2022

New multimedia resources for ecological resilience education in modern university classrooms

K. Hogan
University of Nebraska - Lincoln

J. Fowler
University of Nebraska - Lincoln

C. Barnes
University of Nebraska - Lincoln

A. Ludwig

D. Cristiano
University of Nebraska - Lincoln

See next page for additional authors

Received: 5 November 2021 | Revised: 28 March 2022 | Accepted: 26 April 2022

DOI: 10.1002/ecs2.4245

ECOSPHERE
AN ESA OPEN ACCESS JOURNAL

INNOVATIVE VIEWPOINT

Eco-Education

New multimedia resources for ecological resilience education in modern university classrooms

Katharine F. E. Hogan[1] | **Julie A. Fowler**[2] | **Conor D. Barnes**[3] | **Alison K. Ludwig**[3] | **Dominic J. Cristiano**[2] | **Daniel Morales**[1] | **Rubi Quiñones**[4] | **Dirac Twidwell**[3] | **Jenny M. Dauer**[2]

[1]Center for Resilience in Agricultural Working Landscapes, School of Natural Resources, University of Nebraska–Lincoln, Lincoln, Nebraska, USA

[2]School of Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[3]Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[4]School of Computing, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

Correspondence
Katharine F. E. Hogan
Email: katharine.hogan@huskers.unl.edu

Funding information
National Science Foundation Research Traineeship, Grant/Award Number: DGE-1735362

Handling Editor: Laurel Hartley

Abstract

Solutions to global problems such as climate change and biodiversity loss require educational frameworks and accompanying teaching resources that are theory-based, interdisciplinary, and accessible to broad undergraduate and graduate student audiences. Ecological resilience theory (ERT) is a framework with established interdisciplinary application to complex global problems, but despite an emphasis on the utility of resilience in national higher education frameworks, we found that many current ecology textbooks incorporate multiple definitions and highly variable amounts of discussion on core resilience concepts. To facilitate the use of innovative teaching resources in ERT in universities, this paper describes four free multimedia tools and templates that align with national education frameworks and are available for innovation and development by educators interested in ERT. The products are (1) content modules on core terms and concepts of ERT, (2) a classroom game and discussion, (3) interactive case studies, and (4) a complementary podcast based on resilience concepts and interviews with resilience experts to supplement formal classroom education. We contextualize the opportunities of ERT and thinking for students in university classrooms, as well as the benefits of involving graduate students and encouraging their initiative with this type of project. We conclude with a brief discussion of future opportunities for these types of educational resources. Our intent is that these resources be available for educators and researchers to facilitate interdisciplinarity, collaboration, and innovation to address complex global problems from a core educational framework of ERT.

KEYWORDS

case study, classroom game activity, collaboration, ecology, interdisciplinary, lesson plan, multimedia learning, online education, podcast, science communication, student organization

INTRODUCTION

Human-driven alteration of the Earth and uncertainty of future supporting goods and services is a well-documented challenge facing current generations (Costanza et al., 2017; Vitousek et al., 1997). To adapt to these novel challenges, the field of higher education has a need for innovative educational resources to help current and future generations cope with complex problems and increasing global uncertainty (Bai et al., 2016; Biggs et al., 2012; Krasny et al., 2009). Resources that incorporate systems thinking, blend traditional and emerging approaches, and empower individuals to collaboratively construct their own knowledge and evaluate solutions may have particular promise (Ban et al., 2015; Krasny et al., 2009).

Resilience is a key topic for students to understand as they develop ecological literacy. The Ecological Society of America produced The Four-Dimensional Ecology Education (4DEE) Framework outlining core knowledge and experience in which undergraduates should receive instruction (Berkowitz et al., 2018), including core ecological concepts, ecology practices, human–environment interactions, and cross-cutting themes. The 4DEE lists resilience and steady states as core ecological concepts that are critical to understanding ecology. Additionally, the American Association for the Advancement of Sciences and the National Academies of Sciences (NAS), Engineering, and Medicine (2018) indicated the need for an interdisciplinary, system-oriented science content approach in order for graduate Science, Technology, Engineering, and Mathematics (STEM) education to remain relevant and dynamic in the 21st century. The report emphasizes that interdisciplinarity is critical in graduate education for addressing 21st-century complex issues across disciplines and organizational scales.

Resources that facilitate active learning and interactive peer-to-peer activities are increasingly important for science education (Azizan et al., 2018; Benè & Bergus, 2014; Roberts, 2018), additionally so when current events and uncertainty restrict classical teaching methods. The COVID-19 pandemic is an example of how global disruption can increase the importance of teaching activities that are amenable to remote learning. Due to this and the need for educational frameworks to train future professionals to confront complex problems and promote resilient societies (Leshner & Scherer, 2018), tapping into graduate-level expertise to develop undergraduate resilience education may contribute to enhanced skills in future professionals of both demographics. Students can be effective peer teachers across disciplines, documented in sociology (Tsui, 2010), economics (Oates & Quandt, 1970), and medicine (Benè & Bergus, 2014; Lockspeiser et al., 2008; Soriano et al., 2010). Additionally, graduate students are currently becoming scholars at a time when interdisciplinary work and science communication skills are a high priority (Ban et al., 2015). Peer education also develops key skills including teaching, writing, public speaking, leadership, management, and research design (Feldon et al., 2011; Kuehne et al., 2014).

Ecological resilience theory

A framework with interdisciplinary applications for the complex, global issues highlighted in the 4DEE and NAS reports is ecological resilience theory (ERT) (Angeler & Allen, 2016; Gunderson, 2000). Ecological resilience was first formally defined within the field of ecology as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973, p. 14). Ecologist C.S. Holling initially developed ERT to clarify the distinction between the resilience (i.e., predictable behavior) of something engineered to perform specific tasks within a predictable environment, and resilience (i.e., continuing function) of a system affected by environmental changes to the extent that it has to adapt to the unexpected (Holling, 1973). The use of ERT, the more generic term "resilience," and diverse resilience theories has increased substantially in academic literature over the last few decades (Baggio et al., 2015; Xu & Marinova, 2013) and resilience is now defined in multiple ways depending on the system and problem to which the theory is applied (Lundholm & Plummer, 2010), including psychological resilience, social–ecological systems resilience, engineering resilience, and community resilience (Dubois & Krasny, 2016).

