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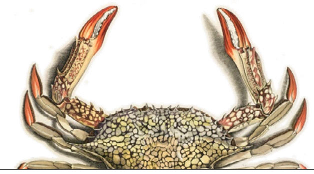

Lessons in Conservation is the official journal of the Network of Conservation Educators and Practitioners (NCEP)– a collaborative project of the Center for Biodiversity and Conservation (CBC) at the American Museum of Natural History–and is published as issues become available. Teaching and learning modules presented here in *Lessons in Conservation* are available in modifiable form for teachers on the NCEP website (ncep.amnh.org). All materials are distributed free of charge. Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the American Museum of Natural History or the funders of this project. All components of a module (Syntheses, Exercises, and Case Studies) have been peer-reviewed and approved for publication by NCEP.

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LETTER FROM THE EDITORS

Dear Reader,

Welcome to *Lessons in Conservation*, the official journal of the Network of Conservation Educators and Practitioners (NCEP), a collaborative project of the Center for Biodiversity and Conservation (CBC) at the American Museum of Natural History. This journal aims to introduce NCEP teaching and learning resources, or *modules*, to a broad audience. Our modules are designed to support undergraduate and professional level education on a variety of conservation topics, and are available for free download at our website (ncep.amnh.org).

For this issue, we present a suite of materials that were either adapted or developed specifically to promote and evaluate the development of skills in students. These materials target three skills areas–oral communication, data analysis, and critical thinking–and were used as part of a collaborative research project supported by the National Science Foundation (NSF). Study results show that the repeated use of these materials, together with opportunities for self-reflection on the skills themselves, generated skill gains over the course of a single term. More details on the study and how the materials have been used can be found in the editorial article included in this issue, titled *What Can Your Students Do? The Importance of Assessing and Developing 21st Century Skills in Conservation Students*.

We are grateful to many people across the CBC, NCEP, and those who participated in the NSF study for their contributions to the development of *Lessons in Conservation*. Please see the back cover for a full acknowledgement of the foundations and individuals that have supported this project.

Enjoy this issue of *Lessons in Conservation* and please visit our website to start using NCEP resources in your classroom! We welcome feedback on our resources and we especially welcome those wishing to become further involved in the Network. Email us at ncep@amnh.org.

Ana L. Porzecanski — Co-Editor

Adriana Bravo — Co-Editor

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Note to educators: To access teaching notes for these modules, visit our website (ncep.amnh.org), register as an educator, and search for module by title.

What Can Your Students Do? The Importance of Assessing and Developing 21st Century Skills in Conservation Students

Ana L. Porzecanski[1] and Adriana Bravo[2,3]

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1. INTRODUCTION

Understanding life on Earth, and how to sustain it, is a fundamental challenge of our time. The task requires professionals and academics who are deeply knowledgeable about the biosphere and its dynamics–a challenge educators rise to meet everyday through courses in environmental sciences and conservation biology. But as educators increasingly adopt evidence-based, scientific approaches to teaching and learning (Handelsman et al. 2004, Freeman et al. 2014, Nordlund 2016), the question arises: what are our courses preparing students to do?

As recent articles and reports have emphasized, educating the next generation of students to address complex societal and environmental issues involves more than the learning of scientific content (NRC 2003, Rhodes 2010, AAAS 2011, Blickley et al. 2013). Intellectual and practical skills–often referred to as professional, "21st Century," or process skills–are considered to be part of the essential learning outcomes of a liberal arts education (AAC&U 2007). It is critical to ensure that undergraduate students develop effective process skills in leadership, communication, working in groups, critical thinking, data analysis, and project management to be effective professionals in conservation science, policy, and practice (Blickley et al. 2013). Yet there is concern that many undergraduate science students in the United States are not currently developing important process skills needed by professionals (Arum and Roksa 2010, NRC 2009, Pascarella et al. 2011).

How can we best teach process skills, and how can we evaluate the development of these skills in our students? The materials featured in this issue of *Lessons in Conservation* formed the basis of a recent study led by the Network of Conservation Educators and Practitioners (NCEP) to answer these questions. The aim of this editorial is to familiarize readers with how the materials were used in the context of this study, and discuss the findings as well as implications for conservation education.

2. STUDY BACKGROUND AND DESIGN

The Network of Conservation Educators and Practitioners project (ncep.amnh.org) develops and disseminates open-access teaching and learning materials to enhance and broaden access to conservation education and training worldwide. NCEP materials, or modules, are multi-component, peer-reviewed, and adaptable. They are design to provide students the opportunity to learn and apply new content knowledge, and develop process skills. Once a critical mass of NCEP modules was available, NCEP partnered with module users to begin to evaluate their effectiveness, starting with knowledge gains. A series of faculty-driven studies demonstrated that NCEP modules can help faculty members improve student content knowledge, student confidence in knowledge, and student interest in biodiversity topics (Hagenbuch et al. 2009).

In 2010, NCEP initiated a new study[1] designed to investigate skill development associated with module use. The study brought together NCEP investigators and faculty participants from diverse institutions to explore how to best operationalize the teaching and assessment of skills in Conservation Biology and other integrative fields. The study selected three focal skills for investigation–oral communication, data analysis, and critical thinking–and built on several existing NCEP modules.

The study targeted five key questions:

1. By using the instructional materials, did students

[1] NSF DUE-0942789, *Developing and assessing process skills in Conservation Biology and other integrative fields.*

improve their abilities, in relation to the targeted process skills?
2. Did student confidence in their abilities change, in relation to a particular skill?
3. Did individual students accurately diagnose their own level of development, in relation to the targeted skill?
4. Were changes in process skills performance correlated with content-related performance?
5. And finally, was the intensity of the teaching intervention correlated with the overall gains in process skills in the classroom?

Materials were developed so that students would complete exercises practicing the target skill (either oral communication, data analysis, or critical thinking) twice during the term of a given course, and be exposed to either a "light" or "intensive" teaching session (an "intervention") focused on the skill between the two exercises. In a second iteration of the course (second term), the same exercises—but a different intervention—were used (see Figure 1).

Light interventions were designed to reinforce students' development of skills while keeping the intervention from the professors to a minimal level. Here students received their graded rubric from the first exercise (Exercise 1) and if questions arose, professors answered them keeping the total discussion to no more than 10 minutes. At the end of this discussion, professors reminded students that the same rubric would be used to evaluate their performance for Exercise 2. On the other hand, intensive teaching interventions also involved receiving feedback on Exercise 1, but there were opportunities for a deeper study of the skill over a full class period, and promoted deeper engagement with

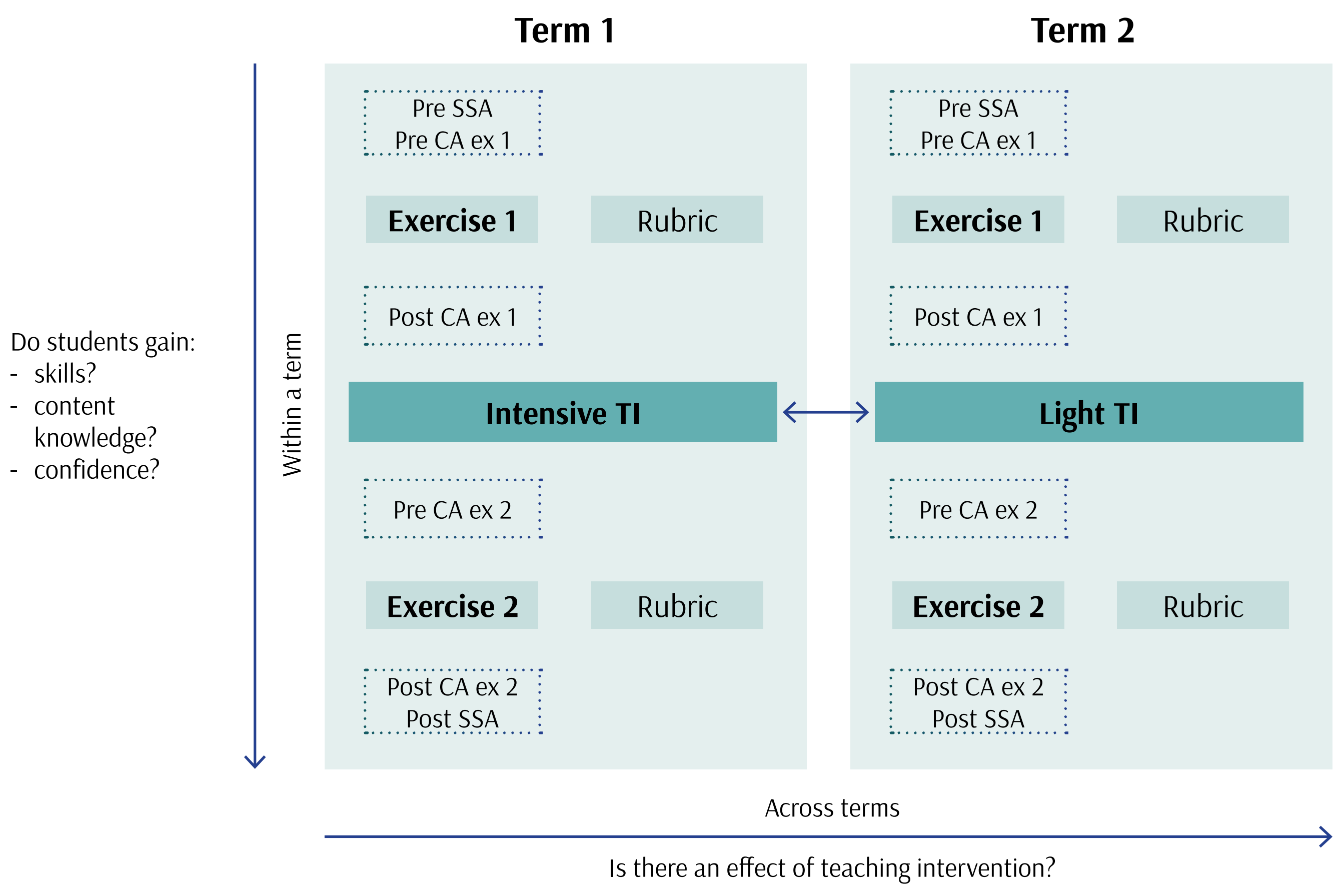

Figure 1. Experimental design and main questions within and across terms. For each target skill, two exercises were used over the course of a term (details in Table 1). The double-sided arrow between light and intensive teaching interventions (TI) indicates an interchangeable order. Abbreviations are as follow: SSA = student self-assessment; CA = content assessment; ex 1 = exercise 1; ex 2 = exercise 2; and TI = teaching intervention.

the rubric as well as self-reflection. A summary of the exercise topics and intensive interventions is provided in Table 1.

Each final set of materials consisted of:

- *Two analogous exercises* designed to promote development of the target skill, with exercise solutions.
- *A rubric* to grade exercise results and score skill level after each exercise. The rubric for each target skill typically encompassed between four and six dimensions, or criteria, with which to assess performance.
- *Pre/post content assessment questionnaires* for each exercise, each consisting of 6–7 multiple-choice questions and three open-answer questions, to assess gains in content knowledge.
- *Pre/post self-assessment questionnaires* for the target skill, with 5–6 questions to assess student attitudes towards the skill, and their perception of proficiency and confidence related to that skill.
- *Instructions for teachers* on how to lead a light and an intensive teaching intervention targeting the skill.

The study design meant that each participating instructor would have to collect data on skill performance, content gains, and confidence gains from individual students during two terms, plus lead either a light or intensive teaching intervention mid-term. Hence, a priority for the research team was to develop materials that could be easily integrated into existing courses, instead of materials that would require major course restructuring or redesign. We strived to maintain a workload for preparation, application, and data collection that would be considered feasible by the instructors.

3. STUDY FINDINGS

The study convened and fostered a productive, rich, learning community of diverse faculty members from

Table 1. Exercises and intensive interventions used in the study, for each target skill.

	ORAL COMMUNICATION	DATA ANALYSIS	CRITICAL THINKING
Exercise 1	*Why is biodiversity important? An oral communication exercise*	*Parrots and palms: analyzing data to determine best management strategies and sustainable harvest levels*	*Applying critical thinking to the amphibian decline problem*
Intensive teaching intervention	*Sharpen your oral communication skills!* Students use the same rubric they received from Exercise 1 to score an oral presentation by another student (video from a conference) and reflect on the video of the five minute oral presentation they prepared and delivered as part of Exercise 1. They are also handed out tips for their second presentation.	*Practice your data analysis skills!* Students use the same rubric they received from Exercise 1 to score the data analysis performed by a hypothetical student on a small dataset on nest parasitism by brown cowbirds on songbirds (adapted from a published study), and discuss ways to improve the responses.	*Overexploitation of parrots in the Neotropics*[a] Students use the same rubric they received from Exercise 1 to score the critical thinking of a hypothetical student responding to questions on a case study on the overexploitation of parrots in the Neotropics, and discuss ways to improve the responses.
Exercise 2	*Selecting areas for conservation: an oral communication exercise*	*What is biodiversity? Analyzing data to compare and conserve spider communities*	*Applying critical thinking to an invasive species problem*

[a]This teaching intervention was previously published in the July 2014 issue of *Lessons in Conservation.*

17 institutions across the United States, the US Virgin Islands, and Puerto Rico. This team collaborated closely on educational research over more than two years, and collected data on 976 students (with IRB approvals). A majority of the faculty participants were highly engaged in data interpretation and reflection on the implications for their own teaching, making this a highly collaborative project with high faculty development value. A summary of the study's main findings can be found in Box 1 and Table 2 and key results are described below. Detailed descriptions of the study results have also been published recently (Bravo et al. 2016, Sterling et al. 2016, Porzecanski et al. in prep).

Students can measurably improve in key process skills in one term by practicing with exercises. Average student performance gains were positive for all skills ranging from 29 to 40 percent (see Table 2). Gains varied among the different dimensions of a given skill (results not shown). This suggests some aspects of these skills are more challenging than others, or more amenable to development over a single course. The more challenging dimensions, such as, in critical thinking, *the ability to make judgments and reach a position, drawing appropriate conclusions based on the available information,* likely need different attention and may be more efficiently targeted through different activities than those used in this study (e.g., longer-term or more intensive learning activities).

Students gain knowledge in core concepts after exercises. Observed average gains in content were between 12 and 31 percent, an important indication that it is possible to target and develop skills in students without sacrificing content gains.

Students often gain in confidence but these show no correlation to changes in skill. While we observed significant gains in some dimensions of self-reported confidence along with practice and teaching interventions, these did not mirror the changes observed in skill performance, indicating that adequately diagnosing their own level of skill is challenging for students.

Box 1. Answers to the five targeted key questions.

1. **By using the instructional materials, did students improve their abilities in relation to the targeted process skills?**
   Yes, students can improve their abilities in relation to the target skills through the use of the instructional materials.
2. **Did student confidence in their abilities change, in relation to a particular skill?**
   Yes, students also change in terms of their confidence with these skills, however….
3. **Did individual students accurately diagnose their own level of development in relation to the targeted skill?**
   They do not always accurately diagnose their own level of development with the skill, such that performance and confidence are not overall positively related.
4. **Were changes in process skills performance correlated with content-related performance?**
   Yes, students can gain in content knowledge as they gain in skill.
5. **And finally, was the intensity of the teaching intervention correlated with the overall gains in process skills in the classroom?**
   Yes, the intensity of the teaching intervention can affect the overall gains in process skills in the classroom in some instances, but not always.

Table 2. Maximum mean gains in skill performance and content knowledge observed over the course of a term in the study, regardless of intervention type, for each target skill. Normalized change (c) is the ratio of the observed change to the total possible change, Marx and Cummings (2007).

	ORAL COMMUNICATION	DATA ANALYSIS	CRITICAL THINKING
Maximum mean gains in skill performance	c = 0.40 ± 0.03 SE	c = 0.29 ± 0.03 SE	c = 0.34 ± 0.04 SE
Maximum mean gains in content knowledge	c = 0.31 ± 0.03 SE	c = 0.12 ± 0.02 SE	c = 0.21 ± 0.04 SE

The intensity of the teaching intervention can increase gains for some skills. We found that the intensive teaching interventions increased average gains from 20 to 40 percent in the oral communication exercises (see Sterling et al. 2016). The teaching intervention involved students watching videos of their initial short oral presentations, and completing homework that promoted self-reflection on the skill. Faculty participating in the study hypothesized that the intense self-reflection required of students was one important factor in the gains. For critical thinking, a higher proportion of students improved their performance under the intensive teaching intervention, although these gains were not statistically significant (Porzecanski et al. in prep).

Finally, we observed that levels of starting student performance greatly varied among institutions and class level, and that some exercises work better with upper-level students.

4. IMPLICATIONS FOR TEACHING

For educators wishing to foster skills in their undergraduate students, there are several key take-aways from this study:

We encourage educators to integrate the practice of key skills with course content. While some activities will be dedicated to skill practice, not content acquisition, the results demonstrate that it is possible to target skills without sacrificing content knowledge gains. Case study-based exercises can be a useful tool for this integration, as they provide opportunities to analyze real world data or scenarios, think critically about complex issues, as well as research, synthesize, and communicate new information, all in the context of conservation topics and concepts.

We recommend educators provide opportunities for students to practice a given skill multiple times over the course of a term, and to reflect in between these instances of practice. In this study, the process of practicing, receiving feedback, reflecting on that feedback, and trying again, was beneficial to skill development.

Finally, we encourage educators to approach their teaching with an experimental lens. We hope the materials in this issue of *Lessons in Conservation* will provide a useful example or starting point. While the materials were used in sets and as tools to collect data on student performance during the study, educators can use them simply as exercises, together or independently, and adapt them as desired to the context of their courses, using the editable versions available through the NCEP module collection.

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Why is Biodiversity Important? An Oral Communication Exercise

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ABSTRACT

The main objective of this exercise is for students to understand why biodiversity is important. Students will conduct some bibliographic research to assess the value of a particular species and will then share these findings in class by giving a five minute presentation.

1. PART 1: INTRODUCTION

1.1. Background[1]

Biodiversity, a contraction of the phrase "biological diversity," is a complex topic, covering many aspects of biological variation. In popular usage, the word "biodiversity" is often used to describe all the species living in a particular area. If we consider this area at its largest scale—the entire world—then biodiversity can be summarized as "life on earth." However, scientists use a more comprehensive definition that considers its many hierarchical levels, and the processes that generate and maintain it. Thus, biodiversity can be considered to comprise the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.

Humans depend upon biodiversity in many ways, both to satisfy basic needs like food and medicine, and to enrich our lives culturally or spiritually. Yet in an increasingly modern, technological world, people often forget how fundamental biodiversity is to daily life and are unaware of the impact of its loss.

Values are also dynamic; they change over time and vary according to specific situations. Both the range of values towards a species and the changes in values over time can be examined in the case of the gray wolf (*Canis lupus*) in the United States. As of the early 1600s, gray wolves were widespread and abundant in North America. Around that time, European colonists, who deemed wolves a threat to human livelihoods, began systematically hunting and eradicating them. In the 1800s, this practice was formalized in US Federal and State government predator control programs, which included the use of bounties. This hunting and trapping pressure, along with habitat loss and degradation and loss in prey base, resulted in wolves being virtually exterminated from the lower 48 states by the early 1900s. But in the late 1970s, in sharp contrast to earlier views of wolves, the US government began programs to restore them to their former range. To some people, wolves have come to signify the wilderness and in some areas, have become an important tourist attraction (such as Yellowstone National Park and in northern Minnesota). Others still view wolves as a threat. The debate over wolf restoration programs demonstrates not only the changes in values but also the multiplicity of values within any one society (Lynn 2002, USFWS 2011).

The value of biodiversity is often divided into two main categories:

- Utilitarian (also known as anthropocentric) value, and
- Intrinsic (also known as biocentric) value.

1.1.1. Utilitarian Value

The *utilitarian value* of living things is determined by its use or function. Usually utilitarian value is measured in terms of its use for humans (anthropocentric), such

[1] Background information in this exercise is based on Laverty, M.F., E.J. Sterling, E.A. Johnson, E. Vintinner, and B.C. Weeks. 2008. *Why is Biodiversity Important?* Synthesis. Network of Conservation Educators and Practitioners, American Museum of Natural History. Available from ncep.amnh.org

as for medicine or food. However, it can also represent the value of an organism to other living things or its ecological value. For instance, pollinators, such as bees, are essential to the reproduction of many plants.

Economists typically subdivide utilitarian values of biodiversity into *direct use value* for those goods that are consumed directly, and *indirect use value* for those services that support the items that are consumed, including ecosystem functions (Table 1).

1.1.2. Intrinsic Value

In contrast to the utilitarian value, the *intrinsic* or *biocentric value* describes the inherent worth of an organism, independent of its value to anyone or anything else. In other words, all living things can be considered valuable because they have a right to exist, regardless of their utilitarian value (Cafaro and Primack 2014, Soulé 2013, Soulé 1985).

However, determining the value or worth of biodiversity is complex and often a cause for debate. This is largely due to that fact that the worth placed on biodiversity is a reflection of underlying human values, and these values vary dramatically both among societies and individuals (Perlman and Adelson 1997, Karp et al. 2015, Millennium Ecosystem Assessment 2005). The perspective of rural versus urban dwellers towards wildlife is one example. People who don't live with elephants on a daily basis appreciate elephants for their sheer size, charisma, and intelligence. Those who live near elephants, however, sometimes perceive them as a threat to people and their crops and property (Desai and Riddle 2015, Redpath et al. 2013).

Considering the value of biodiversity raises important but complex questions, such as:

- Do we, as a society, bear an obligation to act as responsible stewards of other species?
- Should we conserve species for the present or the future values (potential value) that they contribute to humans?
- What importance should be given to biodiversity conservation in the context other societal concerns?

2. PART 2: INVESTIGATING WHY SPECIES ARE IMPORTANT

Your task is to prepare a *five minute oral presentation* that assesses the value or importance of a particular species. You will be expected to present your findings in class in no more than five minutes and use visual aids.

To complete this assignment, you will need to research information available in the literature about your assigned species and assess its value. At least four of the bibliographic sources you use need to be reliable, such as peer-reviewed journals, refereed books or book chapters, and authorized databases (e.g., International Union for Conservation of Nature (IUCN) website). You must provide the references on your presentation. If you are not sure about what "reliable sources" means, please ask your instructor.

In your presentation, you must include:

1. A description of where your species fits within the tree of life (that is, how is it classified taxonomically).

Table 1. Categories of utilitarian values of biodiversity

UTILITARIAN VALUE	EXAMPLES
Direct use values (goods)	Food, medicine, building material, fiber, fuel
Indirect use values (services)	*Ecological value*: atmospheric and climate regulation, pollination, nutrient recycling. *Cultural, Spiritual, and Aesthetic value**
Non-use values	Potential value;[a] existence value;[b] bequest value[c]

**Some authors choose to differentiate these values from those services that provide basic survival needs such as the air we breathe.*
[a]*Potential value: future value either as a good or service*
[b]*Existence value: value of knowing something exists*
[c]*Bequest value: value of knowing that something will be there for future generations*

2. A description of the range. Is it a common or rare species within its range?
3. Is this species endemic to a particular area or region?
4. Is this a threatened species? Explain how it ranks in threat level using the IUCN criteria and why.
5. What are the known threats the species faces and what are the potential threats this species may face in the future?
6. In what ways can this species be considered valuable? *Remember that this should constitute the major focus of your presentation.*
7. A list of valid references.

