LESSONS IN CONSERVATION

**STUDIO
ISSUE**

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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 on our website (ncep.amnh.org).

In this issue, we present a collection of case studies and exercises developed by NCEP *Conservation Teaching and Learning Studio* participants. NCEP Studios aim to create a "community of practice" by bringing together individuals and teams of conservation educators to train in evidence-based pedagogical approaches, exchange teaching strategies, practice new teaching techniques, and integrate these approaches by co-developing new teaching resources. Studios have convened annually since 2015 and have brought a total of 93 educators from nine countries to the museum. We are excited to feature the work of four educator and practitioner teams that attended past Studios for this ninth volume of *Lessons in Conservation*.

In keeping with the NCEP Studio process, the resources presented here are designed to promote active learning as well as develop critical thinking skills through case studies, games, conservation decision-making exercises, and research projects. Specifically, they encourage students to grapple with the realities of "tradeoffs"—a frequent feature of real-world conservation decision-making.

Please enjoy this volume of *Lessons in Conservation* and we'd like to remind you that all NCEP materials are meant to be modifiable for each teacher's specific classroom or training needs. Adaptable Microsoft Word versions of these modules are available for download at ncep.amnh.org along with accompanying teaching notes, exercise solutions, presentations, and links to other relevant open educational resources. For more information on NCEP and Studios, please see this issue's editorial, *Building capacity for conservation through education: the what, how, why, & who of the Network of Conservation Educators and Practitioners*. If you are interested in becoming further involved or participating in future Studios, please contact us at ncep@amnh.org.

We are grateful to many people across the CBC for their contributions to the development of *Lessons in Conservation*. Please see the back cover for a full acknowledgment of the organizations, institutions, and individuals that have supported the authors' participation in an NCEP Studio and the module creation process. Remember to visit our website, and we hope you'll use these or other NCEP resources in your classroom!

Kristin Douglas   Suzanne Macey

Co-Editor   Co-Editor

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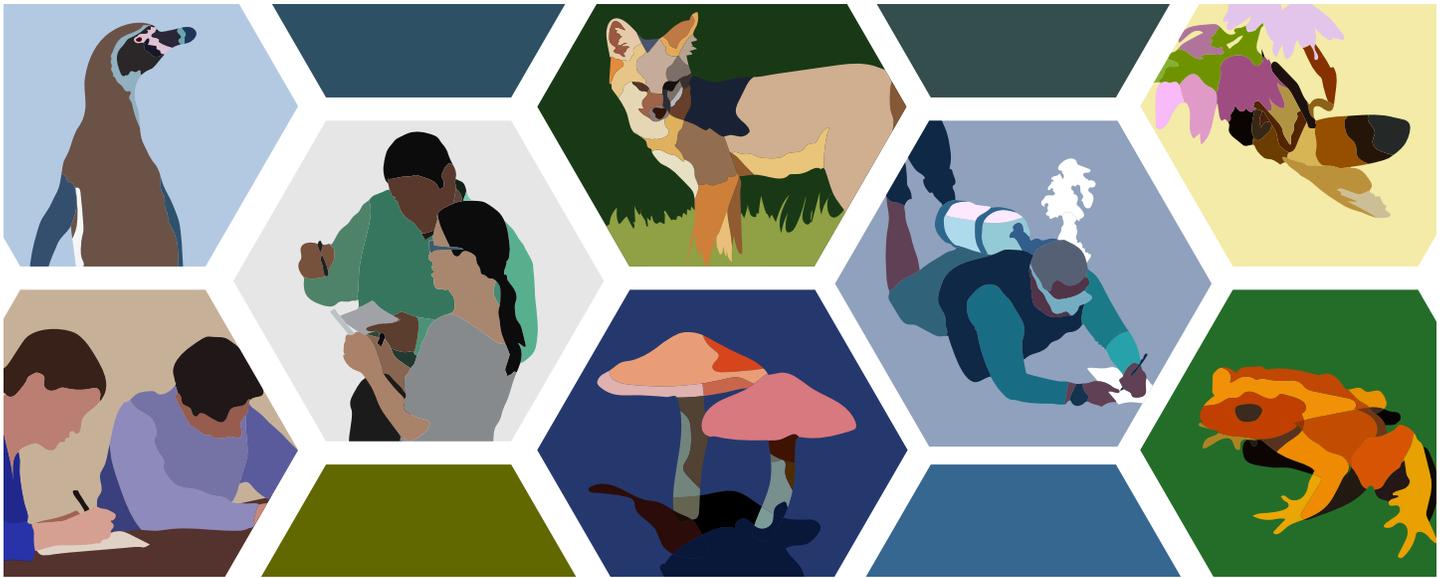
Building Capacity for Conservation Through Education: The What, How, Why, & Who of the Network of Conservation Educators and Practitioners