While this has created a rich body of theoretical and applied scholarship, many definitions of a generic concept can lead to confusion, particularly upon the first introduction to the concepts or when working across disciplines (Walker, 2020). The resources presented in this paper focus on foundational ERT concepts (ecological resilience, alternative states, heterogeneity, and scale) and more recent conceptual developments of ERT (adaptive cycle and panarchy) that have been applied to problems in economics, food systems, law, adaptive land management, and other disciplines (Gunderson et al., 2022; Hogan et al., 2021). While current resilience research displays an increasing focus on the dynamics of earth systems interactions that influence what is called "multisystemic resilience," the resources in this paper focus on ERT (Holling, 1973) as an older and more established arm of resilience theories that addresses key goals and themes in the 4DEE and NAS reports on undergraduate and graduate science education.

ERT in current ecology textbooks

To the best of our knowledge, content discussing ERT is highly variable in the 21st-century ecology and STEM post-secondary experience. A review of nine recent (last 15 years) commonly used undergraduate ecology textbooks that were readily available (Table 1) for the core ERT concepts of "resilience" and "alternative states" revealed widely varying levels of mention, discussion, and definition of resilience and associated terminology across textbooks. Two textbooks included chapter-level discussion of ecological resilience and alternative stable states, and two textbooks each had brief mentions or chapter sections on either alternative stable states or resilience, but not both. Additionally, three ecology textbooks defined resilience as the time required for an ecological system to return to its original state following disturbance, which is sometimes distinguished as engineering resilience in contrast with ecological resilience (Pimm, 1984). The subtle difference between these definitions centers around the role of time in ecosystem recovery and mechanisms of resilience and requires careful consideration when elements of resilience theories are used in research and education. Defining resilience as either the time needed for a system to recover from disturbance (engineering resilience) or the capacity of a system to recover from disturbance (ecological resilience) without the context and awareness of similar definitions may create a collective misunderstanding by students and professionals in training and reduce the applicability of ERT to complex global problems.

Aside from our review of ecology textbooks, other research reports that ERT does not often feature in current college curricula (Day et al., 2020; ElSabry, 2017). However, it should be noted that there is active research and practice applying social–ecological resilience concepts in classrooms (Dubois & Krasny, 2016; Fazey, 2010; Krasny et al., 2009; Lundholm & Plummer, 2010; Spellman, 2015), which suggests there are opportunities to leverage lessons, methods, and insight between both ERT and social–ecological resilience. For example, Fazey (2010) describes a teaching module called "Sustainable Societies" derived from many interrelated frameworks (including a general form of resilience), which was designed to teach social–ecological "resilience thinking" to undergraduates. Other classrooms have incorporated concept maps, computer modeling, and timeline creation to teach resilience to younger (seventh grade) students (Spellman, 2015). Despite these efforts, challenges to incorporating social–ecological and ecological resilience into classrooms remain, partly due as highlighted in the 4DEE and NAS reports to the lack of a guiding

TABLE 1 Recent (within 15 years) ecology textbooks reviewed for the terms "resilience" and "alternative stable states."

Textbook	Edition	Authors	Year	Pages	Terms	Depth
Ecology: Concepts and Applications	Eighth	Molles Jr	2019	446	Engineering resilience	Brief mention (paragraph)
Ecology: The Economy of Nature	Eighth	Ricklefs and Relyea	2018	436	Alternative stable states	Brief mention (several paragraphs)
Ecology	Fourth	Bowman, Hacker, and Cain	2017	392	Alternative stable states	Chapter section
Ecology: Evolution, Application, Integration	First	Krohne	2015	366	Ecological resilience	Brief mention (paragraph)
Landscape Ecology in Theory and Practice	Second	Turner and Gardner	2015	364	Ecological resilience	Definition and brief mentions throughout
Essentials of Ecology	Fourth	Begon, Howarth, and Townsend	2014	275	Engineering resilience	Brief mention (paragraph)
Principles of Terrestrial Ecosystem Ecology	Second	Chapin	2011	20 and 339	Alternative stable states and ecological resilience	Chapter sections, chapter
Ecology: Global Insights & Investigations	First	Stiling	2011	387	Engineering resilience	Brief mention (paragraph)
The Princeton Guide to Ecology	First	Levin, Carpenter, Godfray, Kinzig, Loreau, and Losos	2009	395	Alternative stable states and ecological resilience	Chapter

framework and materials (Ban & Cox, 2017). We therefore suggest that creating classroom materials focusing on core concepts of ERT as both a standalone body of ecological theory and as a complement to other fields of study such as social–ecological resilience will provide opportunities to develop an interdisciplinary, coherent framework for addressing complex global problems.

To create innovative opportunities for ERT concept inclusion in college classrooms, we (a group of graduate students) began the Council for Resilience Education (CRE) at the University of Nebraska-Lincoln in 2018, with a mission of developing educational resources on core concepts of ERT. We developed four free multimedia educational resources to facilitate innovation in ERT education by leveraging wide public access to modern computer technologies and game-based exercises, two of which are active learning classroom activities grounded in constructivist pedagogy (Tam, 2000). The resources, which are aligned with 4DEE objectives in cross-cutting themes, human–environment interactions, core ecological concepts, and ecology practices (Table 2) are (1) content modules on core resilience concepts (Table 3); (2) a classroom game with corresponding discussion questions that illustrate resilience in policy and management (Table 4); (3) case study modules for deeper classroom engagement with ERT concepts through role-playing activities; and (4) a complementary, informal podcast featuring episodes on ERT concepts and interviews with resilience experts as an example of how pioneer educational techniques may assist learning and increase engagement. We designed these products for classroom use and as a template for educators (including other graduate students) interested in incorporating ERT into their classrooms who may not have the time or resources to develop materials themselves.

MULTIMEDIA RESOURCES FOR TEACHING ECOLOGICAL RESILIENCE

Traditional online content modules

We developed traditional online content modules for educators to teach central ERT concepts (Lundholm & Plummer, 2010) as a supplement to introductory ecology textbooks. The overarching module objectives are to (1) provide students with class-appropriate summaries of core ERT concepts and (2) provide interdisciplinary examples to help students apply core ERT concepts across diverse professions. The material presented in the individual modules aligns with the 4DEE Framework elements listed in Table 1. There are currently six modules written at an undergraduate level that correspond with the terms defined in Table 3. ERT stems from the field of ecology, but in light of the interdisciplinary themes in the 4DEE and NAS reports, we wrote the modules to also have utility for classes in social–ecological resilience, agronomy, land management, economics, historical studies, public policy, and city planning. We also designed

TABLE 2 Alignment of ERT educational resources with 4DEE Framework themes, concepts, and practices.