Your instructor will provide a list of species and assign you one of those species on which to present. When constructing your presentation, assume your audience knows very little about the natural history of your species. So, make sure you provide key information to introduce your assigned species.

You will be evaluated on your understanding of the subject, selection, and use of supportive evidence as well as organization. In addition, delivery, use of visual aids and text, and timing will also be considered. For further details, please see the evaluation rubric provided for oral presentations (See: *Sharpen your oral communication skills!*, Appendix 1, in this Issue).

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Selecting Areas for Conservation: An Oral Communication Exercise

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ABSTRACT

Resources to implement conservation actions are very limited compared to the potential needs in a given area, which means conservationists usually have to make difficult choices and establish priorities for action. Therefore, it is important to demonstrate the value of a proposed conservation area or project for it to be considered a high priority for funding. In this exercise, you will research the importance of a specific area for conservation, and through a short oral presentation, make the case for its value and high priority for funding. The exercise should give students an enhanced understanding of the different approaches and criteria used for priority setting in conservation, and a chance to practice their oral communication skills.

1. PART 1: INTRODUCTION

1.1. Background[1]

An essential role of protected areas is conserving biodiversity, by reducing threats and the risk of extinction. They may be implemented to conserve targets at multiple scales—from species, populations, and genetic diversity, to landscapes and ecosystems and their emergent ecological processes. They may also be designed to act as buffers against anthropogenic or natural uncertainty, such as climate change, and drought, floods, or storms. But in the face of widespread threats to biodiversity, which areas should be considered high priority for conservation? Areas can be set aside for conservation in response to a number of factors and criteria.

1.1.1. Protecting Specific Taxa

Many protected areas are designed to conserve specific threatened organisms. Sites may be chosen to protect taxa listed on the IUCN Red List (www.redlist.org), which includes species at risk of extinction. Focal species may also be used as surrogates to conserve other groups and ecosystems as well. Charismatic taxa may serve as *flagship species*, garnering public attention and support that can then be used to conserve their ecosystems (Figure 1a; Caro and Doherty 1999). Another option is to focus on *indicator species*, which are species used as an indicator of the environment quality or the status of other species (Figure 1b). The conservation of communities or habitats can also be achieved by protecting *umbrella species* (Figure 1c). These are organisms, such as migratory wildebeest, whose habitat requirements and range also encompass the needs of other conservation targets (Caro and Doherty 1999). Protected areas may also be designed based on organisms that are important to ecosystems. *Keystone species* such as figs (Moraceae), mast-fruiting dipterocarps (Dipterocarpaceae) in Asia, or habitat-forming organisms like corals have important ecological roles (Figure 1d; Caro and Doherty 1999). Thus, removal of these keystone species can have significant impacts on their communities or ecosystems. A related but different concept is that of *landscape species*, such as forest elephants, which use large areas with a great diversity of habitats and have significant impacts on the structure and function of the whole ecosystem (Figure 1e; Redford et al. 2000). Because of their large area requirements, landscape species are sensitive and susceptible to human impacts. Contrary to the

[1] The background information in this exercise is based on Naro-Maciel, E., E.J. Sterling, and M. Rao. 2007. *Protected Areas and Biodiversity Conservation I: Reserve Planning and Design*. Synthesis. Network of Conservation Educators and Practitioners, American Museum of Natural History. Available from ncep.amnh.org

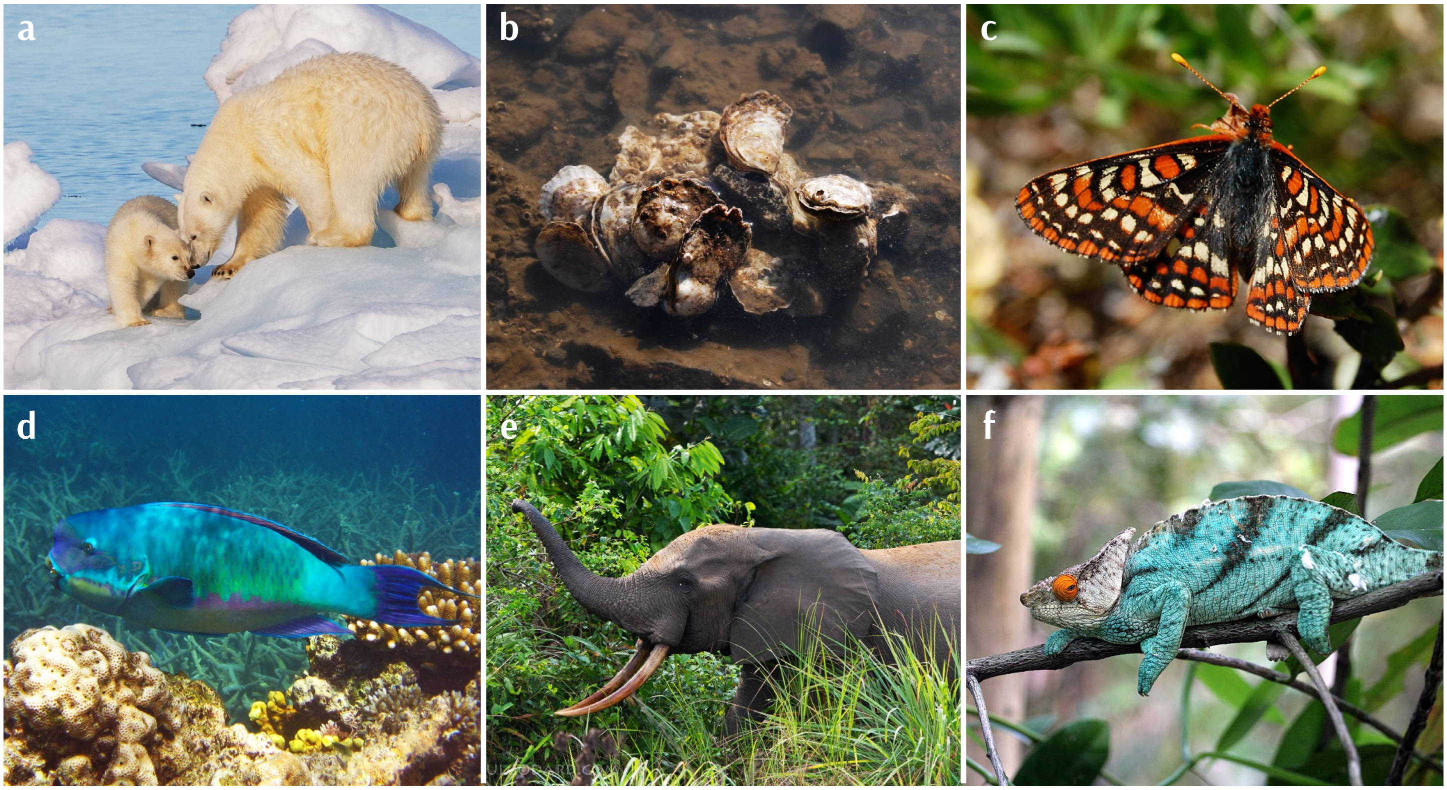

Figure 1. Examples of a) flagship species: polar bears; b) indicator species: oysters; c) umbrella species: Bay checkerspot butterfly; d) keystone species: parrotfish; e) landscape species: African forest elephant; and f) endemic species: Parson's chameleon.

Images: a) AWeith [CC BY-SA 4.0]; b) Oregon State University [CC BY-SA 2.0]; c) Fcb981 [CC-BY-SA-3.0]; d) jdegenhardt (Flickr user) [CC BY-NC-ND 2.0]; e) Paul Godard [CC BY-NC-ND 2.0]; and f) JialiangGao [CC BY-SA 4.0-3.0-2.5-2.0-1.0].

other focal species, landscape species are associated with large and also ecologically diverse areas and thus ensure the conservation of multiple species, habitats, and ecological processes that occur at the landscape level.

1.1.2. Conserving Specific Habitats

Beyond a focus on species, certain habitats with exceptional characteristics and/or threats may also be chosen for conservation. Coral reefs, the rocky intertidal, mudflats, seagrass beds, and wetlands can be considered at-risk marine systems worthy of conservation in protected areas (Airamé et al. 2003). Significant natural communities—for example, pine barrens, freshwater tidal marshes, floodplain forests, chestnut oak forests, and talus cave communities in New York (Howard et al. 2002)—may be chosen for protection in reserves. Site choice may be based on habitat characteristics, including substrates, such as hard or soft sediments, and coastline features, like sandy beach or rocky coast (Airamé et al. 2003). Depending on data availability and scale, aspects of species distributions and demography (such as abundance, distribution, and population growth) are also considered in selecting habitats for conservation (see Airamé et al. 2003). In the absence of reliable comprehensive data, environmental, climatic, or physiographic surrogates—such as rainfall, temperature, and vegetation structure—can be employed. It is important to consider how selected sites represent the spatial area and resources used by a community of species.

1.1.3. Conserving Ecological Processes

Maintaining ecological processes or ecosystem functionality are important considerations in conservation planning. For instance, maintaining community-level interactions (such as prey-predator interactions or partners in mutualism and addressing natural levels of disturbance) are key elements of an ecological approach to foster natural processes (Scott and Csuti 1997). It is also important to consider the appropriate size and shape of an area necessary to sustain viable populations with the adequate number of individuals. Large areas may be required to maintain metapopulation dynamics, preserve intact and/or functioning ecosystems, and to accommodate wide-ranging species.

1.1.4. Conserving Taxonomic Diversity

Priority areas may be selected to preserve *species richness* or *species diversity*. Species richness refers to the number of species present at a site while species diversity is the species number weighted by their relative abundance. Conservation priorities can be based on abundance, rarity, threat levels, phylogenetic or evolutionary distinctiveness, the extent to which assemblages represent regional diversity, or endemism. *Endemic species* are those species whose distributions are naturally restricted to the defined region (Figure 1f). Combinations of these criteria are also employed; for example, conservation planners are increasingly interested in taxonomically rich and threatened sites that could be chosen to maximize cost-effectiveness. Concentrated, long-term, and careful effort focused on such high-priority areas may ensure that a large proportion of the world's biodiversity will escape extinction.

Currently, there are several global conservation priority-setting methods based on species distributions, threat levels, and financial considerations (reviewed by Brooks et al. 2006, Venter et al. 2014). These approaches tend to focus on irreplaceability, targeting areas with high diversity and endemism of plants or terrestrial vertebrates, and threat levels. Priority-setting approaches focusing on sites with high levels of threat are considered reactive. For instance, 36 *biodiversity hotspots* have been identified[2] across the globe. They occupy 2.3 percent of the earth's land surface, but hold 77 percent of the world's total vertebrate species, with 11,980 (or 42 percent) of mammal, bird, reptile, and amphibian species being endemic (www.cepf.net). They also encompass at least 150,000 endemic plant species, and half of the world's vascular plants (www.conservation.org, www.cepf.net).

[2] For an area to be designated as a biodiversity hotspot, it needs to contain at least 0.5% of the world's vascular plant species as endemics and have lost at least 70% of its original habitat (Myers et al. 2000, www.conservation.org, www.cepf.net)

On the other hand, priority-setting approaches focusing on sites with low threat are considered *proactive*. An example of a proactive approach is the Wildlife Conservation Society's (WCS) *Last of the Wild* (Sanderson et al. 2002, Woolmer et al. 2008). Last of the Wild areas are the largest wild, or least influenced, areas in each of the biomes of the world. They are identified using biodiversity indices in combination with threat indicators, such as human population density, accessibility of the regions to human development, and land transformation (Sanderson et al. 2002, Woolmer et al. 2008).

In some cases, the level at which conservation priority areas are defined may be too coarse for effective conservation planning, possibly failing to capture finer-scale variation (Olson et al. 2001). The entire Caribbean, for example, is considered one biodiversity hotspot (Myers et al. 2000). To address this, a hierarchical approach may be employed whereby smaller sites are evaluated in terms of their importance, sometimes within these larger areas. The World Wildlife Fund (WWF), for example, focuses on priority *ecoregions* (www.wwf.org; Olson et al. 2001). An ecoregion is "a large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (www.wwf.org). The *Global 200 Ecoregions* are the subset of terrestrial and aquatic ecoregions with exceptional biodiversity, such as high species richness or endemism, and ecosystem representation that are considered high priorities for conservation.

2. PART 2: INVESTIGATING THE BIODIVERSITY VALUE OF CONSERVATION AREAS

Your instructor will assign you a tract of land, nature reserve, park, or land reclamation project about which to make a case for conservation. Your task is to prepare a *five minute oral presentation* to present convincing evidence that an area deserves to be considered a high priority for conservation. Imagine that your audience will be voting on which area has the highest conservation priority, and this area will be awarded $1 million USD. You are expected to present your findings using visual aids *in no more than five minutes*.

To complete this assignment, you will need to research information available in the literature about your assigned area. At least three of the bibliographic sources you use need to be reliable sources such as peer-reviewed journals, refereed books or book chapters, and authorized databases (e.g., IUCN website). You must provide the references on your presentation. If you are not sure about what "reliable sources" means, please ask your instructor.

Your presentation should be visually appealing, and provide the following *specific information*:

1. A description of the basic physical/geographical and socioeconomic characteristics of the area.
2. A description of the major biological communities in the area of interest, including information on endemic species, critical habitats for selected species, and other unique characteristics.
3. A description of the main threats faced by the area.
4. A description of the current conservation actions and programs taking place in the area.
5. A critical analysis of how the area of interest differs from others: what does this area offer in terms of conservation value that others do not?
6. A list of valid references.

When constructing your presentation, assume your audience knows very little about your site. Make sure you provide key information to introduce your assigned area.

You will be evaluated on your understanding of the subject, selection, and use of supportive evidence, as well as organization. In addition, delivery, use of visual aids and text, and timing will also be considered. For further details, please see the evaluation rubric provided for oral presentations (See: *Sharpen your Oral Communication Skills!*, Appendix 1, in this Issue).

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Sharpen Your Oral Communication Skills!

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ABSTRACT

In this exercise, you will learn about the elements and criteria that define successful oral presentations. Using a "rubric" or assessment guide, you will evaluate a 15-minute student presentation. In the process, you will review and reflect on what is required for effective oral communication, so that you can use that knowledge to improve your own skills and future performance.

1. INTRODUCTION

In this exercise, you will learn about the elements and criteria that define successful oral presentations. Using a "rubric" or assessment guide, you will evaluate a 15-minute student presentation. In the process, you will review and reflect on what is required for effective oral communication, so that you can use that knowledge to improve your own skills and future performance.

1.1. Steps

1. Review the Oral Communication rubric (Appendix 1). This rubric, or guide, outlines five key criteria for preparing and evaluating oral presentations: Organization, Content and Supporting Evidence, Student Comprehension, Delivery and Language, and Visual Aids and Text. Read each criterion carefully.
2. Watch the video of a presentation provided by your instructor. Keep the key criteria in mind as you watch, and after the presentation is over, use the rubric as a guide to assign a score between 1 and 4 for each of the criteria accordingly. In addition, you may want to read some tips on how to make visual presentations (Appendix 2) that can help you with some criteria of your assessment.
3. Discuss your results with your neighbor, and then with the rest of the class.
4. Finally, considering your past oral presentations and any feedback you have received from instructors, identify specific areas in the rubric where there is room for you to improve.[1] Please write out a 1 to 3 paragraph answer to the following question and submit it to your instructor for the next class meeting.

Which of the presentation criteria/elements do you think is the most challenging for you, and what could you do to overcome that difficulty?

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[AAC&U] Association of American Colleges and Universities. 2009. Inquiry and analysis VALUE rubric. Association of American Colleges and Universities, Washington, DC, USA. Available from https://www.aacu.org/value/rubrics/inquiry-analysis (accessed January 2012).

[1] If applicable, refer to the rubric used to evaluate and provide feedback on your past presentations in class, and/or any video recordings of your performance.

APPENDIX 1

Table 1. Oral Communication Rubric.[2] *Oral communication involves a prepared, purposeful presentation designed to increase knowledge, to foster understanding, or to promote change in the listeners' attitudes, values, beliefs, or behaviors. Levels of achievement (1–4) range from Beginning to Exemplary.*

	1	2	3	4
Organization	Presentation is very hard to follow, with no evident organization.	Presentation is somewhat organized, but not easy to follow. Several ideas seem out of place or irrelevant.	Presentation is clearly organized, easy to follow. One or two ideas seemed out of place or irrelevant to the question.	Presentation is clearly organized and easy to follow, with a specific introduction and conclusion, and clear transitions. No information seems out of place or irrelevant.
Content and Supporting Evidence	Content is not directly relevant to the assigned topic. Presentation does not include adequate evidence supporting the presenter's arguments or includes irrelevant evidence. Student does not provide sources of evidence.	Some of the content is not relevant to the assigned topic. Some of the arguments/results are insufficiently supported by evidence or research seems insufficient. Some of the evidence used seems inaccurate, derived from poor quality sources, or is unrelated to the topic. Student does not provide sources for all the evidence.	Most of the content is directly relevant to the topic. Sufficient, supporting evidence included for each argument. Inaccuracies, if present, are minor. Most evidence properly cited, but of mixed quality or from a limited variety of sources.	All of the presentation is on topic. All evidence brought to bear on the question seems accurate, derived from high quality sources, and relates to the topic, allowing greater understanding. Includes a variety of high quality and relevant supporting evidence, properly cited.
Student Comprehension	Student displays minimal understanding of the subject, provides no explanation, or a minimal explanation, of any supporting evidence, and fails to leave audience with clear and comprehensive take-home message.	Student displays some understanding of the subject, attempts to explain supporting evidence but does so incompletely or erroneously in some cases, and/or provides audience with a take-home message that is not sufficiently clear or comprehensive.	Student displays near-complete understanding of the subject, clearly explains most of the supporting evidence, and provides the audience with a clear, comprehensive take-home message.	Student displays a complete understanding of the subject, clearly explains all of the supporting evidence, and ends with a clear, comprehensive, and compelling take-home message.
Delivery and Language	Delivery techniques detract from the understanding of the presentation. Speaker appears uncomfortable, uses speech crutches, or uses language inappropriate for the context. Speaks too low to be heard. Talks too fast or too slow most of the time.	Delivery techniques make the presentation understandable, but speaker appears uncertain, occasionally uses inappropriate language, or does not speak loudly enough. Student talks too fast or too slow during some sections.	Delivery techniques make the presentation interesting and speaker appears comfortable. Appropriate language and volume used. Student talks too fast or too slow part of the time but spoke at a generally appropriate pace.	Delivery techniques make the presentation compelling and speaker appears polished and confident. Appropriate, clear language and volume used for the audience. Student demonstrates an appropriate, moderate pace effectively in all sections.
Visual Aids and Text	Presentation includes many images/diagrams that are confusing, irrelevant to the topic, or detract from presentation clarity. Text is excessive, cluttered, hard to read, or irrelevant on most slides.	Presentation includes some images/diagrams that are confusing, irrelevant to the topic, or detract from presentation clarity. Text is excessive, cluttered, hard to read, or irrelevant on some slides.	With 1-2 exceptions, the presentation includes clear, relevant images and diagrams that enhance understanding of the topic. Most slides have an appropriate amount of text and precise and relevant information.	All of the images/diagrams are clear, relevant, visually pleasing, and enhance understanding of the topic and convey information more effectively. All slides have an appropriate amount of text and precise and relevant information.
Timing	Time not used effectively. Presentation substantially over or below the allotted time.	Presentation slightly over or below the allotted time. Time distribution among sections inappropriate in relation to section importance.	Student does not exceed the allotted time, but time distribution for sections could improve.	Appropriate and sufficient time is allocated to each part of the presentation.

[2]*Modified From The AAC&U Value Rubric By The Network of Conservation Educators and Practitioners.*

APPENDIX 2: ORAL PRESENTATION SUGGESTIONS

1. Principles of Good Speaking with a Visual Presentation

Despite the presence of visual media, principles of good speaking also apply to presentations that incorporate slides prepared with PowerPoint, Keynote, or other similar software. These visual tools should only enhance your presentation—not to substitute for it.

1. *Focus on the content*: As the saying goes, "The main thing is to keep to the main thing." Do not let the use of the media hinder you in addressing your topic.
2. *Do not read from the screen*: Overly relying on the presence of the text is by far the most common problem with novice presenters. Your audience can, and should be able to read for themselves. Additionally, reading from the screen prevents you from elaborating beyond what they see—do not limit your presentation to the screen. Consider providing additional information and clarifying your comments.
3. *Maintain depth*: Due to the nature of the media, it's easy to resort to citing facts. However, are you also providing interpretation? Let the slides assist you in conveying complex ideas to your audience.
4. *Maintain eye contact with your audience*: It is very easy to be distracted by the content on your screen. A minor exception to this guideline is a need to draw your audience's attention to a specific part of your slide. For example, you could use a pointer to identify a trend of a graph. Otherwise, there's no reason to show your back.
5. *Keep pace with yourself*: At first, you may find it difficult to coordinate speaking and showing your slides simultaneously. However, coordination of the two is essential in preventing confusion. *Practice* before giving presentation. You may find it helpful to make notes to yourself of when you need to advance slides. Doing so minimizes the need to look at the screen itself.
6. *Remain succinct*: Slides should be used for communicating concisely. Packing too much content in a single slide could be confusing. For example, writing 20 word paragraphs on a slide defeats the objective of digital slides. Bullet points are more effective than whole sentences.
7. *Make your slides count*: Is the slide necessary? If not, omit it or combine it with another slide.

2. Design Tips: Make It Easy on the Eyes

Visual presentations should be easily readable. Although certain formatting may look appealing at first, you should consider several issues before completing your presentation.

1. *Font size*: Font size 18 to 24 point or larger ensures that those in the back of the room can easily read the text. If you require a smaller size to accommodate the amount of text, consider writing fewer words instead.
2. *Use contrast*: Many people find that reading dark text on a light background is easier to read than light text on a dark background. Whatever template you use or customize, ensure that you provide an adequate contrast in color. On a yellow background, dark blue font is much more readable than a white font.

3. Prevent Distraction: Minimize Bells and Whistles!

Your priority should be to create a presentation with substantive content rather than a hyperactive show. The overuse of eye-catching features is distracting and could even be annoying. Do not be embarrassed by content-filled slides without fancy multimedia. The most effective animation involves a simple point-by-point side "fly-in" or "appear." A good motto: "Don't do it just because you know how to!"

1. *Incorporate figures and powerful graphics*: PowerPoint or similar software is ideal for providing diagrams and conceptual representations that help illustrate your ideas and enhance your presentation. Note, however, that the overuse of large images reduces your amount of usable screen space for text and stock images could be inappropriate and irrelevant to your content. Each image should have relevance and proper identification/attribution.
2. *Consistent transitions*: Transitions, those effects

that introduce slides, should be consistent throughout your presentation.

