exercise, we also note that this topic is still debated in the academic literature (e.g., Boyd and Banzhaf, 2007; Fisher et al., 2009) and underscores the challenge and complexity of teaching the concept of ecosystem services.

We also note several limitations about evaluating the effectiveness of the exercise. In particular, we did not implement a control, such as a class in which the exercise was replaced with a traditional lecture. Therefore, we cannot fully attribute the students' improvements on the assessments to the exercise, rather than simply to additional contact time for teaching the concept of ecosystem services. Additionally, students completing the field-based exercise enjoyed it more and found it more effective than did students completing the in-class version. These findings, however, may be biased by the different populations that the courses served. For instance, the course that we implemented the field-based version was composed of students with majors directly related to the focus of the class, whereas many of the students using the in-class version did not have majors related to the course.

The application of the field-based version of the exercise also has limitations. Given that there needs to be relatively close proximity to multiple ecosystem types that students can use to make observations, instructors may find it challenging to access a diversity of ecosystem types. Additionally, the logistics involved in getting students into and back from the field can take significant time and requires longer (e.g., 2 h) class blocks or laboratory sessions. Larger enrollments can also increase logistical challenges. We considered also using the field-based exercise in the larger sustainability course but decided instead to develop the in-class version because of these challenges.

Adaption in Geosciences Courses

The exercise presented here focused on eight categories of ecosystem services: soil formation and stability, climate regulation, water quantity and quality, timber and forest products, recreation, habitat/refugia, pollination, and aesthetic, cultural, and passive use (available in the online journal and at <http:dx.doi.org/10.5408/15-138s1>). This represents only a small subset of ecosystem services listed in the literature. For example, Costanza et al. (1997) considered 19 categories of ecosystem services. The variants of the exercise presented here emphasized ecosystem services produced by ecological and biological processes, although two of the services, soil formation and water quantity and quality regulation, are primarily controlled by geologic processes. Because the goal of this activity in our courses was to present a broad overview of the range of ecosystem services, our choice of ecosystem services represented a balance between biologically, ecologically, and geologically produced ecosystem services.

However, the inherent flexibility of this exercise makes it easily adaptable to geosciences courses by focusing on the geological systems that produce ecosystem services. For example, the exercise could focus on soil-formation processes and use field trips or photos to show soils in different environments. The students could, based on literature values, make their own assessments of the relative value of soil formation in each environment. The value of erosion control, an ecosystem service identified by Costanza et al. (1997), could also be incorporated into such an exercise. In addition to ecosystem services related to soil, those concerning water supply and water regulation would be ideal for geosciences classes to focus on. As pointed out by Field et al. (2015, 2016), the processes that regulate these systems extend throughout the critical zone, and students could be asked to assign relative values to the different parts of the hydrologic cycle in several locations. Beyond these specific examples, it is easy to envision versions of the exercise that look at ecosystem-service production in different layers of the critical zone or in different geologic provinces. Another version could consider the timescales at which ecosystem services are produced and consider the values given to those that operate on ecological timescales versus those that operate at geologic timescales.

One benefit of implementing this activity as part of a discussion of ecosystem services in a geosciences class was the opportunity to discuss the challenges of assigning value to ecosystem services that operate on geologic timescales. One of the biggest lessons from this exercise is that even for processes that operate on relatively short timescales, accurately assigning monetary values to those processes is extremely difficult and subjective. This is particularly true for processes that take millions of years, such as mineral weathering. Although these processes are essential to ecosystem function and the production of ecosystem services, it is especially challenging to use the benefit-transfer approach to accurately value such processes. Although this is a formidable problem, it is one that can only be solved by involving geoscientists in ecosystem-service valuation discussions (Field et al., 2015, 2016), a process that begins by integrating the concept of ecosystem services into geosciences courses.

Implications for Teaching Ecosystem Services

After designing and implementing this exercise in two different settings, we learned two key lessons. First, we found that, in accordance with the literature (Edelson, 2001; Bell et al., 2010), inquiry learning is an effective pedagogical strategy. Students came away with a sophisticated understanding of the complicated concept of ecosystem services in a short time. Although we have no data from a "lecture only" treatment, our experience suggests that this exercise was a much more effective teaching tool in both its in-class and field versions. We also feel that either variant of the exercise would have been effective with either audience (lower-level environmental-science majors or upper-level students from a variety of majors). Second, the exercise we present here could be altered to focus not only on different types of ecosystem services (e.g., those that are driven primarily by biotic or abiotic processes) but also on different aspects of the ecosystem concept. For example, the exercise could highlight the differences between ecosystem services in rural and urban areas or between those that produce global versus local benefits. The exercise is also easily customizable in terms of geography and can quickly be modified to suit ecosystems that are available for visiting or those that are of importance in a local area. Such place-based learning opportunities have been shown to enhance learning (Gautreau and Binns, 2012) and to increase students' connection to a local environment.

CONCLUSION

This exercise creates an inquiry-learning opportunity for students to understand and apply the concept of ecosystem services, a topic of great importance to a wide range of environmental disciplines. As part of the exercise, students critically evaluated the issues surrounding the valuation of ecosystem services and the challenges of implementing the benefit-transfer approach into environmental policy. Based on assessments of student learning, we believe that this exercise was more effective in accomplishing these goals than a traditional lecture would have been. We have already demonstrated that the exercise was successful as a field-based laboratory and as an in-class activity and believe that it is easily customizable to focus on a specific suite of ecosystem services (e.g., those provided by ecological processes or geological processes), to different aspects of the ecosystem service concept (e.g., implementation into policy), and to a wide range of courses. Integrating the concept of ecosystem services into geoscience classes is particularly valuable because it helps prepare future geoscientists to contribute their knowledge of geological processes to the interdisciplinary field of ecosystem services.

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