Resource	Cross-cutting themes	Human–environment interactions	Core ecological concepts	Ecology practice
Content modules	4.1-Scales, 4.2-Stability and change	3-How humans shape and manage resources/ecosystems/the environment, urban ecosystems, urban ecology, urban–rural gradient	3.4-Stability–resistance–resilience–disturbance–steady-state–fluctuate	1.2-Making observations and connections
Jenga game and discussion	1-Structure and function, 4.2-Stability and change	1.1-Ecosystem services, 3-How humans shape and manage resources …	3.4-Stability–resistance–resilience–disturbance–steady-state–fluctuate, 4.4-Energy flow-productivity	1.2-Making observations and connections, 1.5-Working collaboratively, 1.6-Communicating and applying ecology
Case studies	1-Structure and function, 4.2-Stability and change	1.1-Ecosystem services, 2.2-Environmental toxicology: biomagnification–bioconcentration, 3-How humans shape and manage resources …	3.4-Stability–resistance–resilience–disturbance–steady-state–fluctuate, 4.4-Energy flow-productivity	1.2-Making observations and connections, 1.5-Working collaboratively, 1.6-Communicating and applying ecology
WHRA podcast	1-Structure and function, 2-Pathways and transformations of matter and energy, 3-Systems, 4.1-Scales, 4.2-Stability and change	1.1-Ecosystem services, 2.1-Global climate change, 3-How humans shape and manage resources …	3-Communities, 4-Ecosystems, 7.2-Global climate change	1.2-Making observations and connections, 2-Fieldwork, 4-Designing and critiquing investigations, 6-Communicating and applying ecology

Abbreviations: 4DEE, Four-Dimensional Ecology Education; ERT, ecological resilience theory; WHRA, What the Heck is Resilience, Anyway?

TABLE 3 Core concepts of ERT, chosen with advice from multiple expert ERT researchers and with consideration of "key concepts" listed by the Resilience Alliance, a research organization of seminal ERT scholars founded in 1999 (Resilience Alliance 2015).

Core concept	Definition	Reference(s)
Ecological resilience	The amount of disturbance a system (e.g., an ecosystem, economy, or government) can absorb without undergoing fundamental structural change or loss of system processes.	Holling (1973), Gunderson (2000)
Alternative stable states	Fundamentally different arrangements of a system's characteristics, functions, processes, and interrelationships, which are maintained through different stabilizing feedbacks with discontinuous shifts between them, that is, they cannot operate within the same space or time as one another.	Lewontin (1969)
Scale	The spatial or temporal dimension of a given phenomenon, which can provide context for quantifying aspects of ecological, social, and political systems.	Turner and Gardner (2015)
Heterogeneity	Any measure of variability within a system that takes scale into account.	Fuhlendorf et al. (2017)
Adaptive cycle	A conceptual model of complex system behavior over time that consists of four phases of growth, conservation, release, and reorganization.	Holling (1992), Gunderson et al. (1995), Carpenter et al. (2001)
Panarchy	A set of multiple nested adaptive cycles that interact across spatial and temporal scales.	Gunderson and Holling (2002), Allen et al. (2014)

Abbreviation: ERT, ecological resilience theory.

TABLE 4 Description of Jenga classroom activity scenarios and rules.

Scenario	Description	Rule(s)
Obstructive policy	Harvest the most yield, but policy and management constraints limit your actions to an area that can make the problem worse—not better	Players may only pull from bottom four layers of the tower
Policy with little knowledge of the system	Harvest the most yield, but lack of knowledge of the system resulted in policy constraints that limit actions to randomly generated resource harvest	Players are assigned a random number each turn and must pull blocks with that number written on them
Policy to maximize harvest	Maximize yield and harvest efficiency	Players must pull a block with the highest value written on it
Policy to maximize return while minimizing tradeoffs	Maximize yield and harvest efficiency, while minimizing loss of tower integrity and collapse	Players must pull a high-valued block while also considering integrity of the tower
Resilience policy for working lands	Avoid collapse while harvesting as many blocks as possible	Players must pull a block that protects the integrity of the tower. Players may not pull blocks from fewer than two layers apart from one other unless the tower becomes too small

these modules for students who may benefit from ERT knowledge but are unable to take a dedicated resilience course, a particularly relevant attribute of flexibility as online learning becomes more common (Mayadas et al., 2009). As mentioned, these modules can be assigned as homework, but do not require classroom integration and may also be useful to resource managers, policymakers, and the public in the future (Van Gerven et al., 2003).

We worked with an online educator specialist and ERT faculty input within our university to develop these modules as a starting point and not as an exhaustive review of important concepts. Faculty and education staff throughout the process provided insight into which modules to develop, appropriate format and elements for online delivery, and how to draft learning objectives utilizing Bloom's Taxonomy. The modules follow the University of Nebraska lesson framework from the Plant and Soil Science eLibrary (PASSeL, 2020), where the modules are currently housed. The modules entail learning objectives, concept introduction and definition, utility, real-world application examples, quiz questions, summary, references and further reading, and a glossary. The examples, images, and figures chosen to illustrate concepts feature their application to different disciplines (Franco & DeLuca, 2019; Roberts, 2018) and use inspiration from outside traditional disciplines, including the video game World of Warcraft that implicitly includes basic resilience concepts within its gameplay (Blizzard Entertainment, 2022). After initial development, construction, and within-group peer review, each module received feedback from internationally recognized scholarly experts in ERT and external faculty and subject experts for additional peer review. We solicited feedback from experts who (1) had publication or public service records on the topics or application of the content modules and (2) collectively represented a range of the sub-fields in which ERT is applied. Specifically, we asked them to assess if the modules contained ambiguities or factual inaccuracies, and if the content of the modules aligned with the module learning objectives. Feedback was largely positive and led us to revise elements such as removing unnecessarily technical terms, expanding on examples relevant across disciplines, and improving graphics for clarity. The modules were then transferred online to PASSeL (https://passel2.unl.edu/view/community/70ffd07aff59), where they are free to use and can be updated if necessary.