3. *All build effects are not equal*: Like transitions introduce entire slides, build effects introduce bulleted text or graphic objects within a slide. For example, you may choose to have your points "Fly from the right" side. Selections are generally a matter of preference; however, some build effects could divert your audience's attention.
4. *Minimal animation*: Used sparingly, animation lends a dramatic element to a presentation.
5. *Sounds*: Sound should be used minimally—if even at all.

4. Additional Tips

- Plan for each slide to last one minute on average.
- Have slides read from left to right; from top to bottom.
- People see graphics first, then text.
- A logical flow of information is essential.
- Outline and/or summary slides are appropriate for long presentations.
- Use sufficient "white"/blank space.
- Limit use of bold, italics, or underlining.
- Do not write in all UPPERCASE.
- No more than two fonts on a screen (preferably one).
- One main concept per slide.
- No more than five items per screen.
- Background patterns make slides harder to read.
- When creating original images, use high quality equipment/programs.
- Use high enough resolution images to avoid pixelated appearance on large screen.
- Edit files to a reasonable size.
- Remember that the goal is to improve learning.

Parrots and Palms: Analyzing Data to Determine Best Management Strategies and Sustainable Harvest Levels

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ABSTRACT
This exercise[1] presents a scenario and raw data on a realistic conflict between parrot conservation and palm tree harvest. It requires that students analyze data very comparable to what would be gathered in the field, to: 1) construct a life tables for the palm and parrot, 2) extract vital statistics about both the palm and parrot population from the life tables, 3) estimate maximum sustainable yield for both species, and 4) make a decision about the sustainability of harvest intensity. It illustrates the importance of data analysis skills for conservation.

1. PART 1. INTRODUCTION

1.1. Objectives

Debates in conservation often focus on population management issues. For example, how do we reverse declines in endangered species, or harvest, in a sustainable way, populations of abundant species? Any population undergoes changes through time that are determined by interactions between age-specific mortality (death) and fecundity (birth) rates and the numbers of individuals of different ages. A first step toward understanding these processes is to use life table analysis to calculate the population's vital statistics. The analysis of demographic data can provide many insights into the population's behavior, and into management options for that population.

This exercise aims to provide you with an introduction to *applied demographic analysis*.[2] We examine a scenario involving parrots and harvesting of the trees they require for nesting. Our objectives are to: 1) evaluate different strategies for sustainable harvesting of parrots for the pet trade, and 2) balance sustained yield for trees and parrots simultaneously. The exercise is intended to provide you with first-hand experience analyzing the type of population data typically gathered by field biologists within a realistic context. That context is one in which conservation biologists are struggling to find a balance between parrot conservation and harvest for the pet trade as well as timber harvest and the incidental loss of nesting trees for the parrots.

1.3. Background

This scenario is contrived but matches closely many details of real parrot populations as well as situations affecting parrot conservation, that is, harvest for the pet trade and loss of vital nest trees due to timber harvest (Figure 1). Consider a hypothetical species of small parrot that *matures at age three and then breeds at a modest level (two or three chicks per year) for approximately three years*. The parrot is much sought after for sale in the pet trade. Adults can be harvested directly through netting outside the nesting season or nestlings can be removed from nest trees and reared by hand. These parrots only nest in holes in a particular species of palm that is sought after by humans as a source of building material and thatch. Parrot nests are fairly inconspicuous and the harvesting of palms is done without knowledge of where the parrots nest. It also occurs during the dry season, which happens to be the nesting season of the parrots. Thus, some of the palms felled incidentally kill young parrots in nests as well as the attending female.

We are concerned with a 10,000 km² community forest.

[1] For advanced student version of this exercise, see *Applied Demography: Parrots and Palms* found at ncep.amnh.org.
[2] For more background reading, refer to *Applied Demography* found at ncep.amnh.org.

*Figure 1. Red-bellied macaws (*Orthopsittaca manilata*) on a dead Buriti palm tree (*Mauritia flexuosa*). Image: Ltoniolo (own work) via Wikimedia Commons, [CC BY-SA 4.0].*

Palm density is 100 per km^2, although under the best of conditions at *carrying capacity* (*K*) they can be twice as abundant. The parrots typically occur at a density of 1 parrot (of all ages) per 10 km^2; again, K is double the typical density (*K = 2 parrots/10 km²*). During palm harvest, every thousandth palm felled will, on average, destroy a nest and the attending pair of adult parrots.

Based on this scenario, the exercise tackles three questions:

1. How many young can be sustainably removed from the parrot population each year?
2. What is the maximum sustained yield of the palm?
3. Given that some parrot mortality occurs incidentally to palm harvest, is managing palms at their optimal yield level acceptable in terms of maintaining the parrot population?

2. PART 2: DATA

2.1. Observations from the Field

The following data (Tables 1, 2) are collected from an unharvested population of parrots. Table 1 lists longevity data from a cohort of 91 females. The data are only from females because reproductive output in males is difficult to measure. We will assume that life table estimates for females also apply to males. The longevity data are the age at death (in years) of a sample cohort member. For example, #16 at 0.1 years represents individual #16 that died at age 0.1 years (or about 1 month).

In Part 3 of this exercise, you will use these data to determine the number of individuals that survived to each age, starting with age 0.

The next set of data (Table 2) describes the maternity (birth rate/fecundity) rates in the parrot population. The data were collected from a representative sample of females in the population. Biologists climbed nest trees of known-aged females and determined how many young they produced. Each individual is just one sample of the reproductive output of a female of a particular age. You will note from the data that *reproductive maturity is reached at age 3 years and senescence sets in by age 6 years*. The maternity data correspond to the number of female offspring produced by females of a particular age. For example, 3 at 5 years indicates that 3 female offspring were produced by this 5-year-old female. Using these data you will calculate the average maternity rate for females of a given age.

3. PART 3: DATA ANALYSIS

3.1. Construct the Life Table

Now construct a life table (see Table 8) for this population so that you can determine the: 1) survivorship values, 2) survival rates, 3) mortality rates, 4) maternity rates, and 5) population growth rates.

The first step is to determine the number of females alive (*N*) at the beginning of each time interval *x* (*Nx*). N_0 is the total number initially present in the cohort, or 91. For the subsequent time intervals, determine the number of females still alive from the longevity data provided above. The easiest way to do this is to tally the number of individuals that died at each age. Then make a cumulative summation from the oldest age class upward to the youngest. This will provide you with each

Table 1. Longevity data (in years) for individual parrots.

INDIVIDUAL NUMBER	AGE AT DEATH (YEARS)
46	0.1
16	0.1
82	0.1
20	0.1
22	0.1
55	0.1
91	0.1
64	0.1
66	0.1
10	0.2
43	0.2
45	0.2
56	0.2
62	0.2
18	0.3
85	0.3
60	0.3
52	0.4
32	0.4
68	0.7
36	0.7
75	0.7
50	0.7
4	0.9
48	0.9
59	0.9
33	0.9
71	1
9	1
11	1
78	1
13	1
53	1
89	1
57	1
70	1.2
14	1.2
23	1.2
25	1.2
31	1.2
8	1.4
28	1.6
27	1.9
44	2
19	2
40	2.2
12	2.2
81	2.2
54	2.2
87	2.2
65	2.2
5	2.3
41	2.4
63	2.4
39	2.7
37	2.9
24	3
58	3
7	3.2
76	3.2
90	3.2
34	3.3
74	3.3
49	3.3
6	3.7
73	3.9
72	4
42	4
17	4.1
1	4.2
88	4.4
61	4.7
2	5
35	5
3	5
47	5
80	5
26	5
51	5.2
86	5.7
29	5.7
15	6
79	6.2
21	6.4
30	6.8
84	6.9
83	7
38	7.3
77	7.4
69	7.6
67	8.8

of the *Nx* values, with N_0 = 91 as noted earlier. So, if the last individual died at age 8, then N_8 = or number of females alive at age 8 = 1, if 4 others died at age 7, then N_7 = 4 + 1 = 5, if 5 others died at age 6, then N_6 = 5 + 4 + 1 = 10, etc. (See Table 3).

Survivorship values are denoted by the symbol l_x and are the proportion of individuals born who survive to an age *x*. The zeroth survivorship l_0 is defined to be 1 (all individuals born are alive). Thereafter the survivorship values get smaller until they reach zero at the maximum age. So, survivorship at any age *x* is simply the proportion of the 91 individuals born that are still alive at that age. So, given the example N_x values above, l_8 = N_8/N_0 =

Table 2. Number of female offspring produced by females of a particular age (in years), from a sample of 25 females.

OFFSPRING	AGE (YEARS)
2	3
0	4
1	5
1	3
1	4
2	3
3	3
4	4
4	4
3	5
3	3
3	4
6	4
0	5
0	3
1	4
2	3
2	3
3	3
3	5
3	4
4	5
4	4
3	3
3	5

1/91 = 0.011, $l_7 = N_7/N_0$ = 5/91 = 0.055, etc. Calculate survivorship values using your data from Table 3 and fill out Table 4. When you are finished, transfer your answers to the corresponding column in Table 8.

Organisms that survive until later in life and then succumb to age-related mortality have a *Type I survivorship curve*. For example, larger mammals, such as whales, bears, and elephants, have Type I survivorship curves. Some organisms have relatively constant survivorship throughout their life. Most reptiles, for example, fall in this category. This steady decline typifies

Table 3. Calculate the number of females alive at each time interval by using the data given above to fill in the blanks. Transfer your answers to the corresponding column in Table 8.

TIME INTERVAL	NUMBER OF INDIVIDUALS DYING IN EACH TIME INTERVAL	N_x
N_0		91
N_1		
N_2		
N_3		
N_4		
N_5		
N_6	5 + 4 + 1	
N_7	4 + 1	5
N_8	1	1

a *Type II survivorship curve*. On the other extreme are organisms such as insects and many fish with little or no parental care and vulnerable young. In these organisms, a *Type III survivorship curve* declines quickly with age owing to high mortality in the younger age classes and lower mortality in older animals (Gotelli 2008). These survivorship curves are illustrated in Figure 2. In the case of this figure, for example, 50 percent of the organism born into a population with a *Type II survivorship curve* lived to year 10.

3.2. Constructing a Survivorship Curve for Parrots

Now, using the values you calculated in Table 4, create a graph that depicts survivorship. The y-axis values are l_x and are presented on a logarithmic scale.

1. What variable will go on the x-axis?
2. Draw your graph, label axes x and y, and add a caption in the space provided in Figure 3.
3. Does the shape of the curve most approximate a Type I, Type II, or Type III survivorship curve, and why?

Survival rates, s_x, are the proportion of individuals alive at age *x* that will survive to age *x* + 1. The survival rate of age *x* is equal to the quotient of $l_x + 1/l_x$. Because survivorship values decrease with age, survival rates will always range from 0 to 1. So, given the sample l_x values above, s_7 = 0.011/0.055 = 0.2, etc. Calculate survival

Figure 2. Types I, II, and III of survivorship curves within a population. Survivorship is the fraction of newborns living to a particular time.

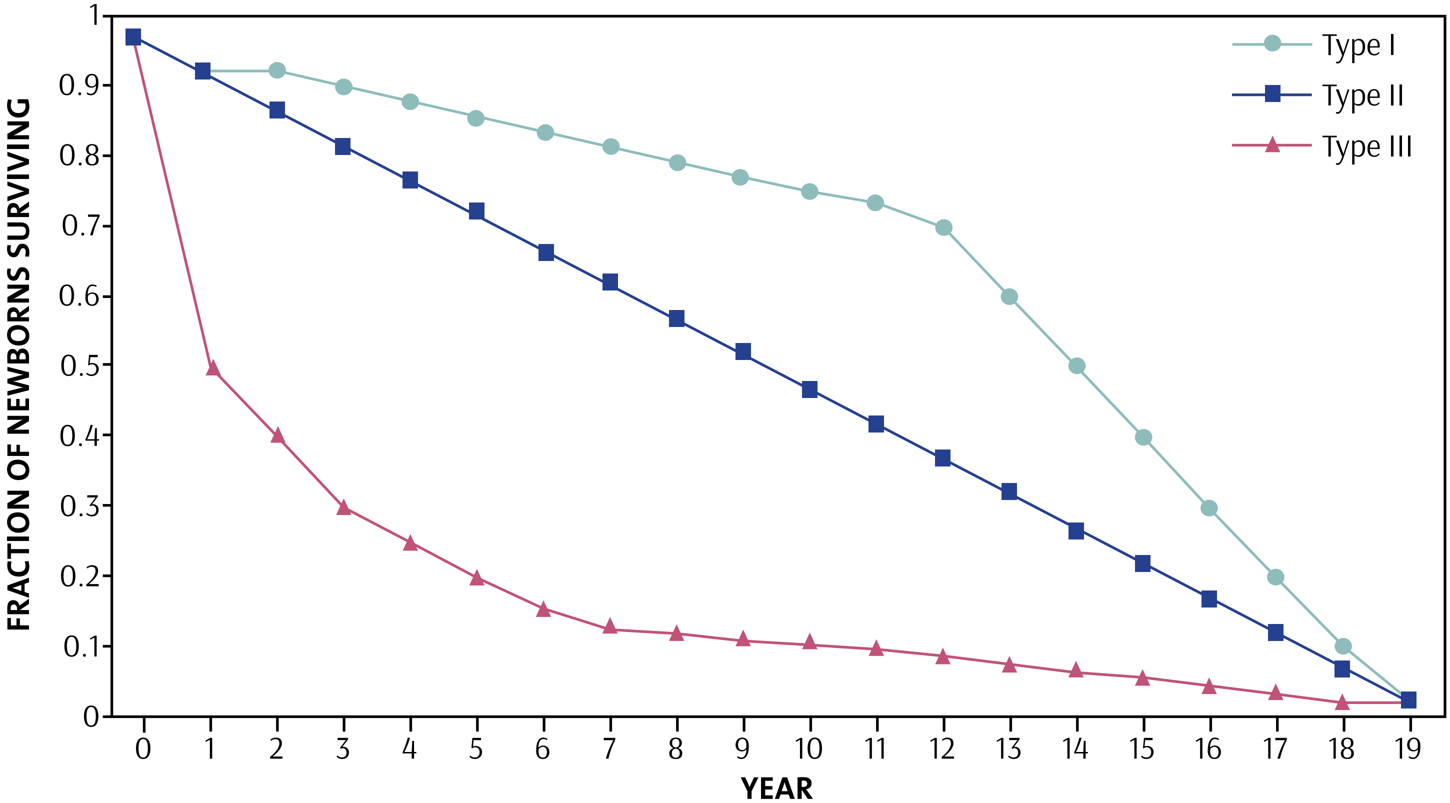
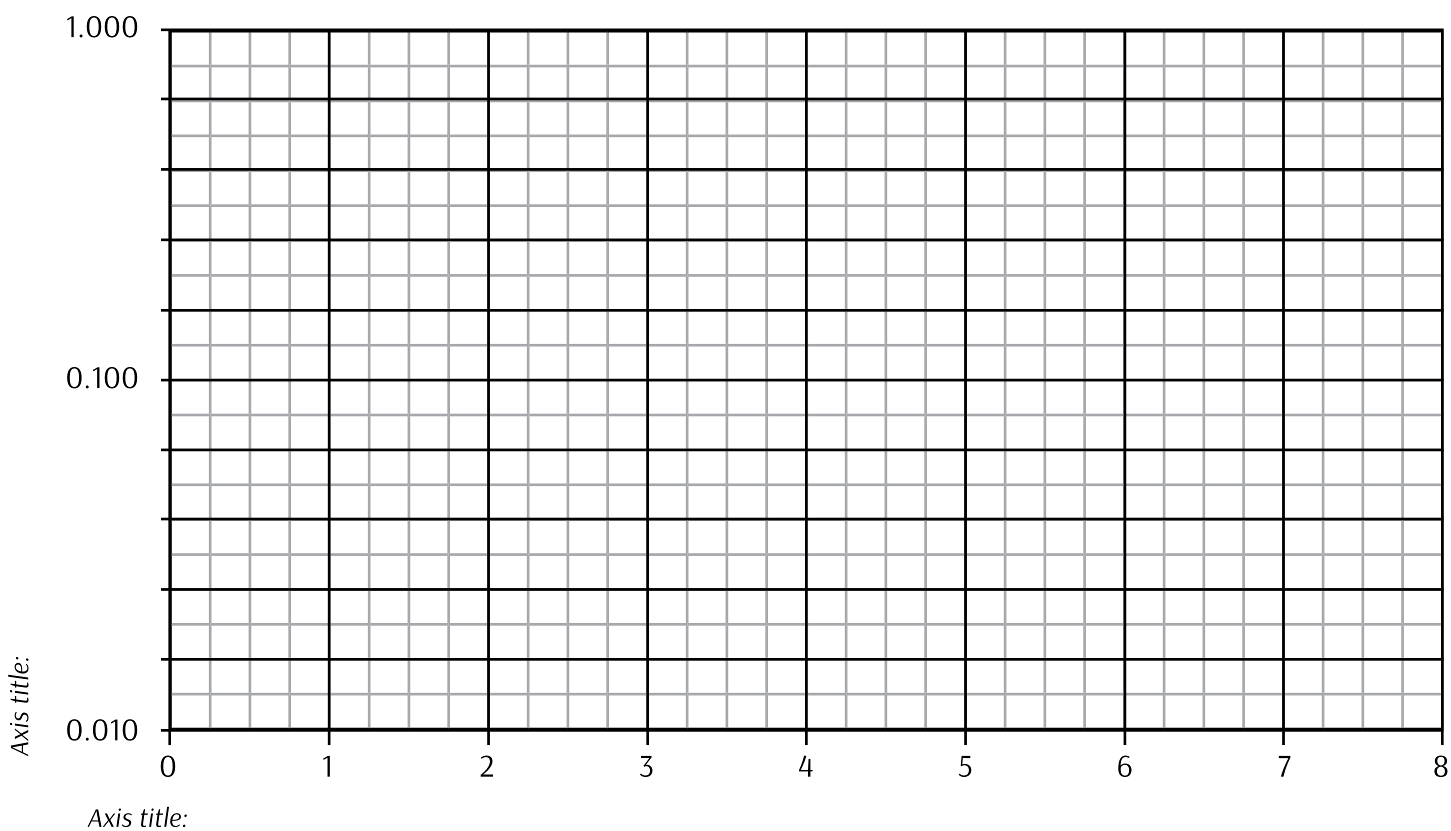


Figure 3. Caption:



rates using your data from Table 4 and fill out Table 5. When you are finished, transfer your answers to the corresponding column in Table 8.

Mortality rates, d_x, are the proportion of individuals alive at age x that will die before age $x + 1$. These are the reverse of survival rate values, so for any age x, $d_x = 1 - s_x$. Calculate mortality rates using your data from Table 5. and fill out Table 6. When you are finished, transfer your answers to the corresponding column in Table 8.

The *maternity rate*, m_x, is the number of individuals produced per unit time per individual of a given age. It is usually calculated for females only in a female-based life table such as this, that is, as daughters per mother. For age class 5, 6 individuals had 14 female offspring, so 14/6 = 2.33. Calculate maternity rates using the data provided in Table 2 and fill out Table 7. When you are finished, transfer your answers to the corresponding column in Table 8.

4. Why are there no data for age classes 1 and 2, or 6, 7 and 8 (in Table 7)?

Table 4. Calculate survivorship values using your data from Table 3. When you are finished, transfer your answers to the corresponding column in Table 8.

SURVIVORSHIP VALUES	$l_x = N_x / N_0$	l_x
l_0	91 / 91	
l_1		
l_2		
l_3		
l_4		
l_5		
l_6	10/91	
l_7	5/91	
l_8	1/91	0.011

Table 5. Calculate survival rates using your data from Table 4. When you are finished, transfer your answers to the corresponding column in Table 8.

SURVIVAL RATES	$s_x = l_{x+1} / l_x$	s_x
s_0		
s_1		
s_2		
s_3		
s_4		
s_5		
s_6	0.055/	
s_7	0.011/0.055	0.2

Table 6. Calculate mortality rates using your data from Table 5. When you are finished, transfer your answers to the corresponding column in Table 8.

MORTALITY RATES	$d_x = 1 - s_x$	d_x
d_0		
d_1		
d_2		
d_3		
d_4		
d_5		
d_6		
d_7	1 - 0.2	
d_8	1 - 0	1

Table 7. Calculate maternity rates using the data provided in Table 2. When you are finished, transfer your answers to the corresponding column in Table 8.

MATERNITY RATES	**m_x PER INDIVIDUAL**	**m_x AVERAGE PER AGE CLASS**
m_0		
m_1		
m_2		
m_3		
m_4		
m_5	(1+3+0+3+4+3)/6	2.333
m_6		
m_7		
m_8		

Table 8. Life table for parrots using data provided in Tables 1 and 2. The last two columns will be useful for the calculations in the rest of the exercise (see below).

x	N_x	l_x	s_x	d_x	m_x	$l_x m_x$	$x l_x m_x$
0	91						
1							
2							
3							
4							4 x 0.794 =
5			0.526	0.474	2.333	0.209 x 2.333 =	
6							
7	5						
8	1	0.011	0	1			

3.3. Calculate Vital Statistics for the Population

From the life table you have constructed (Table 8), one can calculate some useful statistics for the population. The first such statistic is the net reproductive rate, which is a measure of the productivity of a population:

R_0 Net reproductive rate = average number of female offspring that will be produced per female during her lifespan

$= \sum l_x m_x / l_0$, or $\sum l_x m_x$ when $l_0 = 1$

This is calculated by summing the products of the age-specific survivorship and maternity values in the life table. Simply multiply the values of l_x and m_x across the age classes (rows of the life table) and then sum these products over the various age classes. The sum will equal the net reproductive rate for the population.

5. What is the net reproductive rate of this parrot population? Show your calculations.

A second useful statistic is the generation time. Generation time is the time elapsed between the birth of an individual and the birth of its offspring.

G Mean generation time = average time between the birth of females and the birth of their female offspring

$= (\sum x l_x m_x)/R_0$

6. What is the mean generation time of this parrot population? Show your calculations.

A third useful statistic is the intrinsic rate of increase. An approximation of this rate is:

$r_{estimate}$ the intrinsic rate of increase, which is in essence the natural log of the net reproductive rate adjusted for generation length to provide a measure of population growth per unit of time

$= \ln(R_0)/G$.

7. What is the estimate of *r*? Show your calculations.
8. Does the population appear to be increasing or decreasing? How do you know?

4. PART 4: EVALUATING A HARVEST STRATEGY FOR PARROTS AND PALMS

4.1. Parrots

Now you can calculate the *maximum sustained yield (MSY)* for this parrot population using the following equation:

MSY the highest harvesting rate of individuals from a population that will not reduce its population size

$= r_{est}(K/4)$

K is the size of the population when it is unharvested, that is, at *carrying capacity*, and r_{est} is the intrinsic rate of increase.

Recall that the life table was for females but that there are males also in the population so *multiply your resulting maximum sustained yield figure by 2* (assuming equal sex ratios).

9. What is the maximum sustainable number of parrots that can be harvested each year from the entire forest? Show your calculations.