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Sufficient conservation capacity—the ability to set and achieve conservation goals—is critical to meeting the environmental challenges we face globally as individuals, organizations, and societies (e.g., see Fox et al. 2017, Gill et al. 2017). The Network of Conservation Educators and Practitioners (NCEP) seeks to build that capacity for conservation through evidence-based higher education and professional development. By thinking about *what* is taught and *how, why* is it effective, as well as *who* is included at the table and in the classroom, we work to improve the teaching and learning of conservation in universities and other professional settings. The works presented in this volume of *Lessons in Conservation* are the product of NCEP Conservation Teaching and Learning Studios and, more broadly, of the NCEP community. Here we share the evolution of NCEP as a program and as a community to outline how we arrived at Studios and the resources presented here, why they matter, and where they are headed in the future.

What We Teach: The Beginnings of the Network

In the early 1990s, as a doctoral student studying a nocturnal lemur (the aye-aye) in Madagascar, Center for Biodiversity and Conservation (CBC) Jaffe Chief Conservation Scientist Dr. Eleanor Sterling was inspired to learn about how environmental science was taught in the country. Madagascar was and is a widely recognized global hotspot for biodiversity and she was curious about how the next generation of conservation actors was being trained. What she found was that Malagasy educators were limited by a scarcity of resources such as textbooks, and that (when available) these were often out-of-date and irrelevant to the local context. In Madagascar, and elsewhere (e.g., Mendez et al. 2007), there was an urgent need for up-to-date, high-quality resources for teaching and training science. If the scientific community wanted to support conservation into the future, it needed to ask some important questions: What training does the next generation of conservation educators and practitioners need? What skills? Will they be effective?

Dr. Sterling, her CBC colleague Dr. Nora Bynum, and Dr. James Gibbs (of the State University of New York, College of Environmental Science and Forestry) created the Network of Conservation Educators and Practitioners—or NCEP—in 2000 to meet this capacity challenge. With a small team based at the American Museum of Natural History (AMNH), the project began by creating a suite of open and active educational materials on a variety of conservation topics, leveraging the expertise of CBC, AMNH, and other scientists by enlisting them as authors and reviewers. The resulting "modules" each included an explanatory background Synthesis document, a visual Presentation for the classroom with accompanying Teaching Notes, at least one practical Exercise with Solutions for the instructor, and related Case Studies. Following a rigorous peer review process, these modules became freely available online. In tandem, NCEP initiated projects on the ground in countries like Madagascar, Mexico, and Bolivia, where we worked with local project staff and scientists to distribute and adapt these resources to specific contexts (e.g., see Bynum and Porzecanski 2004, Sterling et al. 2005, Porzecanski et al. 2006, Bravo et al. 2017). In Madagascar, for example, we began by putting together a small, locally-based team of conservation professionals to coordinate the development of a suite of modules in French (the country's primary language of instruction) tailored to the Malagasy context. These topics ranged from *What is Biodiversity?* to *Characteristics of Endangered Species in Madagascar*. Over the span of a decade, our network within the country grew to over 1,300 professionals and educators from conservation institutions across Madagascar. To date, the NCEP program as a whole has developed over 170 modules in eight languages on diverse conservation topics with experts from around the globe and engaged with a community of module users worldwide.