Classroom game and discussion: Jenga

The use of games or interactive "serious play" in classrooms (Madani et al., 2017; Rieber et al., 1998) may enhance student basic reasoning skills (Ramani et al., 2012), teamwork (Azizan et al., 2018), and cognitive resources mobilization to solve complex problems (Montrezor, 2016). Interactively learning concepts can help students move from relatively passive memorizing to actively applying new concepts in and outside the classroom (Franco & DeLuca, 2019).

The game Jenga (Pokonobe Associates, 2016) can be viewed as a simple perspective of resilience, that is, how much disturbance a system (the Jenga tower) can absorb before it collapses (Holling, 1973) or shifts to another state (Beisner et al., 2003; Lewontin, 1969). In Jenga, players construct a tower of 54 rectangular wooden blocks and take turns pulling single blocks from the tower until there are no more moves or the tower collapses. While a Jenga tower is obviously not capable of complex ecosystem behavior and process, it can be a method for students to learn foundational concepts. We designed a junior-level undergraduate classroom activity that utilizes the gameplay of Jenga with the goal of developing a basic understanding of ecological resilience, how it relates to natural resource management, and how resilience-based management compares to traditional yield-focused management strategies. The content and learning objectives of this activity align with the elements of the 4DEE Framework listed in Table 1.

The overarching learning objective of this activity is to illustrate the concept of resilience by contrasting it with the productivity of a system, such as crop yield. Yield in this model Jenga system corresponds to numbers that the educator is instructed to write on each Jenga block, and ecological resilience is measured by the number of blocks that could be removed before the collapse of the tower. The classroom game and activity packet (available as a free download at https://cre.unl.edu/our-work) includes learning goals and objectives, educator instructions, student instructions and handouts, a scoresheet, Kahoot! Quiz questions, scoresheet, and take-home essay questions. A separate preformatted Excel spreadsheet is also available to input student scores and dynamically graph results to illustrate lesson concepts.

The activity assigns students to five teams with rules (student handouts) corresponding to five different real-life policy and decision-making scenarios (Table 4). Our in-class testing went smoothly with students in groups of 3–6, but the activity can accommodate variable group sizes or the addition of more groups, which would be given the rules for one of the five available scenarios to follow. Once the activity begins, students take turns removing blocks from the tower according to their teams' preset rules, recording on a sheet how many blocks they remove and how much of the resource they harvest (the sum of numbers written on the blocks) before the tower collapses or is dismantled. After all student groups are done with their games, the results are compiled and graphed in the preformatted spreadsheet to visually graph how systems might behave (i.e., persist or collapse) under different policy and decision-making scenarios. The activity concludes with a follow-up discussion, quiz questions, and take-home essay questions to discuss real-life applications.

We tested this activity twice in junior-level classrooms of approximately 30 students each. While student feedback on the activity was informal, we used this process to gauge student engagement, connections made and verbalized in wrap-up discussions, and student ability to comment on system resilience and system productivity. Multiple students reported that the activity helped them see how resilience is both understood and misunderstood in society today, and they were able to have group discussions on the challenges of managing for resilience in a real-world complex system. As a result of this informal pilot testing, we revised elements such as unclear points in the student instructions and discussion questions that seemed to capture student learning experiences more accurately.

We designed this activity to illustrate how a productive system is not necessarily resilient (Holling, 1973) and how different definitions of ecological resilience can lead to different conclusions about a system (Pimm, 1984; Walker, 2020). During our classroom testing process, we asked students to rebuild the tower as quickly as possible following collapse. Jenga towers are often haphazardly rebuilt during their haste, illustrating how efforts to make systems "bounce back" can compromise Holling's resilience in the future (i.e., the tower more easily collapses in the next round).

The goal of this albeit simple exercise is to introduce beginner students to the concept of ecological resilience and some ways in which it can be unclear or misunderstood. We emphasize this in the teacher and student instructions, the quiz, and the discussion activities within the classroom packet. Jenga is simple, nonliving, and nonadaptive, allowing the complexity associated with resilience to be a key epiphany for students engaging with the concept in a tactile, physical way. This use of active learning in a team environment followed our review of the literature, reporting that students who build their own knowledge of introduced concepts are encouraged to take ownership in their learning process (Allsop et al., 2020; Honebein, 1996).

Case studies

The National Center for Case Study Teaching in Science and the Social-Environmental Synthesis Center use case studies as an active learning method in higher education (SESYNC, 2021; Wei et al., 2015). By participating in case studies, students learn how to engage with concepts through real-world examples while strengthening collaboration and critical thinking skills (Boehrer & Linsky, 1990; Herreid & Schiller, 2012). We formatted case studies as classroom activities that require approximately 4–6 h of class time and designed for student groups of 4–6 individuals each. While the learning objectives vary between individual case studies, they were developed with the overarching goal of using hypothetical or real-life situations and events to help students actively understand, apply, and analyze ERT concepts (Wei et al., 2015). The content of the case studies aligns with the elements of the 4DEE Framework listed in Table 1.

Our first case study focuses on the adaptive cycle concept. We created an ecological challenge for students to solve in the fictional, rural town of Sandville, Nebraska. The case study features town residents faced with the proposition of whether to allow the development of a wind energy farm outside town. After a brief introduction covering background concepts like the adaptive cycle and concept mapping, students are assigned to groups with a unique stakeholder identity. Each stakeholder has a detailed biography that highlights their personal values and attitudes toward the development of the wind farm. The case study culminates in a community town hall where stakeholders debate the issue and reorganize their views on the topic as they hear other stakeholders' perspectives. The case study has four sections that reflect adaptive cycle's four phases (Figure 1): (1) growth (accumulation of knowledge), (2) conservation (establishment of stakeholder perspective), (3) release (community debate), and (4) reorganization (reconciliation of views and a decision on wind energy policy).

In this case study, students use the concept of the adaptive cycle to explain how a small town's economy can reorganize over time. The adoption of stakeholder identities that may be wildly different from students' personal realities promotes critical thinking (Franco & DeLuca, 2019). Acting as stakeholders with different perspectives and values helps students consider novel viewpoints as they try to reconcile them in a mock town hall discussion, using this conflict to adapt their own perspectives (Lundholm & Plummer, 2010).