4.2. Palms

Compared to parrots, palms take longer to mature and have vastly higher maternity rates. Palms are monoecious (pollen and ovules produced on the same plant); like many tropical plants, their seeds are heavily predated once they fall to the ground and hence have very low germination rates. However, if seeds do germinate, the seedlings enjoy fairly high survival rates and most become reproductively mature by 15 years of age. Each palm produces approximately 1,000 flowers per year, most of which will develop into a one-seeded fruit. After approximately 10 reproductive years, the palms will succumb to trunk rot and die.

10. If R_0 = 47.3 and G = 19.30, what is r_{est} for this species?
11. What is the maximum sustainable number of palms that can be harvested each year from the entire forest? Show your calculations.

4.3. Balancing Palm Harvest Versus the Incidental Killing of Parrots

Now let's first evaluate whether harvesting palms at their optimal level can be tolerated by the parrot population, which is incidentally affected when palms felled inadvertently enclose nesting parrots. If the palm populations can be harvested in a sustainable manner at the same rate at which they can potentially grow, then what was the estimated maximum sustainable annual harvest rate for the palms? What was it for the parrots? Based on data originally given in the scenario, recall that the area is 10,000 km^2, that 10 km^2 hosts one parrot (of any age) and 1,000 palms, that felling every thousandth palm kills a nesting pair of parrots, and that carrying capacities for each species are twice their current densities. You now have all the information you need to address the questions at hand:

12. If the palm population is harvested at its maximum sustainable limit, will the parrot population be at risk? Please explain how you arrived at your conclusion and show any calculations used.
13. What annual harvest of palms would you recommend to maintain a healthy parrot population, and why?
14. Describe an alternative scenario that would change your answer for question 12 above. Explain.

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What is Biodiversity? Analyzing Data to Compare and Conserve Spider Communities

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ABSTRACT
In this exercise, students will classify and analyze data on spider communities to explore the concept of biological diversity and experience its application to decision-making in biological conservation. This exercise was adapted to further develop data analysis skills. Specifically, this exercise asks students to: 1) create an appropriate and informative graph, 2) interpret trends and patterns in the graph, 3) understand and correctly solve equations, and 4) make well-reasoned conclusions from data.

1. PART 1: INTRODUCTION

Spiders are a species-rich group of invertebrates that exploit a wide variety of niches in virtually all the Earth's biomes. Some species of spiders build elaborate webs that passively trap their prey whereas others are active predators that ambush or pursue their prey. While spiders are one type of invertebrate, they represent useful indicators of environmental change and community level diversity because they are taxonomically diverse, with species inhabiting a variety of ecological niches, and they are easy to catch.

2. PART 2: SORTING AND CLASSIFYING A SPIDER COLLECTION

1. In Appendix 1, you will find a spider collection from a forest patch in Africa ("Site 1"). The spiders were captured by a biologist traveling along transects through the patch, stroking a random series of 100 tree branches. All spiders that were dislodged and fell onto an outstretched sheet were collected and preserved in alcohol. They have since been spread out on a tray for you to examine (portrayed as illustrations in Appendix 1). The illustrations of the spiders are aligned in rows and columns so that, if desired, you can cut them out with scissors for sorting and identification.
2. Working in a group, the next task is for you to identify and sort the spiders. Your instructor will provide your group with a high-resolution paper copy to help you identify all the specimens in the collection. To classify the spiders, look for external characters that all members of a particular group of spiders have in common but that are not shared by other groups of spiders. For example, look for characteristics such as *leg length, relative size of body segments,* or *abdomen patterning and abdomen shape*.
3. Look for groups of morphologically indistinguishable spiders, and describe briefly the set of characters unique to each group. These "operational taxonomic units" that you define will be considered separate species. To assist you in classifying these organisms, a diagram of key external morphological characters of spiders is provided (Figure 1). Note that most spider identification depends on close examination of spider genitalia. For this exercise, however, we will be examining only general external morphological characteristics of different species.
4. Assign each species a working name, preferably something descriptive. For example, you might call a particular species "small, spotted abdomen" or "short legs, spiky abdomen." Just remember that the more useful names will be those that signify to you something unique about the species. You will use these data for Part 3 of the exercise. For your information, the species are also identified to the Family level in Appendix 2.
5. Complete Table 1 by listing each species, its distinguishing characteristics, the name you have

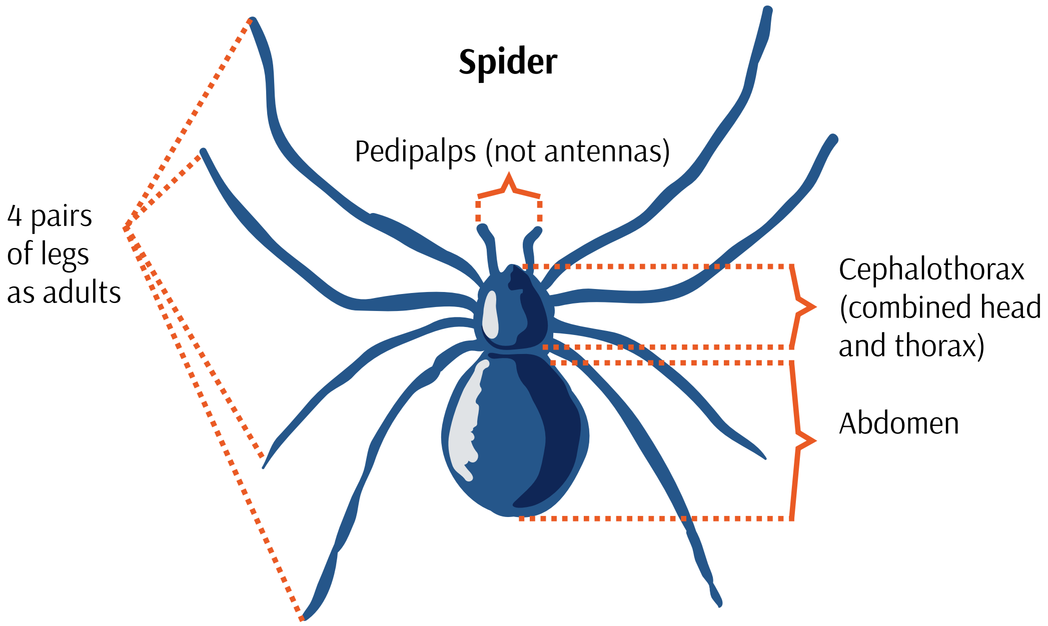


Figure 1. Basic external characteristics of spiders useful for identifying individuals to species. Illustration: Nadav Gazit.

applied to it, and the number of individuals of the species in this collection ("Site 1" in Appendix 1).

3. PART 3: ASSESSING THE COLLECTION

Next, working individually, you will investigate whether this collection adequately represents the true diversity of spiders in the forest patch at the time of collection. Were most of the species present sampled or were many likely missed? This is always an important question to ask to ensure that the sample was adequate and hence can be legitimately contrasted among sites in order to, for example, assign areas as low versus high diversity sites.

To do this, you will perform a simple—but informative—analysis that is standard practice for conservation biologists who do biodiversity surveys. This analysis involves constructing a so-called "species accumulation," or "collector's curve" (Colwell and Coddington 1994). These curves plot the cumulative number of species observed against the cumulative number of individuals

Table 1. Species name, characteristics, and number of individuals for Site 1 spider collection.

SPECIES NAME	DISTINGUISHING CHARACTERISTICS	NUMBER OF INDIVIDUALS

collected and classified. The slope of the species accumulation curve will decrease as more individuals are classified and as fewer species remain to be identified.

Using the spider collection from forest Site 1, create a graph using Figure 2 that depicts the species accumulation curve. The y-axis values are number of species observed.

1. What variable will go on the x-axis?

To construct the species accumulation curve for this spider collection, choose a specimen within the collection at random. This will be your first data point, such that x = 1 and y = 1, because after examining the first individual you have also identified one new species! Next move consistently in any direction to a new specimen and record whether it is a member of a new species. In this next step, x = 2, but y may remain as 1 if the next individual is not of a new species or it may change to 2 if the individual represents a new species different from individual Repeat this process until you have proceeded through all 50 specimens and construct the collector's curve from the data obtained (just plot y versus x).

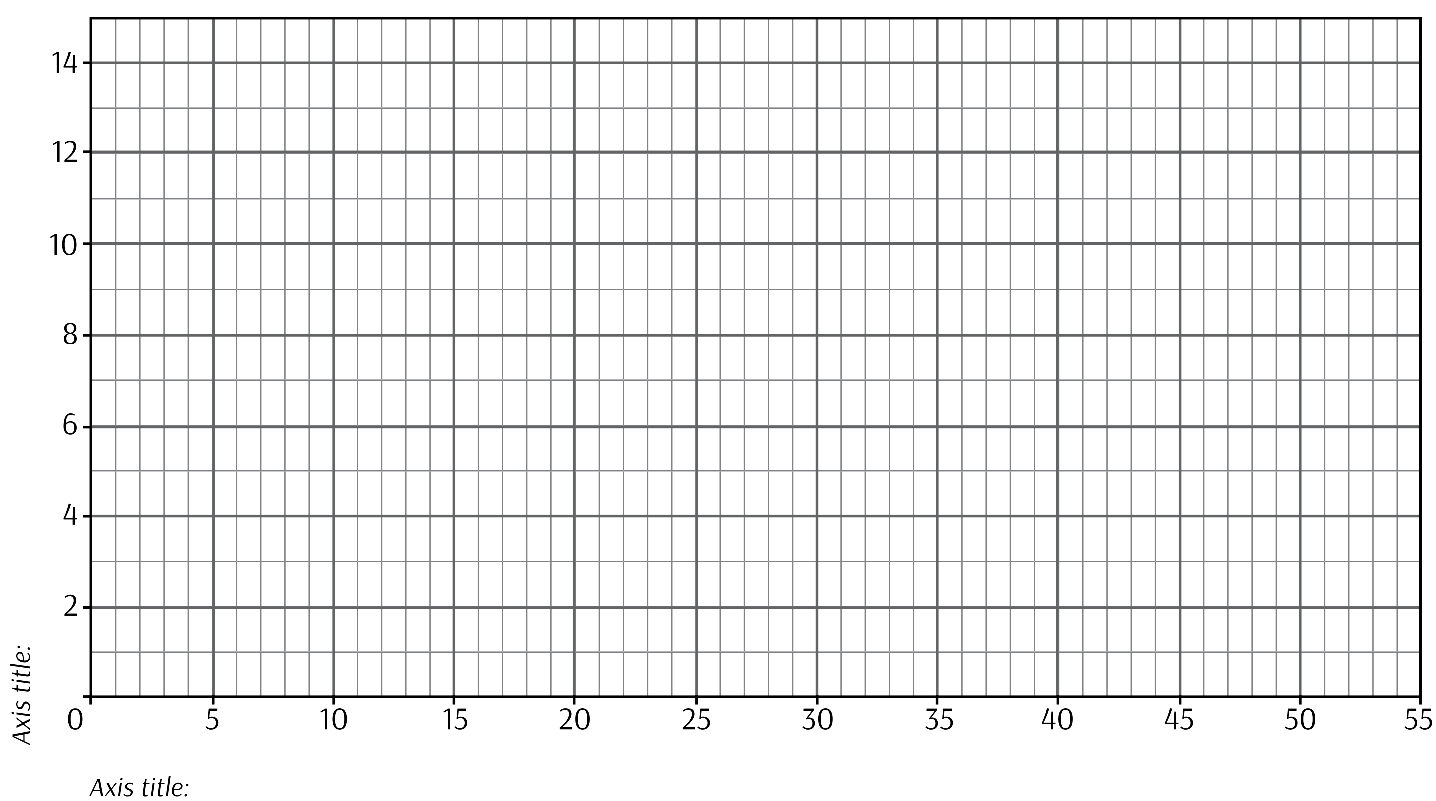
2. Draw your graph, label axes x and y and add a caption in the space provided in Figure 2.

As you will have seen, the species accumulation curve is an increasing function with a slope that will decrease as more individuals are classified and as fewer species remain to be identified. If sampling stops while the curve is still rapidly increasing, sampling is incomplete and many species likely remain undetected. Alternatively, if the slope of the collector's curve reaches zero (flattens out), sampling is likely adequate as few to no new species remain undetected.

Please answer the following questions:

3. Does the curve for forest Site 1 flatten out?
4. If so, after how many *individual spiders* have been collected? If not, is the curve still increasing?
5. Based on the shape of your species accumulation curve, do you feel this spider collection is an adequate representation of spider diversity at the site? *Please explain your answer.*

Figure 2. Caption:



4. PART 3: PRIORITIZING SITES FOR CONSERVATION BASED ON SPIDER DIVERSITY

4.1. Contrasting Spider Diversity Among Sites to Prioritize Conservation Efforts

Now you have data from five forest patches that contain different spider communities. If you had to make a recommendation, how would you rank these sites for protection and why? Through this assignment you will learn how to analyze the available data to answer this question.

The forest patches used to be connected as part of a much larger, continuous forest that was fragmented. A map of these forest patches, showing their size and proximity to each other, is shown in Figure 3.

Table 2 has detailed data on the species collected at each of the five spider communities. Although you only need species-level information for this exercise, the species have also been identified to family. More details about the families are provided in Appendix 2. Each cell in the table has the number of individuals (or specimens) of that particular species found in the collection from each patch.

You can now analyze these data further to generate different measures of community characteristics to help you to decide how to prioritize protection of the forest patches. Recall that you need to rank the patches in terms of where protection efforts should be applied, and you need to provide a rationale for your ranking.

You will find it most useful to base your decisions on four community characteristics:

- *species richness* within each forest patch
- *species diversity* within each forest patch
- number of endemic, or unique, species within each forest patch
- the similarity of spider communities between patches.

Species richness is simply the tally of different spider species that were identified in a forest patch. Check Table 1: do you already have this measure for each patch?

Species diversity is a more complex concept. It not only reflects the number of species present but also their relative abundances. This can reflect how balanced communities are in terms of how individuals are distributed across species. As a result, two communities may have precisely the same number of species, and hence species richness, but substantially different diversity measures if individuals in one community are skewed toward a few of the species whereas individuals are distributed more evenly in the other community.

To estimate *species diversity* we will use a standard index called:

Simpson Reciprocal Index = 1/*D*.

Figure 3. Map of five forest patches where spiders were collected.

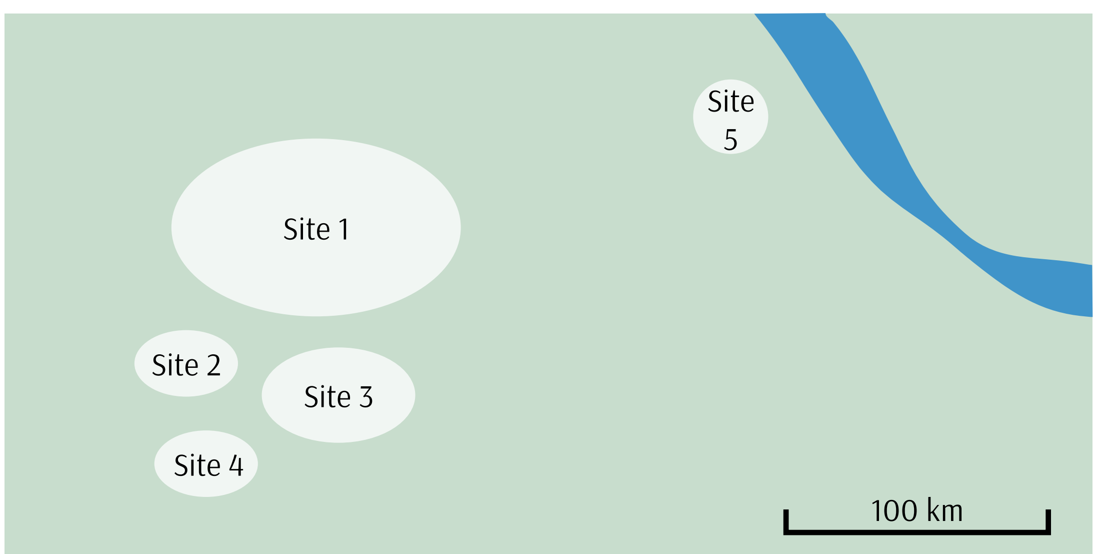


Table 2. Species collected at each of the five forest patches, identified to family (see Appendix 2).

		SITE				
		1	**2**	**3**	**4**	**5**
FAMILY	**SPECIES**	**SPECIMENS**				
Araneidae	1	-	-	-	15	-
Araneidae	2	4	6	41	-	-
Araneidae	3	3	-	-	-	8
Araneidae	4	7	-	-	-	-
Araneidae	5	-	4	1	-	-
Araneidae	6	4	6	1	-	-
Araneidae	7	3	-	-	-	-
Araneidae	8	4	-	-	-	-
Araneidae	9	5	-	-	-	-
Araneidae	10	2	-	-	-	-
Clubionidae	11	-	-	-	7	-
Dysderidae	12	-	-	-	-	8
Eresidae	13	-	-	-	-	10
Gnaphosidae	14	3	6	1	-	-
Palpimanidae	15	-	5	1	-	8
Salticidae	16	-	-	-	7	-
Salticidae	17	-	-	-	7	-
Sicariidae	18	-	-	-	-	8
Theridiidae	19	3	4	2	7	8
Theridiidae	20	3	6	1	-	-
Theridiidae	21	5	8	1	-	-
Thomisidae	22	4	5	1	7	-
Total individuals collected		**50**	**50**	**50**	**50**	**50**
Total species identified		**13**	**9**	**9**	**6**	**6**

where $D = \sum p_i^2$ and p_i = the relative abundance of the i^{th} species in a site.

To obtain p_i, you need to convert the number of individuals to the proportion that each species represents of the total individuals captured at that site. For example, if you had a sample of 10 spiders from a site, and they belonged to two species, represented by five individuals each, then the relative abundance of each species is 5/10 = 0.5. Calculating relative abundance is equivalent to asking: what proportion of the total individuals (or specimens) captured belongs to this species?

For the same example of a sample of two species with five individuals each, then *species diversity*, or *Simpson's Reciprocal Index (1/D) = 1 / [(0.5)² + (0.5)²] = 2.*

The higher the value, the greater the diversity. The maximum value of species diversity is the total number of species in the sample, which is reached when all species contain an equal number of individuals. What is the spider species diversity of each forest patch? Use the worksheet in Table 3 to help you calculate species diversity and provide the values in the Diversity (1/*D*) row, for each site.

Table 3. Worksheet to aid species diversity calculations for each of the five sites.

SPECIES	SITE 1			SITE 2			SITE 3			SITE 4			SITE 5		
	specimens	p_i	p_i^2	specimens	p_i	p_i^2	specimens	p_i	p_i^2	specimens	p_i	p_i^2	specimens	p_i	p_i^2
1	-	0	0	-	0	0	-	0	0	15	0.3	0.09	-		
2	4	0.08	0.0064	6	0.12	0.0144	41			-			-		
3	3	0.06	0.0036	-			-			-			8		
4	7	0.14	0.0196	-			-			-			-		
5	-			4			1			-			-		
6	4			6			1			-			-		
7	3			-			-			-			-		
8	4			-			-			-			-		
9	5			-			-			-			-		
10	2			-			-			-			-		
11	-			-			-			7			-		
12	-			-			-			-			8		
13	-			-			-			-			10		
14	3			6			1			-			-		
15	-			5			1			-			8		
16	-			-			-			7			-		
17	-			-			-			7			-		
18	-			-			-			-			8		
19	3			4			2			7			8		
20	3			6			1			-			-		
21	5			8			1			-			-		
22	4			5			1			7			-		
***D* ($\sum p_i^2$)**	-	-		-	-		-	-		-	-		-	-	
Diversity (1/*D*)	-	-		-	-		-	-		-	-		-	-	
Specimens	50			50			50			50			50		
Species	13			9			9			6			6		

In addition, note some sites have higher numbers of *endemic species*. Endemic species are those found *only* at a given site or area. Next, tally the number of endemic species per site in Table 4.

Finally, another important perspective in ranking sites is how similar or different the communities are from one another. We will use the simplest available measure of community similarity, that is, the *Jaccard coefficient of community similarity*, to compare all possible pairs of sites:

$$CC_J = c/S$$

where c is the number of species common to both communities and S is the total number of species present in the two communities. This provides us with a measure of how many species two given sites have in common. For example, if one site contains only 2 species and the other site 2 species, one of which is held in common by both sites, the total number of species present is 3 and the number shared is 1, so 1/3 = 0.33, or 33%.

This index ranges from 0 (when no species are found in common between communities) to 1 (when all species are found in both communities, i.e., the two communities contain the same species). You should calculate this index to compare each pair of sites separately, that is, compare Site 1 with Site 2, Site 1 with Site 3, etc. (Hint: there are a total of 10 comparisons). A worksheet is provided in Table 4. In addition, to compare all measures of diversity, transfer to this table the values you previously estimated for species richness, species diversity, and number of endemic species for each site.

4.2. Ranking Sites

Once you have finished these calculations, you can rank these five sites for protection and explain why.

Making an informed decision to rank these sites requires reconciling the concepts of diversity and distinctiveness (inverse of similarity). Your decision can be based on your estimates of species richness, diversity, and community similarity. However, once you have used those estimates you might also want to look at the spatial arrangement of the forest patches shown in Figure 3 and compare that to the species distributions given by the similarity among sites.

Next, taking this information into consideration please read and answer carefully the following questions:

6. A regional office of protected areas asks you to prioritize the conservation of the remnant forest patches shown in Figure 3. They specifically

Table 4. Endemic species per site.

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
Number of endemic species					

Table 5. Worksheet for community similarity and comparison with other measures of diversity.

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
Site 1					
Site 2					
Site 3					
Site 4					
Site 5					
Richness	13	9	9	6	6
Diversity					
# Endemics					

ask you to provide two possible ranking options for protection (e.g., Site 1, Site 3, Site 2, Site 5, Site 4 from highest to lowest priority), and clearly explain the criteria used to make these rankings in Table 6. Note: remember to take into consideration *all* information available on biodiversity, distinctiveness, and geographic location of the patches. To facilitate making your decision, you can use Figure 4 as a worksheet, to summarize Table 4.

7. Describe what kind of additional information might change your recommendations with respect to *two* particular sites of your choice. Use *all* information available from the exercise.

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Table 6. Sites ranked for protection.