How We Teach: The Science of Teaching and Learning

The needs and feedback of this global community—stretching from AMNH in New York to local partners in regions like the Southern Andes, to global module users worldwide—regularly inform our path forward. Consequently, as the program and module collection grew, our focus expanded to increasingly include not only *what* we teach but also *how* it is taught. We found many of our colleagues at home and abroad, while experts in their field, had received little or no training in pedagogy yet were being asked to teach hundreds, even thousands, of students over the course of their careers. Valuable skills such as critical thinking, data analysis, collaborative problem solving, and professional communication were regarded as essential for professional conservation practice (e.g., Kroll 2007) but not explicitly addressed in most courses and curricula. Academic preparation in conservation science remains geared towards academic careers, despite the high demand for professionals outside of academia (Lucas et al. 2017).

At the same time, research in science education was clearly showing the effectiveness of 'active learning,' or the educational philosophy and set of practical techniques in which teachers actively engage students in the learning process (e.g., Burrowes 2003, Knight and Wood 2005, Freeman et al. 2007). The goal of active learning is to create meaningful contexts that motivate students to learn, to think about their learning, and to apply what they learn, thereby mastering content as well as developing important professional skills. Interested in evaluating our work to date, the NCEP team led experimental research to understand how modules affect learning. With support from the US National Science Foundation, our staff worked with faculty from across our network in the United States and Puerto Rico to measure student learning gains and skill development using modules in the classroom. In terms of content knowledge, faculty observed gains in learning and student confidence—as well as greater interest in the field of biodiversity conservation—following the use of NCEP modules in undergraduate courses (see Hagenbuch et al. 2009). In terms of professional skills, we found that student practice and self-reflection can foster enhanced performance in as little as one term (see Bravo et al. 2016, Sterling et al. 2016). These results are applied in our module collection through exercises that target the development of a specific skill (e.g., see *Lessons in Conservation*, Volume 8; *Student Learning* issue) and in innovative approaches to teaching practiced at our training events.

The need for training in pedagogy in our community prompted NCEP to expand its activities to increasingly

focus on evidence-based teaching techniques centered on active learning. To date, the program has held more than 225 training events on topics in conservation biology and evidence-based teaching methods in 20 countries, reaching at least 4,650 conservation professionals. We continue to offer multiple types of training, from workshops on pedagogy to seminars in course and curriculum development to online learning courses for life-long learners, but our predominant training events are now *Conservation Teaching and Learning Studios*. NCEP Studios bring together teams of conservation educators to exchange teaching strategies, train in evidence-based pedagogical approaches, and practice new techniques. They specifically offer training in pedagogical methods that research has shown to be most effective in developing student knowledge and skills (e.g., Freeman et al. 2014). Topics are determined by the needs of the NCEP community (e.g., proposed by Studio alumni or module users) and are used to demonstrate evidence-based techniques. For example, in 2017 the NCEP Studio focused on strategies for developing and assessing professional skills in conservation students, specifically critical thinking and evaluating evidence, using different classroom interventions and assessment rubrics.

Why Studios? Building a Community of Practice

Our network is about making connections—connecting conservation educators to practitioners, trainers to the latest conservation science, and educators to the latest research on teaching and learning—but NCEP Studios do more. We bring together educators and trainers to create a 'community of practice,' defined by Wenger (2011) as "...groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly." At NCEP Studios, conservation educators can share their experiences, learn from one another, and offer each other support into the future. Our most recent Studio, held in June 2018, welcomed 21 university-level conservation science educators from the United States, Peru, Guyana, and Nepal for two and a half days. In addition to training in active teaching approaches and learning about NCEP resources, significant time was spent on practicing evidence-based methods in small groups and on daily activities and presentations led by the participants themselves, where

participants can be both educators and learners. To further support this nascent community of practice, we facilitate regular follow up to address questions raised during the Studio and hold a winter webinar to check in with alumni (for instance, regarding how they are integrating active teaching methods in their classrooms). The next Studio is scheduled for June 2019.

NCEP Studios have also fostered the growth of our original *raison d'être*–the NCEP module collection. As outlined in the Letter from the Editors, the modules included in this volume of Lessons in Conservation are the direct products of NCEP Studios. For example, *Genetically Modified Crops and Biological Conservation on Farmlands*, a case study and exercise by Studio alumni Dr. Timothy Leslie and Dr. Randa Jabbour, is the pair's first formal collaboration with each other on research and writing. Dr. Leslie shared with us that he found this opportunity to collaborate and discuss pedagogy especially valuable because while he and Dr. Jabbour teach similar topics, they do so in very different parts of the United States (in terms of climate, ecosystems, student exposure to agriculture, etc.) and in different university settings. Topics like genetically modified crops and the social and ecological trade-offs encountered in tropical reforestation (also included in this volume) reflect the direction the NCEP program is headed, highlighting topics central to 21st-century conservation practice that address the complexity and trade-offs of real-world conservation decisions.