While educators using case studies in science classrooms overwhelmingly believe case studies help students more deeply understand materials (Yadav et al., 2007),

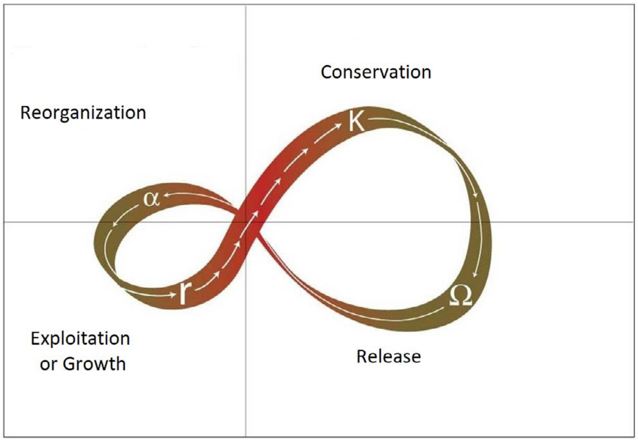

FIGURE 1 The adaptive cycle, consisting of four phases: "r" (exploitation or growth), "K" (conservation), "Ω" (release), and "α" (reorganization). The diagram border and gridlines represent the multidimensional space in which a system could occupy any of the four phases, and do not correspond to a specific variable or set of variables. Modified from Garmestani et al. (2009).

challenges of case studies include potentially developing narrow solutions to problems based on the structure and perceived limits of a scenario (Ban et al., 2015). Case studies such as those developed by the CRE may then provide opportunities either for enhancing student learning or for assessing the effectiveness of the method itself (Fazey, 2010). The completed case studies are available at https://cre.unl.edu/our-work.

A podcast: What the Heck is Resilience, Anyway?

In addition to informal personal development, podcasts are emerging as a tool that can be used in formal education in-class or online as an assignment in a flipped classroom model (Birch & Weitkamp, 2010; Hadjianastasis & Nightingale, 2016). Educators have been encouraged during the ongoing COVID-19 pandemic to create podcasts in their field of study to disseminate their work to wider audiences, and publications are increasing on the potential and documented success of podcasts in higher education fields such as conservation (Strickland et al., 2021), kinesiology (McNamara et al., 2021), medicine (Rodmand & Trivedi, 2020), nursing and midwifery (O'Connor et al., 2020), plant pathology (Lim & Swenson, 2021), and sports management (Johnston et al., 2021). Podcast interviews have the potential to introduce equity by providing an alternative to guest lectures who may be restricted to travel due to financial, personal, or external barriers (internet connectivity, time zone differences, and pandemic). Additionally, this may also potentially expand the interdisciplinarity of fields and expertise that students encounter during their undergraduate education (Gallant, 2021).

We created a podcast titled "What the Heck is Resilience, Anyway?" (WHRA) to bridge the gap between resilience experts, educators, and audiences by teaching ERT in conversational form so students and the public can learn ERT concepts and application either independently or within a structured course (Hadjianastasis & Nightingale, 2016). While WHRA was created as an informal supplement to structured classroom learning, it was designed as an outlet to (1) more broadly make technical ERT concepts understandable for a general audience and (2) interview resilience theory experts and practitioners about their work.

WHRA is hosted by CRE graduate students and has two types of episodes, conceptual episodes and interview episodes. Conceptual episodes introduce a resilience concept such as alternative stable state theory (*Episode 2: Close encounters with alternative stable states*) or the adaptive cycle (*Episode 3: Riding the highs and lows of the adaptive cycle*) and discuss its origins and current research. Interview episodes involve conversations with experts in resilience theory and resource managers who apply resilience concepts in their work practices. Like the conceptual episodes, interviews are conversational, with pre-developed questions available. Most questions are specially prepared for the expertise of each interviewee, with a couple of consistent introductory questions across interviews. Interviewees are invited to show how ERT is applied in different contexts and have included Dr Elena Bennett (McGill University Professor and Canada Research Chair in Sustainability Science) and Chris Helzer (Director of Science for The Nature Conservancy in Nebraska). Podcast episodes average 56 min long and conclude with "Resilience in the News," where the two hosts give examples of the concept being used in popular media sources.

The episodes of this podcast can be found online at https://cre.unl.edu/our-work, https://soundcloud.com/whra, and are available through Apple Podcasts, Spotify, and other common podcasting platforms. As of 2022, our episodes have reached over 1276 downloads in 28 different countries.

DISCUSSION

For undergraduate audiences, we intend the dissemination of these resources to facilitate interdisciplinary innovation and diverse perspective formation through exposure to new concepts and encouraging active learning via personal and group construction of knowledge. We believe exposure and debate of theories and frameworks may help future professionals apply ERT to global complex problems, and hope that diverse experts and researchers contributing their expertise will increase application and relevance outside ecology classrooms. We ask other researchers (including graduate students) interested in ERT and broader elements of resilience to consider creating new branches and expand our student-led CRE to address and share key research questions and problems within their expertise and culture (Ban et al., 2015). Graduate students and researchers are encouraged to use our materials to guide the development of their own examples, resources, and lesson plans. The resources discussed here are intended to help researchers and graduate students teach ERT concepts; practice science communication and education skills; and engage and collaborate with peers. While we encourage graduate student initiative and leadership (Frieze & Blum, 2002), we acknowledge the vital role of mentorship from experts who study ERT or supervise interested students (Kuehne et al., 2014). Their support is critical in this endeavor.

Collaborative, constructive learning networks provide unique opportunities for addressing complex, global problems of the 21st century. We acknowledge our limitations as a group predominantly from the fields of ecology and natural resources, from the United States, and only producing materials in English. This can potentially create intellectual homogeneity, a limitation we plan to remedy through the development of geographically and topically varying extensions of the CRE (Tapanes et al., 2009). For example, CRE has Spanish speakers who have begun translating the content modules to provide another language for viewers. Additionally, as a largely student-lead initiative, it is difficult to plan for further additions and revisions to the current resources in the long term. To provide a more central forum through which to add any new materials, make updates, or accept feedback, static versions of all resources presented here (with the exception of the podcast) are available in a public repository from the corresponding author (Hogan, 2022). The description of the repository includes contact information for the corresponding author and a link to a Google form through which readers and users can submit anonymous feedback about the available resources.