RANKING OPTION	PRIORITY ORDER (e.g., SITE 1, SITE 2, SITE 5, SITE 4, SITE 3)	EXPLANATION OF CRITERION/CRITERIA USED
1		
2		

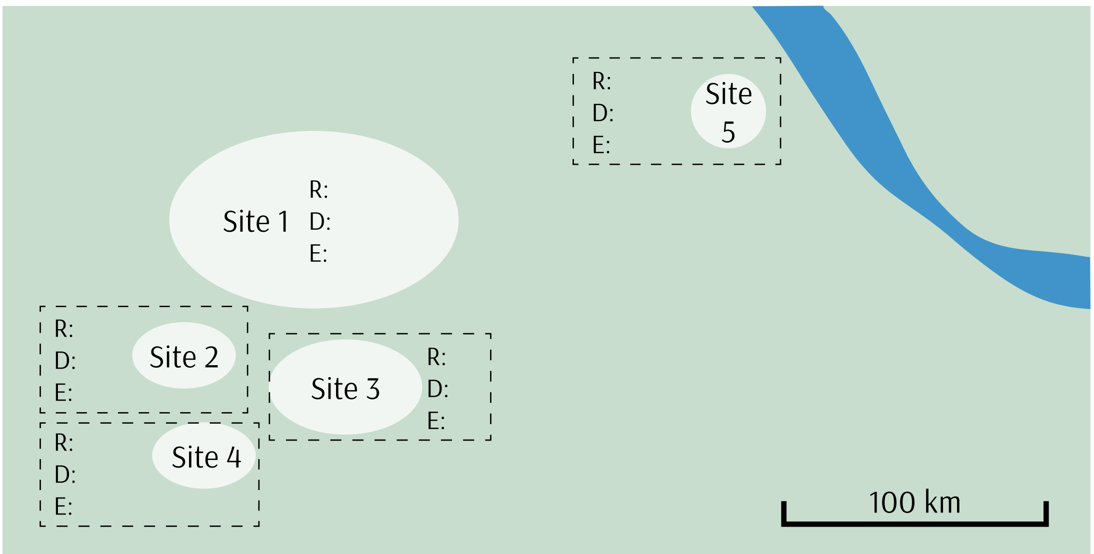
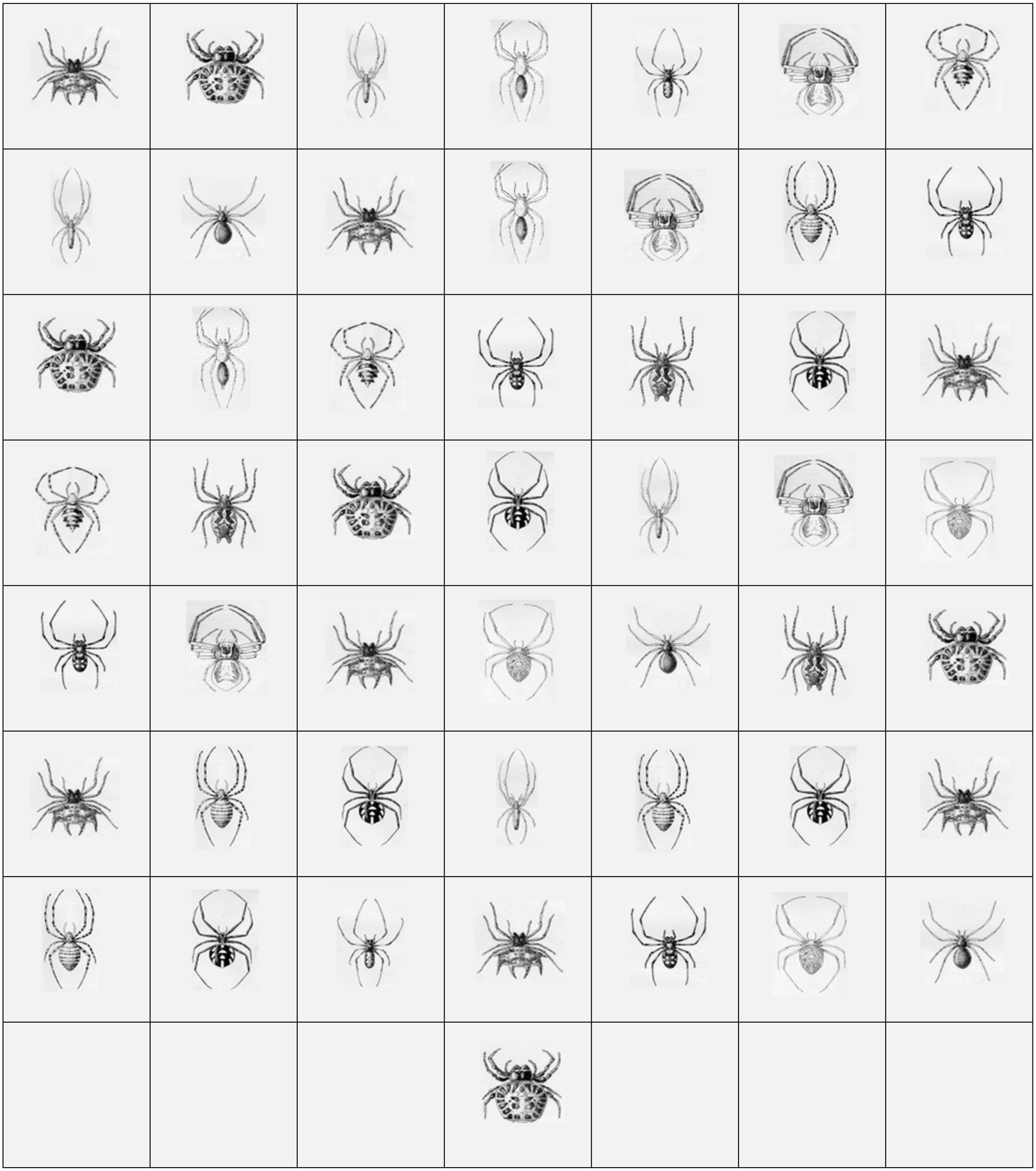
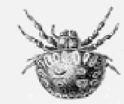


Figure 4. Worksheet showing the map of forest patches where spiders were collected. R = richness; D = diversity; E = number of endemics.

APPENDIX 1. SITE 1 SPIDER COLLECTION



APPENDIX 2. TAXONOMIC TABLE WITH SPECIES ORGANIZED BY FAMILY

Araneidae					
					
Clubionidae					
Dysderidae					
Eresidae					
Gnaphosidae					
Palpimanidae					
Salticidae					
Sicariidae					
Theridiidae					
Thomisidae					

Practice Your Data Analysis Skills!

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ABSTRACT

In this exercise, we present you with a realistic dataset for nest parasitism and a hypothetical analysis performed by a hypothetical student. Using a "rubric" or assessment guide, you will evaluate the analysis, and, where necessary, correct it or improve it. In the process, you will review and reflect on what is required for good data analysis, and you can use that knowledge to improve your own skills.

1. PART 1: DATA

Brown-headed cowbirds (*Molothrus ater*), are North American's most common "brood parasite." These birds parasitize the nests of female birds of another species, laying their eggs in their nests, and leaving the host parents to raise the cowbird chicks (Figure 1). The data in Table 1 are from a study on the effect of brown-headed cowbirds in relation to the position of the nests in the forest. Specifically, the study investigated whether proximity of nests to the forest edge was related to the incidence (or likelihood) of cowbird parasitism. This is an important issue for the conservation of forest birds, because forests are increasingly fragmented by roads—a process that can create new forest edges—and cowbird parasitism can have a strong negative effect on nest success in some cases.

Figure 1. Cowbird chicks. Photo: Kati Fleming [CC BY-SA 3.0]

2. PART 2: DATA ANALYSIS

A student was tasked with analyzing the data recorded in Gaston Forest to decide whether they provide support to a particular hypothesis, and to help make management decisions for the forest about a particular problem. Specifically, the exercise asked:

1. Please describe the pattern found in these data in the form of a graph and an explanatory caption.
2. What do these experimental results tell us? Provide as careful and complete an interpretation of the results as you can, in approximately 1–2 paragraphs.
3. Consider the following hypothesis: *Birds nesting on the edge of the forest will produce fewer offspring than those on the interior*. Do the data support this particular hypothesis? Why? *Explain your answer*.

Now consider the data analysis done by Student X, below.

Name: Student X

1. Please describe the pattern found in these data in the form of a graph (Figure A) and an explanatory caption.

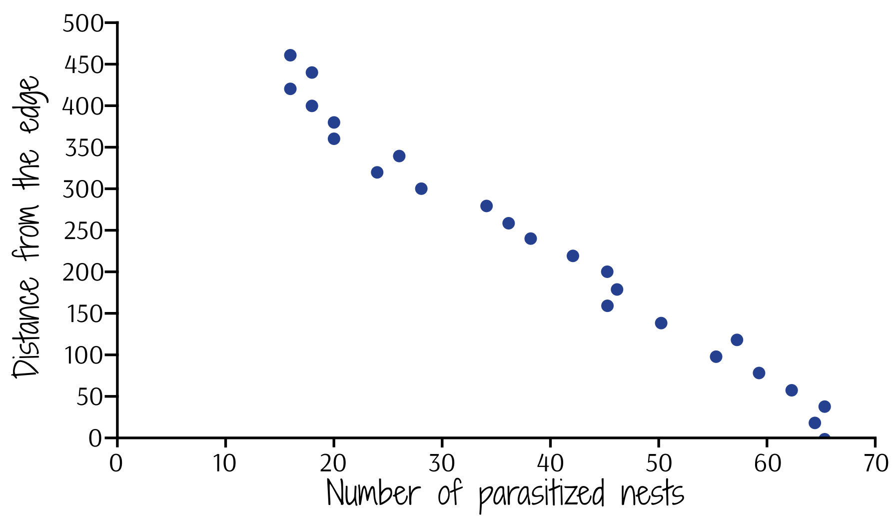
See Figure A.

2. What do these experimental results tell us? Provide as careful and complete an interpretation of the results as you can, in approximately 1–2 paragraphs.

Table 1. Percentage of bird nests parasitized by cowbirds recorded for 24 locations in Gaston Forest (fictitious location). Data based on the information from Brittingham and Temple (1983).

SURVEY LOCATION	DISTANCE FROM THE FOREST EDGE (M)	BIRD NESTS PARASITIZED (%)
1	0	65
2	20	64
3	40	65
4	60	62
5	80	59
6	100	55
7	120	57
8	140	50
9	160	45
10	180	46
11	200	45
12	220	42
13	240	38
14	260	36
15	280	34
16	300	28
17	320	24
18	340	26
19	360	20
20	380	20
21	400	18
22	420	16
23	440	18
24	460	16

Figure A. Number of parasitized nests and how they decline with distance from the edge.



Nests closer to the forest edge always have higher parasitism.

3. Consider the following hypothesis: *Birds nesting on the edge of the forest will produce fewer offspring than those on the interior.* Do the data from Gaston Forest support the hypothesis? Why? *Explain your answer.*

No, the data at hand are not sufficient to provide support for that hypothesis.

3. PART 3: EVALUATING THE ANALYSIS

Working in groups with your classmates, you will use the rubric (Appendix 1) and the tutorial provided at https://www.esa.org/tiee/vol/v5/research/picone/resources.html ("How to Read a Graph" from Picone et al. 2007) to evaluate the data analysis done by Student X, and improve it where necessary.

The rubric has four criteria, or dimensions, that are considered important parts of data analysis: calculation, representation, interpretation, and drawing conclusions. In this particular case, you will not evaluate calculation.

1. What do you consider is the skill of Student X in these criteria, and why? Write down your answers for the following criteria: representation, interpretation, and drawing conclusions.
2. Using the rubric and the tutorial as your guides, provide an alternative analysis for the data of the exercise that you think reaches or approaches the maximum level of achievement ("Level 4") as

described in the rubric. You will present your re-analysis to the class.

4. PART 4: REFLECTING ON YOUR OWN DATA ANALYSIS

Finally, after class, you will individually reflect on your own past data analysis performance using the same rubric you used for this exercise. Can you identify specific areas in the rubric where there is room for you to improve?

Please write brief answers to the following questions and submit them to your instructor at the next class meeting:

1. Which of the different aspects of data analysis is the most challenging for you?
2. As you get ready for your next data analysis assignment, what would you use from what you have learned today?

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Brittingham, M.C., and S.A. Temple. 1983. Have cowbirds caused forest songbirds to decline? BioScience 33:31–35.

Picone, C., J. Rhode, L. Hyatt, and T. Parshall. 2007. Assessing gains in undergraduate students' abilities to analyze graphical data. Teaching Issues and Experiments in Ecology 5:1–54. Available from https://www.esa.org/tiee/vol/v5/research/picone/article.html.

APPENDIX 1

Table 1. Data analysis is the ability to make appropriate calculations, convert data to graphical representation, interpret the information presented in graphical or mathematical forms and make judgments or draw conclusions based on the quantitative analysis of data. Levels of achievement (1–4) range from Beginning to Exemplary.

	1	2	3	4
Calculation Ability to identify and use the correct equations and operations to generate a correct answer.	Calculations attempted but unsuccessful.	Most calculations attempted are insufficient to solve the problem.	Most calculations attempted are successful and sufficient to solve the problem.	Calculations attempted are all successful and sufficiently comprehensive to solve the problem.
Data Representation Ability to convert relevant information into various mathematical forms (e.g., graphs, diagrams, tables).	Selects data not relevant to the problem/question/ task. Incorrect selection of dependent/independent variable. Inappropriate use of title and labels (e.g., lacks units).	Selects data relevant to problem, but incorrectly selects dependent/ independent variables, or incorrectly presents patterns, differences, and/ or similarities in data. Inconsistent use of title and/or labels (e.g., lacks units).	Selects data relevant to problem, and correctly selects dependent/ independent variable. Presents mostly correct patterns, differences, and/ or similarities in data. May have minor errors in the use of title and/or labels (e.g., lacks units).	Selects data relevant to problem, and correctly selects dependent/ independent variable. Presents correct patterns, differences, and/or similarities in data. Title and labels are clear and self-explanatory, with the appropriate units.
Interpretation Ability to explain information presented in mathematical forms (e.g. equations, graphs, diagrams, tables), and appropriately characterize results.	Attempts to explain information presented in mathematical forms, but provides an incorrect explanation of what the information means. *For example, attempts to explain the trend data shown in a graph, but misinterprets the nature of that trend (e.g., confusing positive and negative trends.)*	Provides somewhat accurate explanations of information presented in mathematical forms, but explanations are vague, go beyond what is supported by the data, or contain logical errors that detract from the interpretation. *For instance, accurately explains trend data shown in a graph, but overemphasizes the generality or significance of the results.*	Provides mostly accurate explanations of information presented in mathematical forms, and recognizes the limitations of the data. *For instance, provides a correct but basic explanation of the trend data shown in a graph, or has minor errors.*	Provides fully developed and accurate explanations of the information presented in mathematical forms. *For example, accurately and fully explains the trend data shown in a graph, and its limitations.*
Drawing Conclusions Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of the analysis.	Analysis or judgment of the data is incorrect, leading to conclusions that are logically faulty, incorrect, and not supported by the data.	Analysis or judgment of the data is tentative or incomplete, leading to conclusions that are vague, too broad, or not well-supported by the data.	Uses the quantitative analysis of data as the basis for competent judgments. Conclusions are logical and reasonable, but without nuance—no qualifications or explorations of the assumptions or limitations.	Draws detailed, logically structured, carefully qualified conclusions based on a quantitative analysis and judgment of data. Conclusions may extend to novel situations and/or make reference to underlying assumptions.

[2]*Modified from the AAC&U Value Rubric by the Network of Conservation Educators and Practitioners.*

Applying Critical Thinking to the Amphibian Decline Problem

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ABSTRACT

This exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion—in the context of a complex and real conservation problem: amphibian declines. The exercise has four parts: a case study, ten questions related to the reading, an in-class discussion in groups, and finally a set of questions for reflection and research, either individually or in groups, to understand how the issue has continued to evolve over the last decade.

1. PART 1: WHY ARE AMPHIBIANS DECLINING?

Nora's heart was racing when the plane landed. Finally, back in Costa Rica!
She cherished the memories of her research years in Costa Rica, back in the early 1990s. Living and working right near the forest, she had never felt so alive. She had told her students so many stories from that time–especially the incredible feeling of hearing the forest come alive at dusk with the sound of hundreds of calling frogs.

Later that day after settling in at the field station and an early dinner, Nora and her students made their way to the nearest forest trail and started hiking. As dusk approached, her expectation grew, but an eerie feeling came over her as she began to notice that something was different. The forest was definitely turning dark, but it was strangely silent. As night enveloped them and they came to a clearing, the light from twelve headlamps converged on her.

- *Ms. Torres, shouldn't the frogs be calling by now?*
- *I'm afraid it's much worse than I ever imagined–she had to admit to them –I just cannot believe that so many species have been lost in such a short time!*

Then they all started speaking at once:

- *Are they really gone, Ms. Torres?*
- *How come?*
- *What happened?*

She would have to brush up on the science to answer all their questions by tomorrow.

1.1. Introduction and Instructions

This case study and exercise[1] will illustrate the challenge of understanding and mitigating threats to biodiversity, through the case of worldwide amphibian declines. In our attempts to understand this phenomenon, two main hypotheses have been proposed to explain it. After you've read about each hypothesis and its supporting evidence, you will be asked to carefully and critically use the information presented to answer a series of questions.

As you read, keep in mind that you will be asked to answer ten questions afterwards. *These questions will*

[1] Part of the material was adapted from Mendelson, J.R. III and R. Donnelly. *The Crisis of Global Amphibian Declines: Causes, Consequences, and Solutions.* 2011. Synthesis. Network of Conservation Educators and Practitioners, American Museum of Natural History. Available from ncep.amnh.org.

include providing a summary of the problem amphibians experiencing, what you think is the best supported hypothesis to explain them, and why.

1.1.1. Global Amphibian Declines

1.1.1.1. Amphibian Diversity

There are 7,704 known species of amphibians (Frost 2017).[2] More than half of amphibian species have been discovered in the last 50 years. These new species are discovered both by explorations of under-surveyed areas or by re-evaluation of species using DNA analysis techniques that can reveal multiple species that previously were assumed to represent a single species.

There are three Orders within the Class Amphibia: Anura (frogs and toads; 6,785 species), Caudata (salamanders and newts, sometimes referred to as Urodela; 713 species), and Gymnophiona (caecilians; 206 species) (Frost 2017; Figure 1). Amphibians occur worldwide, with the exception of the Polar regions. They arose about 400 million years ago, with the major groups (the Orders mentioned above) being well differentiated by the Jurassic (approx. 200 million years ago). Fossils of amphibians since the Jurassic are essentially similar in all respects to modern amphibians, meaning that amphibians "as we know them" in terms of anatomy and natural history co-occurred with the famously extinct dinosaurs (Roelants et al. 2007). Whatever caused the extinction of the dinosaurs—or the mega-mammals of the Pleistocene, for that matter—had no evident effect on amphibians.

A salient characteristic of amphibians is their complex skin, which accomplishes the majority of the gas exchange with the environment. Many amphibians lack lungs (or gills) altogether, and those that do have them appear to actually use them only rarely. The skin is the primary physiological interface with the environment. Gas exchange must take place in an aqueous solution (e.g., in vertebrates, it occurs in the moist tissues inside the lungs) and thus amphibians must maintain a moist skin, which in turn requires them to be associated with moist or humid or aquatic environments. Among vertebrates, amphibians show a spectacularly diverse range of diversity of reproductive strategies and adaptations (Crump 2009).

1.1.1.2. Amphibian Declines

Amphibians are experiencing unprecedented rates of population declines and species extinction. The IUCN Red List reveals the alarming reality that nearly one-third (32.4%) of the world's species of amphibians are threatened with extinction (IUCN 2017). The contemporaneous decline of roughly 2,000 species constitutes a mass extinction event on par with those famously known only from the geological record. What's worse is that these terrifying numbers are a certain underestimate because the IUCN committee struggled to decide how to formally list the status of many species

[2] The Amphibian Species of the World is a database hosted by the American Museum of Natural History. It is updated in real time and can even vary from hour to hour, so check often for the most current numbers.

*Figure 1. Representatives of the Order a) Anoura (*Atelopus certus*); b) Caudata (*Oedipina uniformis*); and c) Gymnophiona (*Demorphis mexicanus*).*

Images: a) Brian Gratwike/Flickr [CC BY 2.0], b) Sean Michael Rovito/ CalPhotos [CC BY-NC-SA 3.0], c) Sean Michael Rovito/ CalPhotos [CC BY-NC-SA 3.0] that have been seen very infrequently by scientists, and now cannot be located in the wild. There was no option other than to classify those ~1,500 species (about 24.5 percent of all amphibians) into the category of "Data Deficient." But it is likely that many of them are also experiencing declines.

The five major threats to biodiversity include habitat fragmentation, invasive species, pollution, unsustainable use, and global climate change. More than one factor seems to be responsible for amphibian declines. The Global Amphibian Assessment (GAA) revealed that many declines are due to anthropogenic causes, such as habitat loss and overexploitation. But what was most striking is that 48 percent of the declining amphibian species were initially identified as threatened with extinction by unidentified or enigmatic causes (Stuart et al. 2004). The GAA also found global geographic patterns associated with the declines and their causes. Species declines caused by habitat loss are predominantly found in Southeast Asia, West Africa, and the Caribbean; declines attributed to overexploitation are mostly reported from East and Southeast Asia; declines attributed to enigmatic causes are mainly restricted to South America, Mesoamerica, Puerto Rico, and Australia. Furthermore, the rapid enigmatic declines have particularly affected species that occur at mid- and high elevations and in association with streams.

The fungus *Batrachochytrium dendrobatidis*, also referred to as "Bd" or chytrid fungus, has been proposed as being responsible for the enigmatic amphibian declines. It is known to have caused rapid declines or extinctions of about 200 frog species, many of which were found in remote undisturbed areas (Skerratt et al. 2007). Bd is a pathogenic fungus that causes chytridiomycosis, a skin infection that thickens superficial skin layers compromising a frog's osmotic regulation and leading to death by cardiac arrest (Figure 2; Berger et al. 1998). The optimal temperature range for Bd growth in the laboratory is between 17–25 °C. The fungus dies at temperatures above 29–30 °C and below 0 °C (Piotrowski et al. 2004).

Although Bd is now widely recognized as the leading cause of the enigmatic amphibian declines, the underlying mechanisms or processes involved in the declines are still controversial. *Why has Bd become so lethal to amphibians now?* There are two leading hypotheses that attempt to answer this question: the climate-linked epidemic hypothesis (Pounds et al. 2006) and the spatio-temporal spread hypothesis (Lips et al. 2008).

Figure 2. A chytrid-infected frog.
Image: Forrest Brem [CC BY 2.5] via Wikimedia Commons.

1.1.1.3. The Climate-Linked Epidemic Hypothesis

The climate-linked hypothesis (Pounds et al. 2006) predicts that climatic changes, such as increases in temperature or related variables, will trigger the growth of pathogens, causing outbreaks of disease. While Bd could be the leading pathogen, the hypothesis is not restricted to this particular species of fungus. Climate change, or global warming, is proposed to be the primary driver of the amphibian declines observed.

Is there a correlation between climate and amphibian decline? In the early 1990s, Pounds et al. investigated the timeline of extinction of two species considered extinct at the time: the Jambato toad (*Atelopus ignescens*) of Ecuador and the Monteverde harlequin frog (*Atelopus varius*) of Costa Rica (Figure 3) and found that the last time these species were observed in the field (*last year observed*, or LYO) was in 1988[3] (Pounds et al. 1994,

[3] As of 2017, *A. ignescens* is still considered extinct with LYO in 1988, but in 2005, two *A. varius* frogs were spotted in the central Pacific town of Quepos, Costa Rica (but were not seen again the following year). Then, in 2008, a small population of *A. varius* was found in Talamanca, in south-eastern Costa Rica. The population has fluctuated from five to 40 since 2011.

Pounds et al. 1999, Ron et al. 2003), a year after an unusual warmer year 1987. These species went from being common species to being considered extinct in a short period of time.

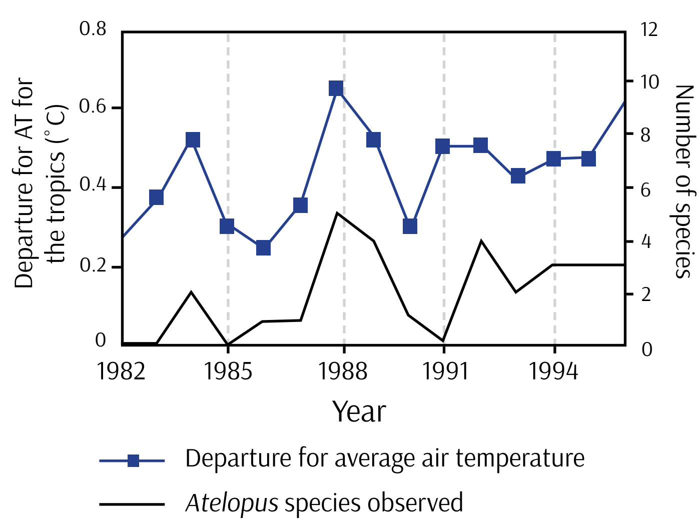
How widespread was this pattern? The decline pattern was also found for other frog species. After investigating patterns of decline for 100 *Atelopus* species, Pounds et al. found that of the 51 species that went extinct, about 80 percent disappeared a year after an unusual warmer year. Using simulations, they concluded that these extinction patterns were not random and that they were strongly associated with large-scale warming events (measured as air temperature, or AT, see Figure 4). Furthermore, they reported that the association between extinction and warm temperatures was strong regardless of altitude, latitude, or species range size. Based on this evidence, the authors argue that global warming is a key factor to explain the decline of frog species.

Could warmer years actually affect local frog habitats? Pounds et al. investigated if climate changes at a regional scale were correlated with changes at local scales. The authors modeled climate at a regional scale (the tropics) using data on sea surface temperature (SST) and air temperature (AT). Then, they determined the correlation between the climate trends observed for the tropics and local trends observed for Monteverde cloud forest (at 1,400 m of elevation) in Costa Rica. The authors found that AT and SST for the tropics correlated with the number of dry days in Monteverde, and the daily minimum AT in Monteverde (Figure 5a–c). The data showed that temperatures increased in the tropics between 1975 and 2000 (Figure 5a), which at a local scale in Monteverde caused a reduction in mist frequencies and in relative humidity. Based on these correlations, Pounds et al. concluded that changes in AT for the tropics could predict changes in temperature at a local scale, and in turn affect local ecological processes.

Why would this increase the incidence of Bd infections? These changes in climate are thought to be beneficial to the chytrid fungus. Pounds et al. reported a decrease in the daily maximum temperature and an increase in the minimum daily temperature in Monteverde, Costa Rica and in 11 other locations in Colombia and Venezuela. Recall that the optimal temperature range for the chytrid fungus is 17–25 °C and the optimum temperature is 23 °C (Piotrowski et al. 2004). In Monteverde, the daily temperature is chytrid friendly, but in the microhabitats such as moss mats, bromeliads, or leaf litter, temperatures are higher than 30 °C. Thus, the chytrid fungus does not survive, but an increase in cloudiness due to higher air temperatures blocks the direct sunlight from reaching those habitats, which become cooler and therefore optimal for the chytrid.

Figure 3. The Monteverde harlequin frog Atelopus varius *from Monteverde, Costa Rica.*
Image: Brian Gratwicke/Flickr [CC by 2.0].

Figure 4. Correlation between departures from the average air temperature (AT) for the tropics (blue and square line) and the number of Atelopus *species observed for the last time (solid black line) (adapted from Pounds et al. 2006).*



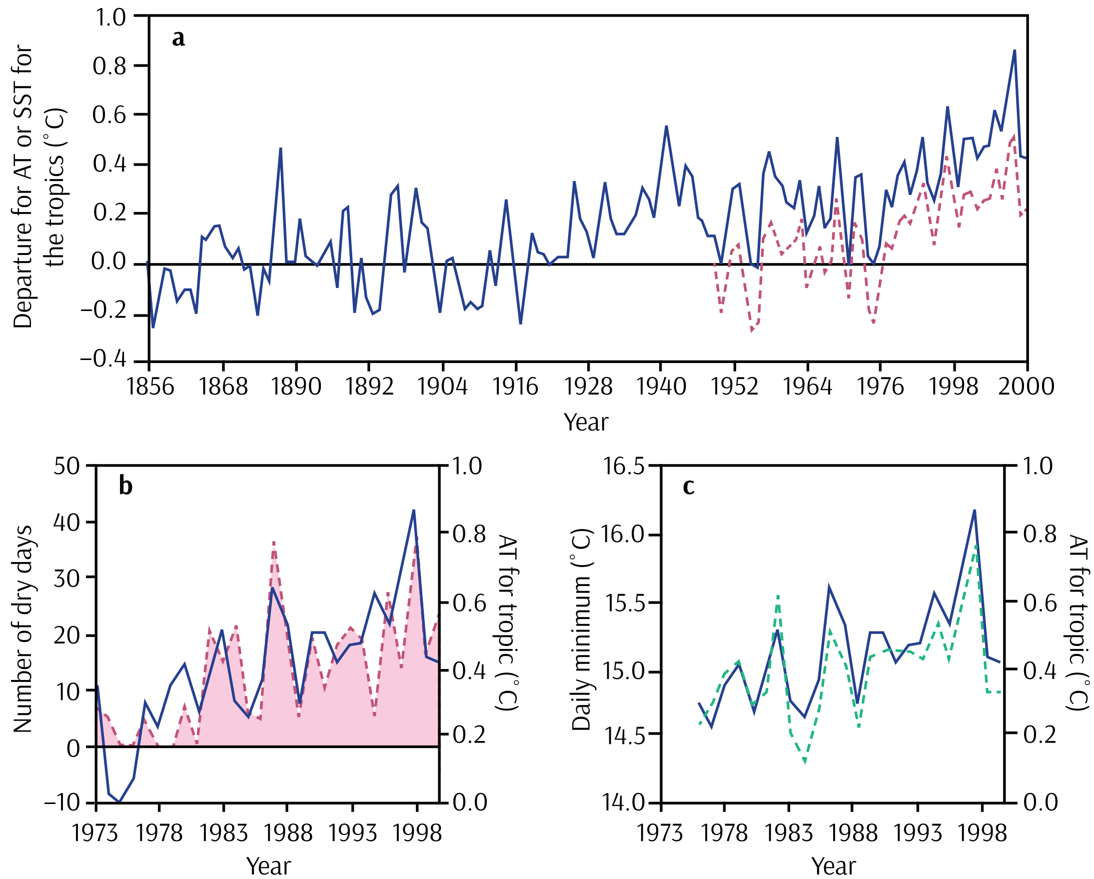


Figure 5. Correlation between departures from the average air temperature (AT) for tropics (solid blue line) and a) sea surface temperature (SST) for tropics (dashed red line); b) number of dry days in Monteverde, Costa Rica (pink shadows); and c) daily minimum temperature (˚C) in Monteverde, Costa Rica (dashed green line) (adapted from Pounds et al. 2006).

Can this explain the vulnerability of frogs living at mid- and high elevations? The authors found that the probability of species disappearance varied across the altitudinal gradient (Figure 6a). The elevation gradient was used as a proxy for a temperature gradient (the higher the elevation, the lower the temperature) and the LYO as a proxy for extinction date. The probability of disappearance was zero at low elevations (0–100 m) but it increased dramatically between 200–1,000 m (63.3%) and even more between 1000 and 2399 m (90.2%). However, this probability dropped between 2,400–4,000 m (65.7%; Figure 5a). Based on these results, Pounds et al. suggest that the lethal effect of the chytrid fungus on amphibians may be restricted to mid-elevations. The authors argue that recent increases in minimum daily temperatures at mid-elevations may allow the survival of the chytrid and are driving the observed declines (Figure 5b).

1.1.1.4. The Spatio-Temporal Spread Hypothesis

The spatio-temporal spread hypothesis (Lips et al. 2008) predicts declines in amphibian populations after the new arrival of a pathogen, and particularly Bd, to a location with optimal environmental conditions. According to this hypothesis, the advancing spread of the pathogen in space (geographically) is the main factor explaining the pattern of declines. An assumption of this hypothesis is that Bd is an exotic species to the Neotropics.

To examine the spatio-temporal patterns of Bd appearance, Lips et al. estimated the date of actual decline (DOD; date of first detection of mortality due to Bd), whenever data was available. They estimated DOD for the same Atelopus species used by Pounds et al. (2006) and other species from Central and South America. Lips et al. argue that "date of actual decline" is a better variable than the "last year observed" (LYO;

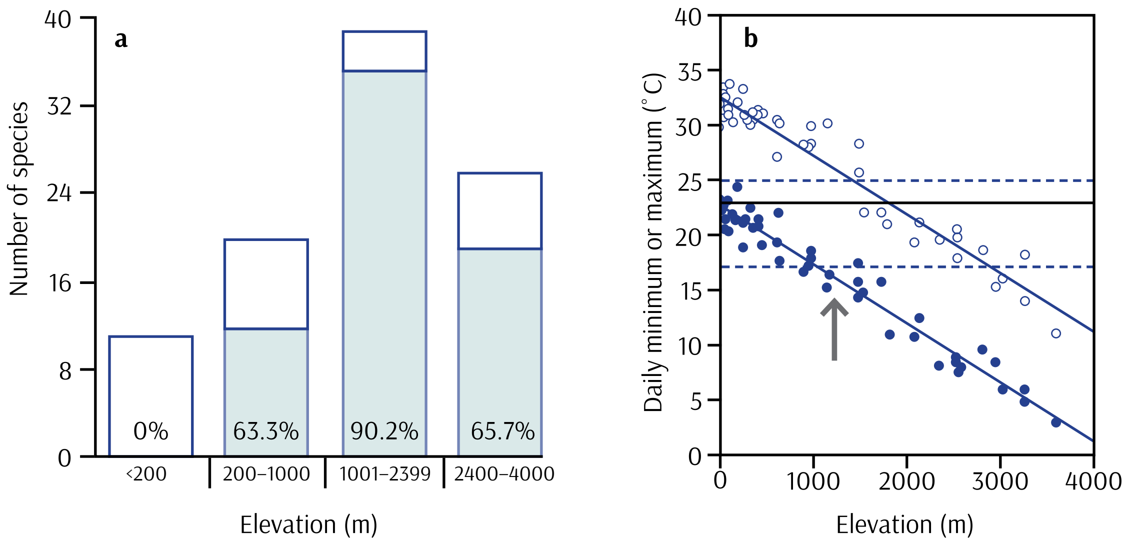


Figure 6. a) Total number of Atelopus *species per altitudinal range and their probability of disappearance (in percentage) at each altitudinal range; b) average daily minimum (black circles) and maximum (open circles) temperatures (˚C) for locations in an altitudinal gradient. Horizontal dashed lines indicate the range of temperatures for growth of* Batrachochytrium dendrobatidis *or chytrid fungus and horizontal solid black line indicates its optimal temperature (23 ˚C). Gray arrow indicates locations at mid-elevations where an increase in the minimum daily temperature can favor the survival of the fungus (adapted from Pounds et al. 2006).*

used by Pounds et al. 2006) to determine the causes of amphibian decline because of the potential error associated to the LYO records. For instance, detection of the last individual of a population may change with population size, survey frequency, time for populations to go extinct after the decline begins, or rediscovery of the species. On the other hand, considering that populations once hit by Bd usually go extinct relatively fast (for *Atelopus* 3.6 +/- 2.6 years; La Marca et al. 2005), DOD provides a better estimate of the date of the population decline.

Next, they plotted those geographically to see whether amphibian declines followed a pattern consistent with spatial spread. They did: the authors identified one wave of Bd expansion in Central America (Figure 7a) and four for South America (Figure 7b).

The authors suggest that two independent introductions of the chytrid fungus occurred in South America. First, it was introduced to Venezuela in 1977 and then to Ecuador in 1980 (see Figure 7b). From these locations, the fungus spread to the whole Andean region. From Venezuela, it spread southeastern towards Colombia; and from Ecuador it spread in three waves, two to the northern region of Colombia and eastern Venezuela, respectively, and a third one to the south (Peru and Bolivia).

For all but one of the Central and South American waves, the authors found significant correlations between the earliest DOD and the distance and rate of spread of Bd (Figure 8). Thus, they concluded that a spread of the chytridimycosis disease is the lead cause of amphibian decline.

Lips et al. also investigated altitudinal patterns of amphibian decline. They found significant high proportions of declines of *Atelopus* frog species at elevation higher than 200 m (Figure 9). Contrary to the pattern reported by Pounds et al. (2006), Lips et al. found no evidence to suggest that declines are more prevalent at middle elevations. Thus, authors concluded that all *Atelopus* species are critically threatened at middle and high elevations. This is consistent with their hypothesis, which focuses on presence of the fungus, and acknowledges that the fungus and changes in temperature may interact to create different conditions in different habitats.

Finally, to confirm that the amphibian declines were caused by the arrival of Bd, Lips et al. examined tissues from frog museum specimens collected in Ecuador (89 specimens) and Monteverde, Costa Rica (64 specimens) prior to the dates when declines were observed. All specimens examined were negative for Bd in tests with a

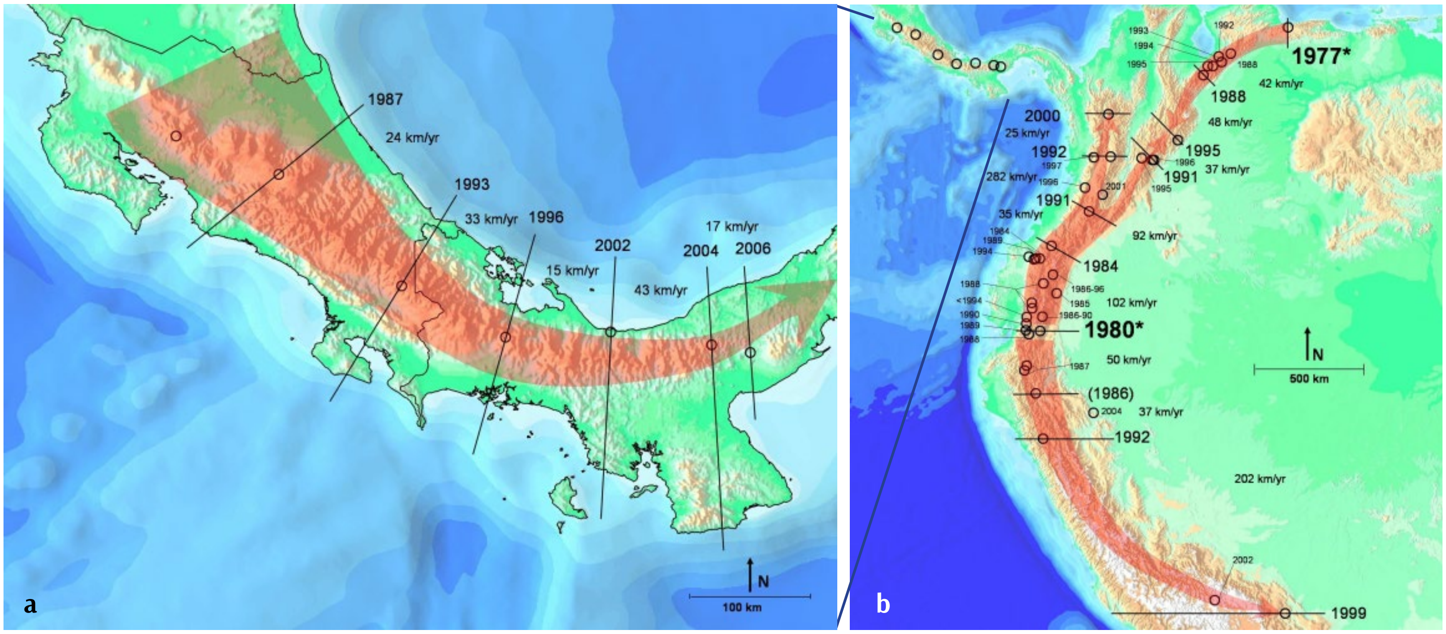


Figure 7. a) Central American and b) South American spreading waves of amphibian declines. Years indicate the date of decline (DOD) and rates indicate the rate of spread of the chytrid fungus (in kilometers per year) (adapted from Lips et al. 2008).

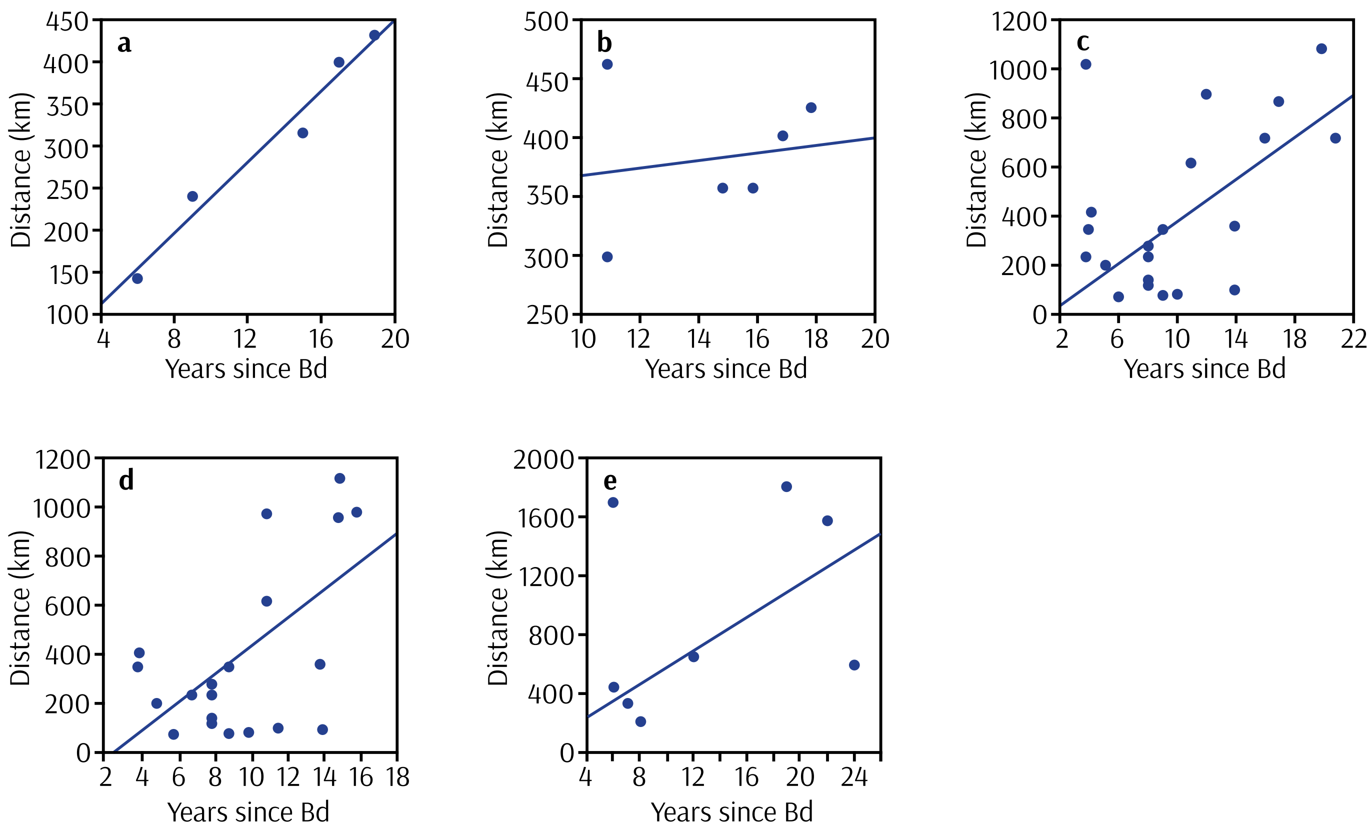


Figure 8. Relationship between time since the earliest date of decline (DOD) and the distance of spread for the waves a) in Central America ($p<0.01$, $R^2 = 0.97$); b) from Venezuela towards Colombia ($p = 0.32$); c) from Ecuador to northeastern Colombia ($p<0.01$, $R^2 = 0.47$); d) from Ecuador towards Venezuela ($p<0.01$, $R^2 = 0.4$); and e) from Ecuador towards Peru and Bolivia ($p<0.05$, $R^2 = 0.49$) (adapted from Lips et al. 2008).

95 percent confidence level. Based on this evidence, the authors suggest that Bd was not associated with frogs in Ecuador or Costa Rica prior to their observed declines.

In summary, although Lips et al. recognize climate change as a threat to biodiversity, they do not think this is the main driver of the declines observed. They conclude that chytrid fungus or Bd is an introduced pathogen to the Neotropics and that its spread is the main driver of the unprecedented amphibian declines observed in the last decades.

2. PART 2: EXERCISE QUESTIONS

In this part of the exercise, we ask you to answer the following questions using the information provided above.

1. What problem are amphibians experiencing world-wide? Please explain it as clearly and completely as you can in the space provided (approximately 150 words).
2. What does the "climate-linked epidemic" hypothesis of Pounds et al. (2006) propose? Summarize it in 1–2 sentences, using your own words.
3. List two of the lines of evidence used to support the "climate-linked epidemic" hypothesis.
4. What does the "spatio-temporal spread" hypothesis of Lips et al. (2008) propose? Summarize it in 1–2 sentences, using your own words.
5. List two lines of evidence used to support the "spatio-temporal spread" hypothesis.
6. How are these two hypotheses different in terms of their predictions? Explain in 2–4 sentences, using your own words.
7. Please list and explain one strength and one weakness of each hypothesis in Table 1.
8. If you were Ms. Torres, and you had to briefly describe to your students why the frogs have disappeared in this forest and what you think is the most likely explanation, what would you say? *Please explain it as clearly and completely as you can (~100–150 words).*
9. In 2011, Cheng et al. described a new molecular technique by which amphibian museum specimens can be tested for the presence of chytrid fungus through a simple swab sample. This DNA-based

Figure 9. Total number of Atelopus *species per altitudinal range and the percentage of them that went lost or that showed population declines (in gray). For the analysis, they used the same species dataset used by Pounds et al. (2006) but instead of using the LYO to estimate the declines, they used DOD. In addition, they excluded species classified as Data Deficient (adapted from Lips et al. 2008).*

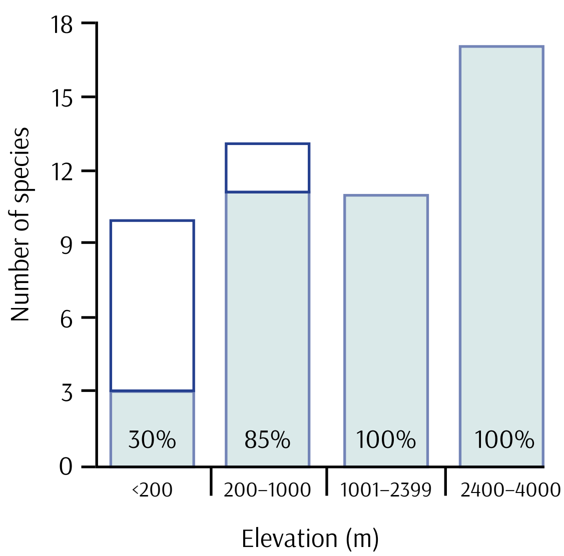


Table 1. The strengths and weaknesses of amphibian decline hypotheses.