Our materials are intended for a broad undergraduate student body, but reaching younger audiences may be even more fruitful for transforming research, decision-making, and career futures (Cost, 2015). We hope these resources empower researchers and other graduate students to take new ownership of their careers and advance resilience education in innovative and diverse ways that may benefit society.

ACKNOWLEDGMENTS

Student support was partially provided by the National Science Foundation through the National Research Traineeship program under Grant Number DGE-1735362. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We would also like to thank the CRE members not represented by authorship in this paper, without whom this body of work would not have happened. We also thank the staff of the Plant and Soil Sciences eLibrary within the Department of Agronomy and Horticulture at the University of Nebraska-Lincoln, the Resilience Alliance Young Scholars program within the Resilience Alliance, and the many experts who provided review, assistance, and inspiration for our products. These staff and experts include Dr Dirac Twidwell, Dr Craig Allen, Dr Rick Alloway, Dr Jessica Burnett, Leah Sandall, A. McKinzie Sutter, Kaye Wolfe, Abigail Snyder, and the external reviewers for providing feedback on the educational modules.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

No data were collected for this study.

ORCID

Katharine F. E. Hogan https://orcid.org/0000-0002-9140-1744

REFERENCES

Allen, C. R., D. G. Angeler, A. S. Garmestani, L. H. Gunderson, and C. S. Holling. 2014. "Panarchy: Theory and Application." *Ecosystems* 17(4): 578–89. https://doi.org/10.1007/s10021-013-9744-2.

Allsop, J., S. J. Young, E. J. Nelson, J. Piatt, and D. Knapp. 2020. "Examining the Benefits Associated with Implementing an Active Learning Classroom among Undergraduate Students." *International Journal of Teaching and Learning in Higher* 32(3): 418–26. http://www.isetl.org/ijtlhe/.

Angeler, D. G., and C. R. Allen. 2016. "Quantifying Resilience." *Journal of Applied Ecology* 53(3): 617–24. https://doi.org/10.1111/1365-2664.12649.

Azizan, M. T., N. Mellon, R. M. Ramli, and S. Yusup. 2018. "Improving Teamwork Skills and Enhancing Deep Learning via Development of Board Game Using Cooperative Learning Method in Reaction Engineering Course." *Education for Chemical Engineers* 22: 1–13. https://doi.org/10.1016/j.ece.2017.10.002.

Baggio, J. A., K. Brown, and D. Hellebrandt. 2015. "Boundary Object or Bridging Concept? A Citation Network Analysis of Resilience." *Ecology and Society* 20(2): 2. https://doi.org/10.5751/ES-07484-200202.

Bai, X., S. van der Leeuw, K. O'Brien, F. Berkhout, F. Biermann, E. S. Brondizio, C. Cudennec, et al. 2016. "Plausible and Desirable Futures in the Anthropocene: A New Research Agenda." *Global Environmental Change* 39: 351–62. https://doi.org/10.1016/j.gloenvcha.2015.09.017.

Ban, N. C., E. Boyd, M. Cox, C. L. Meek, M. Schoon, and S. Villamayor-tomas. 2015. "Linking Classroom Learning and Research to Advance Ideas about Social-Ecological Resilience." *Ecology and Society* 20(3): 35.

Ban, N. C., and M. Cox. 2017. "Advancing Social-Ecological Research through Teaching: Summary, Observations, and Challenges." *Ecology and Society* 22(1): 1–3. https://doi.org/10.5751/ES-08949-220106.

Beisner, B. E., D. T. Haydon, and K. Cuddington. 2003. "Alternative Stable States in Ecology." *Frontiers in Ecology and the Environment* 1(7): 376–82. https://doi.org/10.1890/1540-9295(2003)001[0376:ASSIE]2.0.CO;2.

Benè, K. L., and G. Bergus. 2014. "When Learners Become Teachers: A Review of Peer Teaching in Medical Student Education." *Family Medicine* 46(10): 783–7.

Berkowitz, A. R., C. Cid, J. Doherty, D. Ebert-May, K. Klemow, G. Middendorf, T. Mourad, and B. Pohlad. 2018. "The 4-Dimensional Ecology Education (4DEE) Framework." https://www.esa.org/4dee/framework/.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, et al. 2012. "Toward Principles for

Enhancing the Resilience of Ecosystem Services." *Annual Review of Environment and Resources* 37(1): 421–48. https://doi.org/10.1146/annurev-environ-051211-123836.

Birch, H., and E. Weitkamp. 2010. "Podologues: Conversations Created by Science Podcasts". *New Media and Society* 12: 889–909. https://doi.org/10.1177/1461444809356333.

Blizzard Entertainment. 2022. "World of Warcraft." https://worldofwarcraft.com/en-us.

Boehrer, J., and M. Linsky. 1990. "Teaching with Cases: Learning to Question." *New Directions for Teaching and Learning* 1990(42): 41–57. https://doi.org/10.1002/tl.37219904206.

Carpenter, S., J. Brian Walker, M. Anderies, and N. Abel. 2001. "From Metaphor to Measurement: Resilience of What to What?" *Ecosystems* 4(8): 765–81. https://doi.org/10.1007/s10021-001-0045-9.

Cost, D. S. 2015. "The Role of Public Education in Governance for Resilience in a Rapidly Changing Arctic." *Ecology and Society* 20(3). https://doi.org/10.5751/ES-07757-200329.

Costanza, R., R. de Groot, L. Braat, I. Kubiszewski, L. Fioramonti, P. Sutton, S. Farber, and M. Grasso. 2017. "Twenty Years of Ecosystem Services: How Far Have we Come and how Far Do we Still Need to Go?" *Ecosystem Services* 28: 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008.

Day, S., S. Rennie, D. Luo, and J. D. Tucker. 2020. "Open to the Public: Paywalls and the Public Rationale for Open Access Medical Research Publishing." *Research Involvement and Engagement* 6(1): 4–10. https://doi.org/10.1186/s40900-020-0182-y.

Dubois, B., and M. E. Krasny. 2016. "Educating with Resilience in Mind: Addressing Climate Change in Post-Sandy New York City." *Journal of Environmental Education* 47(4): 255–70. https://doi.org/10.1080/00958964.2016.1167004.

ElSabry, E. H. 2017. "Who Needs Access to Research? Exploring the Societal Impact of Open Access." *Revue Française Des Sciences de l'information et de La Communication* 11: 1–22. https://doi.org/10.4000/rfsic.3271.