	WEAKNESSES	STRENGTHS
Climate-Linked Epidemic		
Spatio-Temporal Spread		

technique uses the polymerase chain reaction (PCR)[4] to detect the presence of Bd DNA in specimens' skins, and can be used for specimens collected up to 50 years ago.

a. How would you use genetic tools to help understand the causes of enigmatic amphibian declines, knowing that many museums have been collecting specimens from Central and South America for decades? Provide a specific example or scenario of where, and for what purpose, you could use this technique.
b. How might this new kind of evidence strengthen the hypotheses above? Explain.

3. PART 3: GROUP DISCUSSION

Once you have completed the exercise questions above, your instructor will provide guidelines for an in-class discussion. Be ready to share, justify, and discuss your answers with your classmates.

4. PART 4: CHANGING CONTEXTS, CHANGING MINDS?

The knowledge we use rely on to explain the patterns we see in the natural world constantly evolves (or becomes refined), depending on the tools at our disposal and the evidence available. The last part[5] of this critical thinking exercise will challenge you to research the current literature around the topic of amphibian declines, and to reach an up-to-date understanding of the global amphibian crisis.

Here we have outlined three focal questions to guide you as you research further, individually or in groups. Your instructor will give you specific instructions for this activity.

Since the original proposals of the "climate-linked epidemic" hypothesis of Pounds et al. (2006) and the "spatio-temporal spread" hypothesis of Lips et al. (2008):

What have we learned about the chytrid fungus?

What have we learned about amphibian declines?

How are conservation biologists protecting amphibians in the face of chytrid fungus?

After you have completed Part 4, you may wish to review your previous answer to Part 2, Question 8: If you were Ms. Torres, and you had to briefly describe to your students why the frogs have disappeared in this forest and what you think is the most likely explanation, what would you say? Did your understanding of the original hypotheses and the global amphibian crisis change? Complex and dynamic issues such as amphibian declines require ongoing evaluation and critical thinking, such as the skills you have practiced here.

[4] PCR is a molecular technique used to amplify specific fragments of DNA. If the chytrid fungus is present on a frog specimen, chytrid DNA fragments will be amplified with the PCR.

[5] Part 4 of this exercise was not part of the original Critical Thinking unit of the research study: NSF DUE-0942789, *Developing and assessing process skills in Conservation Biology and other integrative fields*. For more information about the research study, see *What Can Your Students Do? The Importance of Assessing and Developing 21st Century Skills* in Conservation Students in Lessons in Conservation 8:5–10 and references cited therein, available from ncep.amnh.org/linc.

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Applying Critical Thinking to an Invasive Species Problem

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ABSTRACT

This exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion—in the context of a complex and real conservation problem: invasive species. In particular, students will learn about the rusty crayfish, a freshwater species that has become invasive throughout parts of the United States, as well as the impacts of the rusty crayfish invasion and potential options for controlling them. The exercise has three parts: an introduction, a case study, and six exercise questions that promote critical consideration and strategic problem solving of a specific conservation issue.

1. PART 1: INTRODUCTION AND INSTRUCTIONS

- *Riiiing! Riiiiing!*

It was Monday and John had barely walked into his office at the headquarters of the Bright Valley Wildlife Refuge[1] in Wisconsin when the phone started ringing. He was expecting news from his field team, who had spent all weekend trapping crayfish in Bright Lake.

- *Hello, John Smith here.*
- *Good morning, boss, this is Katherine.*
- *Hello Katherine, I was expecting your call….*
- *I'm afraid the news is not good, boss. The rusties have continued to increase in numbers, and as far as we can tell, all the other crayfish species are even more difficult to find. Macrophytes are down too.*

This was not a surprise, but John paused nonetheless. He knew what this meant. Bright Lake—its ecosystem and its famous status as a fishing destination—was in trouble. Now that they had five years of consistent data, there was only one thing to do: he and his team would have to find a strategy to control the rusty crayfish in Bright Lake—and it was not going to be easy!

This case study-based exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion—in the context of a complex and real conservation problem: invasive species. You will learn about invasive species and in particular, the rusty crayfish, a freshwater species native to the United States but often becomes invasive when it is introduced beyond its original (native) range. What are the impacts of the rusty crayfish invasion? And what options are available for controlling them?

Answers to these questions and more can be found in the attached case study (Part 2). After you've read it, you will be asked to use and carefully and critically consider the information presented to help John and his team to come up with a strategy that fits their budget (Part 3).

The exercise steps are as follows:

1. Read the complete exercise, including the case study, before your class (or as indicated by your instructor). As you read, keep in mind that you will be asked to answer six questions afterwards. *These questions will include providing a summary of the problem that Bright Lake is facing and what you think is the best overall strategy to address it.*
2. You will then compare your answers to questions 1 through 6 to those of your classmates.

[1] This is not a real location.

2. PART 2: CASE STUDY OF AN INVASION: THE RUSTY CRAYFISH IN THE GREAT LAKES[2]

2.1. The Setting

2.1.1. Great Lakes Basin

The Great Lakes make up the largest group of freshwater lakes on Earth (Figure 1). Lake Superior is the largest of them by all measures of volume, depth, and area—greater in size than the state of South Carolina. By volume, Lake Superior is followed by Lake Michigan, Lake Huron, Lake Ontario, and Lake Erie. The Saint Lawrence River is a primary outlet of these interconnected lakes, and connects the lakes to the northern Atlantic Ocean.

[2] Part of the material was adapted from Vintinner, E.C. *A Story of an Invasion: A Case Study of the Rusty Crayfish in the Great Lakes*. 2010. Synthesis. Network of Conservation Educators and Practitioners, American Museum of Natural History. Available from ncep.amnh.org.

Amazingly, about 20 percent of the world's surface fresh water and 84 percent of North America's surface fresh water is contained in the five great lakes, the largest system of fresh surface water on Earth (Fields 2005). The combined surface area of the lakes is larger than the states of New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont, and New Hampshire combined (Michigan Sea Grant 2018).

2.1.2. Biodiversity

This massive watershed contains a variety of habitats and over 3,500 species of plants and animals, including 170 species of fishes (Michigan Sea Grant 2018). The Great Lakes themselves are home to a variety of invertebrates, ranging from mussels to crayfishes and to common fishes such as herring, shad, sunfish, lake trout (*Salvelinus namaycush*) and smallmouth bass (*Micropterus dolomieu*). A diversity of bird species also occupies the Great Lakes area. Overall, nearly 50 percent of species and communities are endemic (EPA 2006).

Figure 1. Great Lakes watershed. Image: US Army Corps of Engineers 2006.

While the Great Lakes boast considerable biodiversity, numerous species are threatened in the region and are now conservation priorities. One example is the critically imperiled lake sturgeon (*Acipenser fulvescens*), an endemic species considered a "priority" for conservation by the United States Fish and Wildlife Service Great Lakes Basin Ecosystem Team (Pollock et al. 2015). Once abundant in the lakes, it is especially vulnerable to rapid habitat changes and over-exploitation in the Great Lakes ecosystem because of its slow maturation rate (Pollock et al. 2015). This fish often requires 25 years to reach reproductive age. Despite recovery efforts, most studies suggest that populations are struggling to remain stable or rebound (as reviewed by Pollock et al. 2015).

2.1.3. Threats

While there are numerous threats to the integrity of the Great Lakes ecosystem, the main threats are: altered water flows, extraction of natural resources, climate change, pollution, unsustainable development, agricultural and forestry practices, and invasive species, which is the topic of this case study.

Non-native species can invade new habitats in two ways: exotic species can be translocated and endogenous species can expand their native ranges. The increased spread of non-native species has become a large-scale threat to biodiversity. Notably, not all introduced species become invasive; the basic requirements for invasiveness are that the species has large rapidly expanding populations and it causes one or more profound effects in the location where it was introduced.

Invasive species are recognized as an important driver of environmental change and are ranked as a leading cause of biodiversity loss in freshwaters (Vitousek et al. 1996, Millennium Ecosystem Assessment 2005, Strayer 2010). Compared with terrestrial ecosystems, aquatic ecosystems are particularly vulnerable to non-native invaders for two primary reasons: there are numerous opportunities for invasion due to anthropogenic movement between bodies of water, and once established, it may be easier for aquatic species to disperse given comparatively fewer barriers than in terrestrial ecosystems (Lodge et al. 1998).

2.2. Meet the Rusty Crayfish

There are over 390 native species of crayfishes in North America—the greatest biodiversity of crayfishes in the world (Lodge et al. 2000). Ninety-three of these species, including the rusty crayfish (*Orconectes rusticus*) (Figure 2), belong to the genus *Orconectes* (Fetzer 2015). When rusty crayfish, or "rusties," reproduce, the females extrude eggs as sperm she has stored from males is released. Eggs are externally fertilized and are attached to the swimmerets on the underside of the female crayfish's abdomen. This is important because the eggs and then the small crayfish remain with the female, which increases their chances of survival. Females can extrude 80–575 eggs at one time (Gunderson 2008).

Crayfishes are central components of freshwater food webs and ecosystems and are dominant consumers of benthic invertebrates, detritus, macrophytes (aquatic plants), and algae. Crayfishes themselves are important forage for fishes. Therefore, additions or removals of crayfish species often lead to large ecosystem effects, in addition to changes in fish populations and biodiversity. Globally, crayfishes are one of the most threatened and endangered taxa in the world. Interestingly, the single biggest threat to crayfish biodiversity worldwide is the introduction of non-native crayfish species (Lodge et al. 2000). Globally, crayfishes are one of the most threatened and endangered taxa in the world. Interestingly, the single largest threat to crayfish biodiversity is the

*Figure 2. Adult rusty crayfish (*Orconectes rusticus*).*
Image: Cgoldsmith1 [CC BY-SA 3.0], via Wikimedia Commons.

introduction of non-native crayfish species (Lodge et al. 2000). Crayfish invasions are occurring within North America but also are occurring worldwide, threatening native populations in South America, Madagascar, and Australia (Lodge et al. 2012).

2.3. The Invasion

Rusty crayfish are native to the Ohio River Basin. Over the last 40–50 years, the rusty crayfish has spread to all the Great Lakes and has been observed in streams, rivers, and lakes in states such as Illinois, Wisconsin, Michigan, Minnesota, Iowa, Tennessee, Pennsylvania, and New Mexico, to name a few (Lodge et al. 2000, McCarthy et al. 2006). The US Geological Survey is tracking their range expansion (see Figure 3).

Figure 4 shows the percentages of rusty crayfish records in Wisconsin between 1870 and 2004 by Olden et al. (2006). The authors divided the invasion into three time periods: 1) pre-invasion years (95 years between 1870–1964), 2) early post-invasion years (20 years between 1965–1984), and 3) extant years (20 years between 1985–2004).

Olden et al. (2006) found that rusty crayfish occurrences have increased from 7 percent of all crayfish records collected during the first 20 years of their invasion (1965–1984) to 36 percent of all records during the last 20 years, and that rusty crayfish have replaced its congeneric species or "congeners," the northern clearwater crayfish (*O. propinquus*) and native virile crayfish (*O. virilis*) as the most dominant member of the contemporary crayfish fauna (Figure 4).

2.4. The Consequences

The impacts of this dramatic range shift in the past few decades have been most pronounced for native crayfishes, as they compete with the invasive rusties for resources. Rusty crayfish can also impact native species through interbreeding and the exchange of genetic material (Lodge et al. 2000, Perry et al. 2001; 2002). Studies have indicated that if the expanding rusty crayfish range begins to overlap with the many other crayfishes that have small ranges, global extinction of these species is very possible (Lodge et al. 2000).

Competition, predation, and hybridization with crayfish invaders have been identified as a primary threat for the

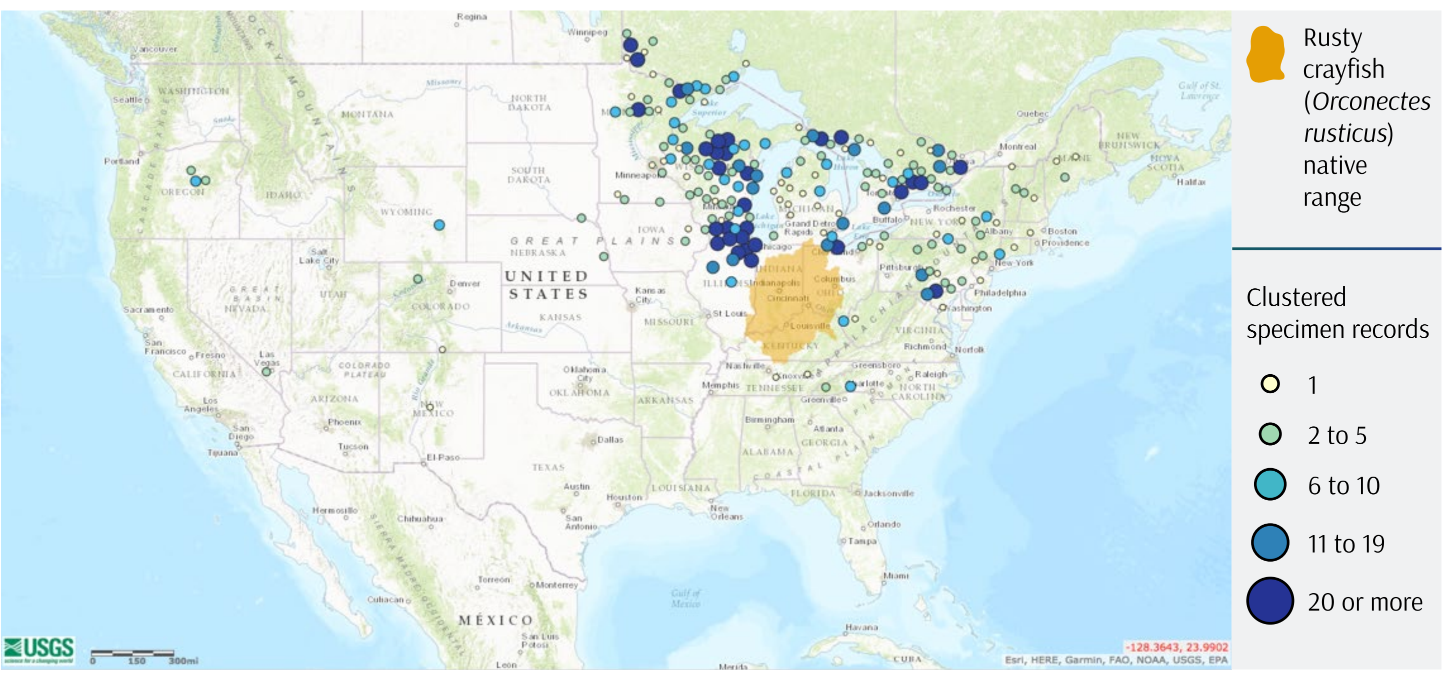


Figure 3. North American specimen records of rusty crayfish outside the native range. This map is derived from the United States Geological Survey (USGS) interactive map that allows users to visualize, search, and report sightings of rusty crayfish (https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=214#). Data represents the collection records and may not reflect the actual species abundance or distribution of established populations. Image: USGS 2017.

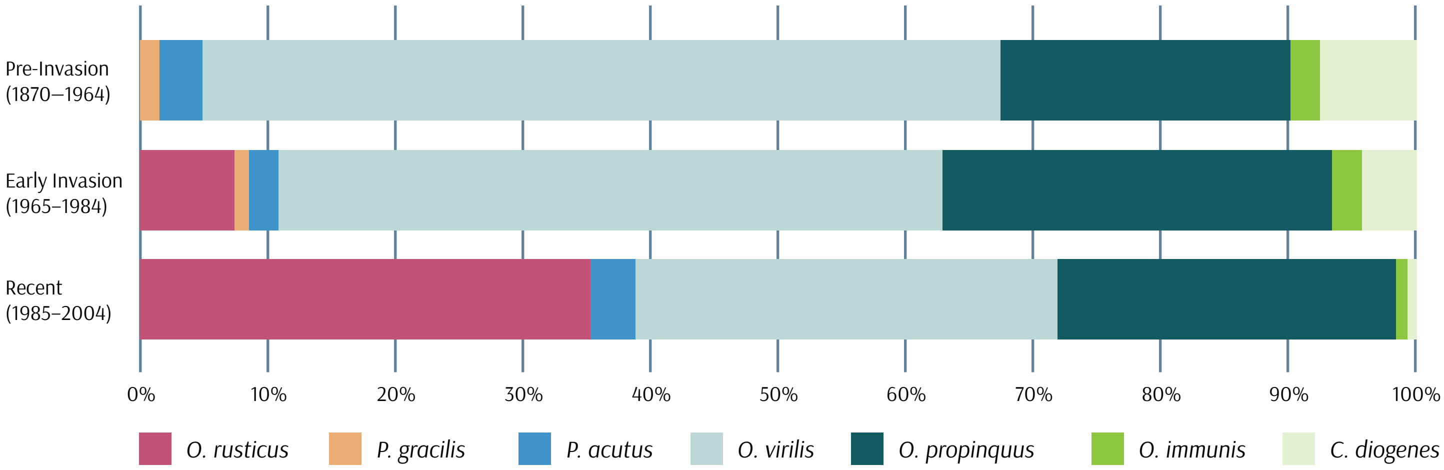
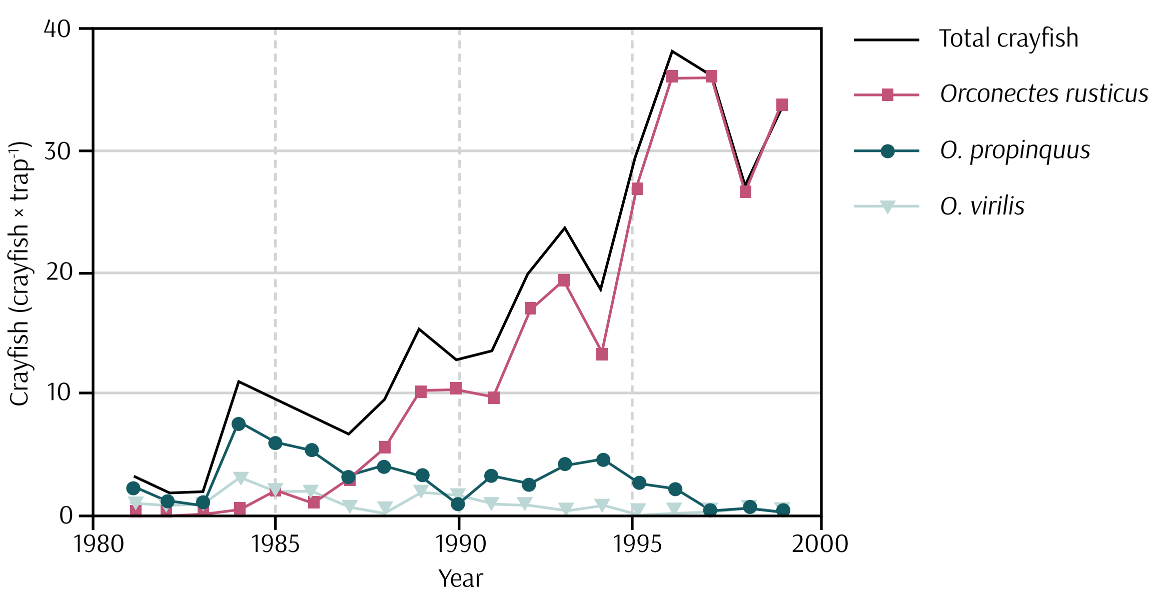


Figure 4. Percentage of invasive rusty crayfish records (pink bar) and other crayfish records of total crayfish records in this study for three time periods (adapted from Olden et al. 2006).

majority of declining North American crayfishes (Lodge et al. 2000, Perry et al. 2001). Evidence for this type of impact has been seen in lakes of northern Wisconsin, where congeners (native *O. virilis* and previous invader *O. propinquus*) have been reduced or eliminated within a few years of rusty crayfish establishment (Figure 5; Lodge et al. 1986, Olsen et al. 1991, Wilson et al. 2004).

The introduction of rusty crayfish to the Great Lakes watershed has also impacted species other than native crayfishes. Rusty crayfish voraciously feed on organisms from all trophic levels: benthic algae, macrophytes (which serve as nurseries for many fishes), invertebrates, snails, and fishes (Lodge et al. 2004, McCarthy et al. 2006, Rosenthal et al. 2006). Thus, non-native crayfish are capable of large effects on several parts of freshwater ecosystems in streams and lake shores. Indirect effects arising from macrophyte destruction are likely to be especially important and are only beginning to be fully investigated, but initial results indicate that there are numerous indirect impacts throughout lake food webs, including on both small and large fishes (Strayer 2010, Kreps et al. 2016). Figure 6 is from a long-term study of the impacts of rusty crayfish on other species in Trout Lake, Wisconsin.

Figure 5. Abundances (as measured by trapping) of crayfish in Trout Lake, Wisconsin from 1979–2000. (adapted from Wilson et al. 2004).



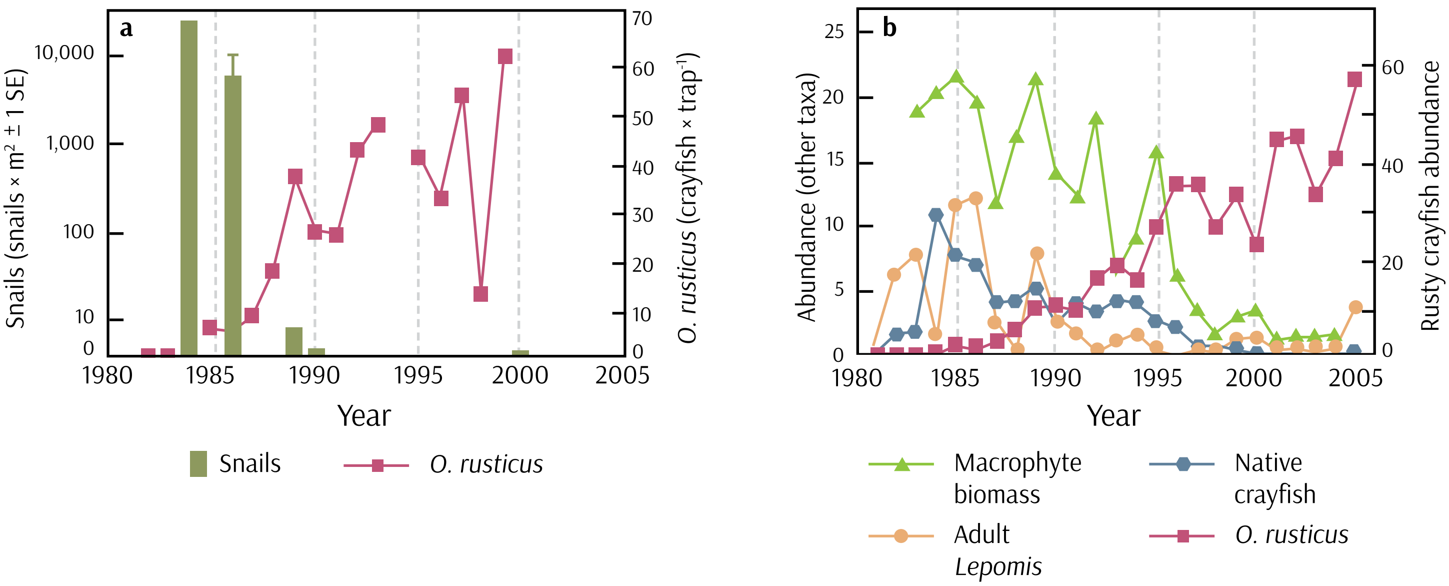


Figure 6. a) Correlation between changes in snail (bars) and O. rusticus *(line) abundance (adapted from Wilson et al. 2004); b) correlation between changes in macrophyte biomass, sunfish (*Lepomis spp.*) abundance in Trout Lake (adapted from Carpenter et al. 2007).*

2.5. Solutions

Indications are that rusty crayfish have established themselves in the Great Lakes and other lakes in the watershed. Solutions can be both proactive (try to prevent an invasion) or reactive (try to remediate the problem after invasion has occurred). For example, proactive measures include preventative or regulatory control, and reactive measures include biological control, chemical control, and mechanical removal. All of these approaches (or combinations of these approaches) may be used to mitigate species invasions, including rusty crayfish invasions.

2.5.1. Preventive or Regulatory Control of Invasive Species

Regulating or banning the import of non-native organisms or quickly dealing with their containment and extermination once detected can prevent many non-native species invasions. New technologies that can aid in the early detection process, such as the use of

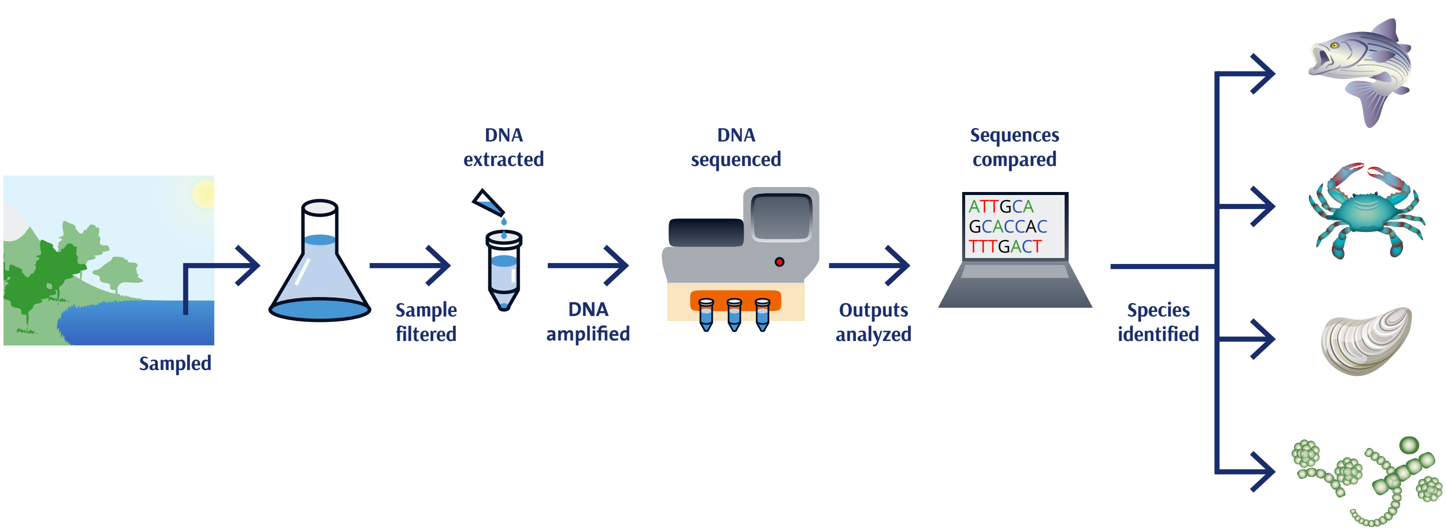


Figure 7. Environmental DNA (eDNA) method. In this example, DNA is isolated directly from a filtered water sample that contains cells or traces of DNA (e.g., from shed skin or excrement) from many species. Illustration: Nadav Gazit.

Box 1. An Example of Preventive Control: The American Bullfrog in France

Though native to eastern North America, the American bullfrog (*Lithobates catesbeianus*) has spread to at least 25 European countries in the past century, and is considered one of the 100 worst invasive species in the world (Lowe et al. 2002, Ficetola et al. 2007, D'Amore 2012). In France, three populations of American bullfrog have been established so far. Control actions such as egg removal, trapping of tadpoles, and shooting juveniles and adults seem to reduce bullfrog densities, but it is likely that failure to detect low-density populations decreases the success of eradication (Tanadini and Schmidt 2011). In recent years, researchers have begun to perform eDNA (environmental DNA) surveys. In this method, DNA is isolated directly from a filtered water sample that contains cells or traces of DNA (e.g., from shed skin or excrement) from many species. Once the DNA is extracted, it is amplified via PCR (polymerase chain reaction), sequenced, and analyzed. The sequences are compared to a large database of known DNA sequences in order to identify whether endangered or invasive species are present in an ecosystem.

Compared with traditional methods, eDNA analysis is rapid and cost-effective, uses standardized molecular approaches, has minimal environmental impact, and can detect low-abundance species that can be difficult to observe using standard monitoring techniques (e.g., trapping, visual surveys). For instance, by combining eDNA surveys with traditional field surveys, researchers in France found that the detection of bullfrog occurrences was five times higher than by traditional surveys alone (Dejean et al. 2012). The ability to detect invasive American bullfrogs at a low density and at any life stage will be key to influencing management decisions for control of invasive species.

environmental DNA (eDNA; Figure 7; Box 1), are starting to emerge (Dougherty et al. 2016). New online mapping tools that incorporate model predictions of invasions based on exposure risk and community susceptibility allow us to identify and prioritize the ecosystems most vulnerable to invasion (Olden et al. 2011). We can then make and enforce regulations attempting to prevent potentially invasive species from getting into potentially vulnerable areas (Olden et al. 2011). However, because non-native organisms often move across political as well as geographic barriers, the success of regulatory control relies on proactive, consistent, and coordinated efforts among countries and states (Mack et al. 2000, Reaser et al. 2003, Dresser and Swanson 2013).

In the case of the rusty crayfish invasion, Lodge et al. (1998) suggest that managers target lakes or drainages that are both vulnerable to colonization by non-native species and that harbor endemic species for priority action. For instance, tighter regulations in the Great Lakes requiring boat and equipment washing prior to leaving a particular lake can also combat the localized spread of invasive rusty crayfish. In addition, restrictions on the use of rusty crayfish as live bait could be better enforced. Live crayfishes are among the favorite baits of anglers, and as a consequence, the release or escape of live baits is a vector of crayfish introductions (Lodge et al. 2000). Restrictions on other fishing activities may also be effective. For instance, in Sparkling Lake, Wisconsin, the combination of adult rusty crayfish removal (via trapping; Figure 8) with regulations restricting harvest of fish species that eat crayfish too small to trap, led to a decline in rusty crayfish abundance. With this type of management, catch rates decreased by 95 percent from 2002 to 2004 (Hein et al. 2007).

Any local regulations, however, should be combined with a regional plan. Management decisions made for any particular lake have implications for the probability of an invasion into neighboring lakes, because these decisions affect how boaters distribute themselves across a lake system and any rusty crayfish that may accompany boaters in bait buckets or as stowaways. For example, throughout the Great Lakes region, regulations vary from

Figure 8. Crayfish trap. Image: Great Lakes Science Center, USGS.

Box 2. An Example of Biological Control: The Cactus Moth in Australia

The cactus moth, *Cactoblastis cactorum*, is a native species of South America that feeds on prickly pear cactus (genus *Opuntia*; Figure 9). In 1930, it was imported into Australia for the biological control of invasive cactus, where approximately 25 million hectares of land were infested with *Opuntia* species (Dodd 1940). A large workforce carried out a coordinated program releasing over 2.7 billion moth eggs on the infested lands (Zimmermann et al. 2004). The cactus moth proved extremely effective in reducing the numbers of the invasive prickly pear in this instance.

Due to its success, the cactus moth was then intentionally spread from Australia into other countries with prickly pear problems. It was introduced to the island of Nevis in the West Indies in 1957 (Zimmermann et al. 2004) where it successfully controlled the invasive species. However, it also spread to the surrounding islands and later landed in the Florida Keys in 1989, where there is a native cactus species (*Opuntia humifusa*). Spreading into mainland Florida, the cactus moth has caused high levels of damage to *Opuntia* cacti on the central Florida coast (Baker and Stiling 2008), and has since spread north to South Carolina, and west along the Gulf of Mexico's coast to Louisiana (Hight et al. 2002, Hight and Carpenter 2009). Its spread poses a serious threat to all 79 native *Opuntia* species from the US and Mexico. In particular, the cactus moth is a major concern for the agriculture industry and the farmers of 250,000 hectares of *Opuntia* plantations in Mexico (Stiling 2002).

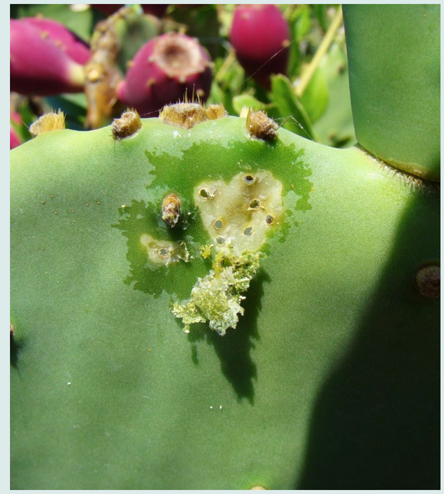


Figure 9. Cactus moth larvae feeding on prickly pear cactus host. Image: Rebekah D. Wallace, University of Georgia, Bugwood.org [CC BY-NC 3.0].

no regulation to prohibition of all crayfish use (Peters and Lodge 2011). This inconsistent regulation among jurisdictions in the Great Lakes region has decreased the success of rusty crayfish invasion preventive efforts (Peters and Lodge 2011). Therefore, regional plans need to be created and enforced to maintain regulation consistency and to achieve the desired outcomes.

2.5.2. Biological Control of Invasive Species

One of the most powerful, yet controversial, tools in managing invasive species is biological control. Bringing natural enemies from the invader's native range has been successful on many occasions. However, the use of biological control is controversial because the strategy may employ the introduction of another organism, often a non-indigenous species, whose target and non-target effects may be largely unknown. These introduced species may, and in many cases already have, become a new invasive in the system (Box 2).

A natural trophic approach can also be used to control established crayfish populations. Adult smallmouth bass (*Micropterus dolomieu*; Figure 10), a native species, has been shown as a successful predator of crayfish, especially of small individuals (Didonato and Lodge 1993, Hein et al. 2006, Hein et al. 2007). Thus, promoting healthy fish populations can help to control crayfish populations through the predation of juvenile or young adult rusties. As mentioned above, Hein et al.

*Figure 10. Smallmouth bass (*Micropterus dolomieu*). Image: National Park Service.*

(2006; 2007) found that regulation of fisheries played a role in controlling the rusty crayfish populations in the isolated Sparkling Lake in Wisconsin. Researchers collaborated with the Wisconsin Department of Natural Resources to regulate the size and amount of fish caught in Sparkling Lake. Increasing the minimum length of fish from 356 mm to 457 mm and reducing the bag limit from five to one fish per person increased the population of the smallmouth bass and the predation rates of the rusty crayfish. The largest decline in population growth rate of rusty crayfish occurred when fishing pressure by humans was reduced and as a result, smallmouth bass predation on rusty crayfish increased. This biological control approach (through the mechanism of a regulatory control approach) was used after the population of rusty crayfish was significantly reduced through trapping (a physical control approach, see below).

Bampfylde et al. (2009) simulated the population dynamics of smallmouth bass and rusty crayfish using different scenarios. They showed that the success of biological control of rusty crayfish is density-dependent. In other words, the density of crayfish has to be low for the biological control by smallmouth bass to succeed. Otherwise, the rusty crayfish outcompetes juvenile smallmouth bass for food and shelter, driving it potentially to local extinction. Thus, they suggest that depending on the densities of crayfish and fish in a lake, a combination of approaches can be used to ultimately succeed in controlling the populations of crayfish.

2.5.3. Chemical Control of Invasive Species

Chemicals can be highly effective in controlling invaders, from algae to vertebrates (Box 3). Chemical controls refer to the use of pesticides, including herbicides, insecticides, and fungicides, to target a specific invasive population. These substances can prevent, destroy, repel, or mitigate an invasion by physically, chemically, or biologically interfering with an invasive organism's metabolism or behavior (NSW EPA 2016). Most pesticides are lethal to their target species (NSW EPA 2016). However, pesticides can have complex environmental and societal costs as well. Pesticides may affect non-target organisms, including livestock and important pollinators like bees, while target invasive species may develop resistance to the chemicals (Bourguet and Guillemaud 2016). Many pesticides also affect humans, and can lead to poisoning, illness, cancer, and death (Pimentel 2005). Pesticide use is therefore highly regulated in order to ensure pesticides are being used in a way that minimizes adverse effects on non-target organisms (USFWS 2009).

In the case of the rusty crayfish, although some chemicals produce 100 percent mortality of crayfish, no selective chemical agent is known that can distinguish between native and non-native crayfishes (Bills and Marking 1988). In addition, many chemicals tested as

Box 3. An Example of Chemical Control: The Coqui Frog in Hawaii

The coqui frog (*Eleutherodactylus coqui*; Figure 11), endemic to Puerto Rico, was accidentally introduced to Hawaii through the trade of plants in the late 1980s. It is one of at least 27 invasive amphibians and reptiles found in Hawaii (Kraus and Campbell 2002). The coqui frog competes with native insectivores and its high densities can deplete population of invertebrates and increase the nutrient input in the system through the high volumes of excrement, which may have effects at the ecosystem level (Sin et al. 2008).

Several approaches to control the coqui frog have been undertaken in Hawaii. Physical or mechanical (see below) and biological control have shown little success in controlling the frogs. However, the use of citric acid, a pesticide with minimum risks, has shown to be the most successful approach (Kraus and Campbell 2002). Spraying citric acid on infested areas and plants will kill frogs and their eggs. The disadvantages are the need for the chemical to contact frogs directly, and the repeated applications needed to ensure that all frogs and eggs are eliminated. Preventive regulations such as inspecting and treating cargo and plant materials, using barriers, and not transporting infested material could stem the spread of the frog to new areas.

*Figure 11. Coqui frog (*Eleutherodactylus coqui*). Image: Wilfredo Falcón, Flickr CC BY 2.0.*

agents to control invasive crayfish are lethal to other living organisms, such as other crustaceans, fish, and insects. Their effects also can potentially be biomagnified through the food chain. For example, some crayfish that survived exposure to chemicals accumulated them in the liver tissue in concentrations 120,000 times the concentration in the water. High concentrations of these chemicals can then be transferred to other organisms at higher trophic levels, such as birds that prey on crayfish, and so on (Hyatt 2004).

2.5.4. Physical or Mechanical Control of Invasive Species

Physical removal of invasive species (digging, hunting, and trapping) has proven to be effective in some cases (Box 4).

For rusty crayfish, the feasibility of mechanical removal was tested by Hein et al. 2006 and 2007 by trapping during multiple years in an isolated lake in northern Wisconsin, Sparkling Lake. According to the authors, previous studies had concluded that reducing populations through trapping was not feasible for invasive crayfish, and several authors note that crayfish traps are highly selective for large males, thus making it difficult to efficiently trap much of the reproductive population. Hein et al. (2007) attempted to increase rates of female trapping by taking into account water temperature (crayfish are more active in warmer temperatures) and life histories of female crayfish when setting traps. They also progressively increased trapping effort over time to offset decreasing capture rates as the population decreased. The authors concluded that while skewed towards adults, this trapping strategy successfully removed individuals with the highest reproductive value and resulted in significant reduction in population growth rate per trapped individual.

2.6. Summary

Rusty crayfish pose significant threats to the Great Lakes basin. Not only have they been shown to impact native biota such as snails, crayfishes, and fishes, but they also alter habitats for other species with the potential for further ecosystem level effects. Since any biological invasion involves novel interactions, successful invasions by non-native species can cause significant unforeseen ecological and economic consequences. Since rusties have not yet invaded many areas of the Great Lakes basin, we have the opportunity to prevent many of the known and unknown negative impacts of a rusty crayfish invasion from occurring in these waters.

3. PART 3: EXERCISE

You are one of the wildlife managers at Bright Valley Wildlife Refuge, in Wisconsin, which includes Bright Lake (see Table 1).

Five years ago, a neighboring protected area reported a growing population of the non-native rusty crayfish in its lakes. Thus, your research team started an intense monitoring program of the Bright Lake ecosystem. After

Box 4. An Example Of Mechanical Control: Sabellid Polychaete Worm

In 1993, a marine worm (*Terebrasabella heterouncinata*, a polychaete) native to South Africa, was discovered infecting the shells of the red abalone (*Haliotis rufescens*) in California (Oakes and Fields 1996; Fitzhugh and Rouse 1999). This worm severely retards the growth of gastropods by interfering with shell growth, shape, and respiration (Kuris and Culver 1999).

Although initially contained within California aquaculture facilities, at least 2.5 million worms became established in the natural environment (Culver and Kuris 2000). To control this invasive species, an eradication program was implemented to: 1) prevent the release of infected abalones from aquaculture facilities, 2) remove abalones and shell debris near the aquaculture facilities' discharge area, and 3) remove approximately 1.6 million black turban snails (*Tegula funebralis*), the most susceptible host. This effort to manually and mechanically remove hosts from the coastal environment required the equivalent of 300 people working continuously for 12 hours!

Overall, this strategy proved a resounding success. Following cleanup of abalones and shell debris, the worm population declined to 64 percent of the original size, too low to be self-sustaining, and new infestations similarly decreased 56 percent (Culver and Kuris 2000). The success of this eradication program is attributed in part to the early detection and rapid response to the invasion, as well as the cooperative efforts of the private, public, regulatory, and scientific communities in eradicating the worm population (Culver and Kuris 2000).

Table 1. Physical characteristics of Bright Lake located in the Bright Valley Wildlife Refuge, Wisconsin.

Perimeter	5.0 km
Surface	0.6 km^2 (60 hectares)
Water volume	7,000,000 m^3

five years of monitoring, the results show the following patterns:

3. Populations of native crayfish species are rapidly declining.
4. There is a sustained growing population of rusty crayfish.
5. There has been an increase in the recreational fishing for smallmouth bass.
6. There has been a decrease in snail abundance.
7. There has been a decrease in macrophyte abundance.

Based on this information, you have been asked to prepare a plan of action to control the rusty crayfish population in the lake.

3.1. Exercise Questions

1. As a first step, you, as a manager of Bright Valley Wildlife Refuge, need to write a paragraph for your supervisors describing and explaining the problem Bright Lake is facing and why it is important to address it. When you explain the issue, be as clear and comprehensive as possible (~150 words).
2. Based on the case study information provided to you, what do you think is the best overall strategy, or combination of strategies, to control rusty crayfish in Bright Lake? *Explain and support your answer.*
3. The federal government wants you to execute a plan in a time frame of five years with a budget of \$1,000,000 USD. This is excluding personnel costs, which are covered separately (and need not be a concern for the purposes of this exercise). Below is information on how much chemical, mechanical, and biological control protocols would each cost. Use that information to calculate how much each type of control would cost over a 5-year period.

3.1.1. Chemical Control

Table 2 shows the effectiveness of four chemicals on crayfish individuals and the costs of applying these chemicals for a given volume of water. Using Table 1, complete Table 2 to calculate the costs for the case of Bright Lake.

3.1.2. Trapping or Mechanical Control

The protocol to trap crayfish that has been presented to you is as follows: set up 1,000 traps (in groups of 10 at regular intervals) every kilometer along the perimeter of the lake (5 km). Traps last a long time and can be reused year after year. Each trap costs \$10. It is recommended to start by trapping 20 days/year, and increase trapping intensity by 10 days on every following year. To attract

Table 2. Approximate costs for chemicals to control rusty crayfish (modified from Hyatt 2004).

TREATMENT	OBSERVED CRAYFISH MORTALITY AFTER ONE APPLICATION	APPROXIMATE COST PER 1,000 m^3 (USD)	COST FOR BRIGHT LAKE (USD)
Ammonia	100%	\$700	
Chlorine	100%	\$600–\$3,000	
Sodium sulfate	100%	\$150	
Pyrethrum	100%	\$200	

Table 3. Calculate trap costs.

TRAP COSTS	TOTAL NUMBER OF TRAPS NEEDED	PRICE PER TRAP (USD)	TOTAL COST OF TRAPS (USD)
Traps			

Table 4. Calculate baiting costs.

BAIT COSTS	NUMBER OF DAYS OF TRAPPING	NUMBER OF TRAPS	PRICE OF BAIT/ DAY/TRAP (USD)	TOTAL COST OF BAITING PER YEAR (USD)
Year 1	20		$1	
Year 2	30			
Year 3				
Year 4				
Year 5				
			TOTAL cost bait	
			TOTAL cost traps	
			TOTAL	

Table 5. Calculate fishery management cost.

	TOTAL ESTIMATED VALUE OF BRIGHT LAKE	10% LAKE VALUE	YEARS OF VALUE REDUCTION	TOTAL COST (USD)
Cost of fishing restrictions				

crayfish, one smelt bait is placed in each trap, every day. The cost of each bait is $1.

3.1.3. Biological Control through Fishery Management

The annual value of a hectare of lake in Wisconsin has been estimated to be $232.16 USD (calculated from revenues from recreational use and willingness to pay using data from US Fish and Wildlife Service Survey of Fishing, Hunting and Wildlife-Associated Recreation, Bampfylde et al. 2009). Increasing regulations of smallmouth bass fisheries in Bright Lake to restrict size of catch is expected to reduce visitation and associated benefits resulting in a loss of 10 percent of its annual value. Again, labor needed for dissemination and enforcement does not need to be considered. Complete the table to estimate the cost for Bright Lake.

4. Given these costs, what strategy would you recommend for Bright Lake over 5 years with budget of $1,000,000 USD? *Explain and support your proposed strategy*.
5. Is the chemical approach a feasible option? Give at least *two* reasons to *support* your answer.
6. Would you change your recommendations under any of the following alternative scenarios?
   a. You have an available budget of $2,000,000 USD over five years. *Explain your answer*.
   b. Instead of attempting to control rusties in Bright Lake, you are trying to address the problem in a small (1,000 m^3) artificial pond located in the Reserve's headquarters property. *Explain your answer*.
   c. A new chemical has been discovered, and in laboratory experiments it has proven to be lethal to rusty crayfish only, showing no toxicity to other crayfish or wildlife. *Explain your answer*.

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