Fazey, I. 2010. "Resilience and Higher Order Thinking." *Ecology and Society* 15(3): 1–22. https://doi.org/10.5751/ES-03434-150309.

Feldon, D. F., J. Peugh, B. E. Timmerman, M. A. Maher, M. Hurst, D. Strickland, J. A. Gilmore, and C. Stiegelmeyer. 2011. "Graduate Students' Teaching Experiences Improve Their Methodological Research Skills." *Science* 333(6045): 1037–9. https://doi.org/10.1126/science.1204109.

Franco, P. F., and D. A. DeLuca. 2019. "Learning through Action: Creating and Implementing a Strategy Game to Foster Innovative Thinking in Higher Education." *Simulation and Gaming* 50(1): 23–43. https://doi.org/10.1177/1046878118820892.

Frieze, C., and L. Blum. 2002. "Building an Effective Computer Science Student Organization: The Carnegie Mellon Women@SCS Action Plan." *ACM SIGCSE Bulletin* 34(2): 74–8. https://doi.org/10.1145/543812.543835.

Fuhlendorf, S. D., R. W. S. Fynn, D. A. McGranahan, and D. Twidwell. 2017. "Heterogeneity as the Basis for Rangeland Management." In *Rangeland Systems*, edited by D. D. Briske, 169–96. USA: Springer. https://doi.org/10.1007/978-3-319-46709-2_5.

Gallant, K. 2021. "Creating Conversational Interview Podcasts to Replace Guest Lectures." *SCHOLE: A Journal of Leisure Studies and Recreation Education*: 1–2. https://doi.org/10.1080/1937156x.2021.1986438.

Garmestani, A. S., C. R. Allen, and L. Gunderson. 2009. "Panarchy: Discontinuities Reveal Similarities in the Dynamic System." *Ecology and Society* 14(1): 15.

Gunderson, L. H. 2000. "Ecological Resilience-in Theory and Application." *Annual Review of Ecology and Systematics* 31(2000): 425–39.

Gunderson, L. H., C. R. Allen, and A. S. Garmestani. 2022. In *Applied Panarchy: Applications and Diffusion across Disciplines*, edited by L. H. Gunderson, C. R. Allen, and A. S. Garmestani. Washington, DC: Island Press.

Gunderson, L. H., and C. S. Holling, eds. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press.

Gunderson, L. H., S. S. Light, and C. S. Holling. 1995. "Lessons from the Everglades: Learning in a Turbulent System." *BioScience* 45. (Supplement: Science and Biodiversity Policy [1995]): S66–73. https://doi.org/10.2307/1312447.

Hadjianastasis, M., and K. P. Nightingale. 2016. "Podcasting in the Stem Disciplines: The Implications of Supplementary Lecture Recording and 'Lecture Flipping.'" *FEMS Microbiology Letters* 363(4): 1–4. https://doi.org/10.1093/femsle/fnw006.

Herreid, C. F., and N. Schiller. 2012. "Case Studies and the Flipped Classroom." *Journal of College Science Teaching* 42: 62. https://www.researchgate.net/publication/306146143.

Hogan, K. 2022. "Free-to-Use (CC-BY-SA) Multimedia Resources for Undergraduate Education in Ecological Resilience Theory (ERT)." https://doi.org/10.5281/zenodo.6677901.

Hogan, K. F. E., K. L. Nash, and E. Bennett. 2021. "Adaptive Management of Ecosystem Services for Multisystemic Resilience." In *Multisystemic Resilience*, edited by M. Ungar, 725–43. Oxford, UK: Oxford University Press. https://doi.org/10.1093/oso/9780190095888.003.0038.

Holling, C. S. 1973. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4: 1–23.

Holling, C. S. 1992. "Cross-Scale Morphology, Geometry, and Dynamics of Ecosystems." *Ecological Mongraphs* 62(4): 447–502.

Honebein, P. C. 1996. "Seven Goals for the Design of Constructivist Learning Environments." In *Constructivist Learning Environments: Case Studies in Instructional Design*, edited by B. Wilson, 11–24. Englewood Cliffs, NJ: Educational Technology Publications.

Johnston, D., C. Rockhill, and D. Pastore. 2021. "The Effectiveness of Podcasts in Sport Management Education Part Two: A Qualitative Analysis." *Journal of Hospitality, Leisure, Sport and Tourism Education* 29(October 2020): 1003385. https://doi.org/10.1016/j.jhlste.2021.100338.

Krasny, M. E., K. G. Tidball, and N. Sriskandarajah. 2009. "Education and Resilience: Social and Situated Learning among University and Secondary Students." *Ecology and Society* 14(2): art 38. https://doi.org/10.5751/ES-03032-140238.

Kuehne, L. M., L. A. Twardochleb, K. J. Fritschie, M. C. Mims, D. J. Lawrence, P. P. Gibson, B. Stewart-Koster, and J. D. Olden. 2014. "Practical Science Communication Strategies for Graduate Students." *Conservation Biology* 28(5): 1225–35. https://doi.org/10.1111/cobi.12305.

Leshner, A., and L. Scherer. 2018. "Graduate STEM Education for the 21st Century." Graduate STEM Education for the 21st Century. https://doi.org/10.17226/25038.

Lewontin, R. C. 1969. "The Meaning of Stability." *Brookhaven Symposium in Biology* 22: 13–24.

Lim, M., and R. Swenson. 2021. "Talking Plants: Examining the Role of Podcasts in Communicating Plant Pathology Knowledge." *Journal of Applied Communications* 105(2): 1–25. https://doi.org/10.4148/1051-0834.2366.

Lockspeiser, T. M., P. O'Sullivan, A. Teherani, and J. Muller. 2008. "Understanding the Experience of Being Taught by Peers: The Value of Social and Cognitive Congruence." *Advances in Health Sciences Education* 13(3): 361–72. https://doi.org/10.1007/s10459-006-9049-8.

Lundholm, C., and R. Plummer. 2010. "Resilience and Learning: A Conspectus for Environmental Education." *Environmental Education Research* 16(5–6): 475–91. https://doi.org/10.1080/13504622.2010.505421.

Madani, K., T. W. Pierce, and A. Mirchi. 2017. "Serious Games on Environmental Management." *Sustainable Cities and Society* 29: 1–11. https://doi.org/10.1016/j.scs.2016.11.007.

Mayadas, A. F., J. Bourne, and P. Bacsich. 2009. "Online Education Today." *Science* 323(5910): 85–9. https://doi.org/10.1126/science.1168874.

McNamara, S. W. T., M. Shaw, K. Wilson, and A. Cox. 2021. "Educational Podcasts in Kinesiology: A Scoping Review." *Kinesiology Review* 10(1): 88–100. https://doi.org/10.1123/KR.2020-0007.

Montrezor, L. H. 2016. "Performance in Physiology Evaluation: Possible Improvement by Active Learning Strategies." *Advances in Physiology Education* 40(4): 454–7. https://doi.org/10.1152/advan.00022.2016.

O'Connor, S., C. S. Daly, J. MacArthur, G. Borglin, and R. G. Booth. 2020. "Podcasting in Nursing and Midwifery Education: An Integrative Review." *Nurse Education in Practice* 47 (June): 102827. https://doi.org/10.1016/j.nepr.2020.102827.

Oates, W. E., and R. E. Quandt. 1970. "The Effectiveness of Graduate Students as Teachers of the Principles of Economics." *The Journal of Economic Education* 1(2): 131–8.

PASSeL. 2020. "Plant and Soil Science ELibrary." https://passel2.unl.edu/.

Pimm, S. L. 1984. "The Complexity and Stability of Ecosystems." *Nature* 307(26): 321–6.

Pokonobe Associates. 2016. "Jenga." https://jenga.com.

Ramani, G. B., R. S. Siegler, and A. Hitti. 2012. "Taking It to the Classroom: Number Board Games as a Small Group Learning Activity." *Journal of Educational Psychology* 104(3): 661–72. https://doi.org/10.1037/a0028995.

Rieber, L. P., L. Smith, and D. Noah. 1998. "The Value of Serious Play." *Educational Technology* 38(6): 29–37. https://doi.org/10.1353/mml.2012.0019.

Roberts, D. 2018. "The Engagement Agenda, Multimedia Learning and the Use of Images in Higher Education Lecturing: Or, How to End Death by PowerPoint." *Journal of Further and Higher Education* 42(7): 969–85. https://doi.org/10.1080/0309877X.2017.1332356.

Rodman, A., and S. Trivedi. 2020. "Podcasting: A Roadmap to the Future of Medical Education." *Seminars in Nephrology* 40(3): 279–83. https://doi.org/10.1016/j.semnephrol.2020.04.006.

SESYNC. 2021. "Publications and Results." National Socio-Environmental Synthesis Center. https://www.remapcap.org/covid19publications?offset=1599710770145&reversePaginate=true.

Soriano, R. P., B. Blatt, L. Coplit, E. Cichoskikelly, L. Kosowicz, L. Newman, S. J. Pasquale, et al. 2010. "Teaching Medical Students How to Teach: A National Survey of Students-as-Teachers Programs in U.S. Medical Schools." *Academic Medicine* 85(11): 1725–31. https://doi.org/10.1097/ACM.0b013e3181f53273.

Spellman, K. V. 2015. "Educating for Resilience in the North: Building a Toolbox for Teachers." *Ecology and Society* 20(1): 46. https://doi.org/10.5751/ES-07243-200146.

Strickland, B. K., J. M. Brooke, M. T. Zischke, and M. A. Lashley. 2021. "Podcasting as a Tool to Take Conservation Education Online." *Ecology and Evolution* 11(8): 3597–606. https://doi.org/10.1002/ece3.7353.

Tam, M. 2000. "Constructivism, Instructional Design, and Technology: Implications for Transforming Distance Learning." *Journal of Educational Technology & Society* 3(2): 50–60.

Tapanes, M. A., G. G. Smith, and J. A. White. 2009. "Cultural Diversity in Online Learning: A Study of the Perceived Effects of Dissonance in Levels of Individualism/Collectivism and Tolerance of Ambiguity." *Internet and Higher Education* 12(1): 26–34. https://doi.org/10.1016/j.iheduc.2008.12.001.

Tsui, M. 2010. "Interteaching: Students as Teachers in Lower-Division Sociology Courses." *Teaching Sociology* 38(1): 28–34. https://doi.org/10.1177/0092055X09353887.

Turner, M. G., and R. H. Gardner. 2015. "Introduction to Landscape Ecology and Scale." In *Landscape Ecology in Theory and Practice*, 2nd edn, 1–32. New York, NY: Springer-Verlag.

Van Gerven, P. W. M., F. Paas, J. J. G. Van Merriënboer, M. Hendriks, and H. G. Schmidt. 2003. "The Efficiency of Multimedia Learning into Old Age." *British Journal of Educational Psychology* 73(4): 489–505. https://doi.org/10.1348/000709903322591208.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. "Human Domination of Earth's Ecosystems." *Science* 277(July): 494–9. https://doi.org/10.1007/978-0-387-73412-5_1.

Walker, B. 2020. "Resilience—What it IS and IS NOT." *Ecology and Society* 25(2): 25–7. http://www.diversitycentral.com/tools_and_resources/inclusion.php.

Wei, C. A., W. R. Burnside, and J. P. Che-Castaldo. 2015. "Teaching Socio-Environmental Synthesis with the Case Studies Approach." *Journal of Environmental Studies and Sciences* 5(1): 42–9. https://doi.org/10.1007/s13412-014-0204-x.

Xu, L., and D. Marinova. 2013. "Resilience Thinking: A Bibliometric Analysis of Socio-Ecological Research." *Scientometrics* 96(3): 911–27. https://doi.org/10.1007/s11192-013-0957-0.

Yadav, A., M. Lundeberg, M. DeSchryver, K. Dirkin, N. Schiller, K. Maier, and C. Herreid. 2007. "Teaching Science with Case Studies: A National Survey of Faculty Perceptions of the Benefits and Challenges of Using Cases." *Journal of College Science Teaching* 37(1): 34–8.

How to cite this article: Hogan, Katharine F. E., Julie A. Fowler, Conor D. Barnes, Alison K. Ludwig, Dominic J. Cristiano, Daniel Morales, Rubi Quiñones, Dirac Twidwell, and Jenny M. Dauer. 2022. "New Multimedia Resources for Ecological Resilience Education in Modern University Classrooms." *Ecosphere* 13(10): e4245. https://doi.org/10.1002/ecs2.4245