Who We Teach: Moving Towards More Inclusive Conservation

Building on what and how conservation is taught, and mindful of the diverse contexts where conservation is learned, we have focused increasingly on questions of *who* we are teaching when we develop our resources and training events. The CBC includes the conservation of both biological and cultural diversity as part of its mission. We recognize that only a diverse, equitable, inclusive, and culturally vibrant workforce will offer the innovation and diverse solutions required to solve today's complex conservation challenges. Launched in 2001, the CBC's Inclusive Conservation Community Initiative (ICON) seeks to address the barriers that impede the full participation of historically underrepresented groups

in the conservation fields. NCEP works to support this CBC commitment to a more inclusive conservation workforce in multiple ways, from our training events to our resources. For example, the topic of how to teach inclusively has come up at several Studio events and we are working to formally include this in our resource collection. We are interested in experimenting with new formats (e.g., videos and other visual learning aids) for NCEP modules, to better reflect the traditions and learning practices of our many partners. This is one reason why we are increasingly featuring new open educational resources, developed by partners and other carefully vetted sources, alongside our own resources.

NCEP also carefully considers whom we are inviting to our Studios and events, and how we reach them, through targeted communications and outreach. We are particularly interested in reaching educators who serve diverse and underrepresented student bodies. Demand for NCEP Studios continues to be high, reinforcing the vital role of teacher training and idea exchange in the conservation field, and outpaces our ability to fund travel to New York City. As we look ahead, we are interested in bringing these training events to our existing and potential partners, particularly in regions with high biodiversity and demand for more professional development opportunities.

In sum, NCEP believes that investing in evidence-based education and professional development for the next generation of conservation professionals will strengthen their ability to meet the conservation challenges of today and the future. Community and collaboration are central to our program, embodied in its name and integral in our work. By linking teachers in the classroom and trainers in the field with evidence-based pedagogy and practitioner insight, we hope we can bridge the current gaps between academic preparation and professional realities. By offering modifiable materials that can be adapted and improved by our user community, we hope to draw on collective and evolving knowledge to build a more inclusive conservation body of knowledge. And by sharing knowledge and creating spaces for exchange, we hope to create communities of practice dedicated to improving training and teaching in biodiversity conservation. Educators who use NCEP modules or attend a Studio bring these resources and skills back to

their own communities, reaching a growing number of additional learners and their peers over time, thereby improving teaching and learning in conservation science and, ultimately, improving conservation practice. For more information on NCEP or to get involved, please visit ncep.amnh.org.

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Bird Conservation Along the Lower Colorado River

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ABSTRACT

Riparian corridors in the southwestern deserts are among the most threatened bird habitat types in the United States of America. In the early 1900s, dams were built along the length of the lower Colorado River, the primary water source for the Southwest, to meet the increasing water needs of a rapidly growing human population. These changes altered annual flood regimes and disconnected the river from its historic floodplain, which dramatically reduced riparian corridors and affected the organisms that inhabit them. In this case study, we present an overview of efforts to conserve riparian birds, restore their habitat, and monitor their populations along the Colorado River. Our goal is to prepare students to think like a professional conservation practitioner who makes decisions that maximize conservation outcomes in light of limitations in local opportunities, budget, and political will for conservation. We also discuss how to determine effectiveness of conservation action, and manage adaptively to further optimize conservation outcomes as new data become available. We use the example of avian population data to describe the role of monitoring in assessing conservation needs, assessing the effectiveness of conservation actions, and the unique opportunity bird monitoring lends for citizen science by the birding public in conservation science.

LEARNING OBJECTIVES

By the end of this case study and its accompanying exercises, students will be able to:
1. Discuss the direct and indirect impacts of anthropogenic changes on bird habitats along the lower Colorado River.
2. Distinguish among different conservation actions, including habitat preservation, restoration, and creation, and debate the relative costs, limitations, and benefits of each in the context of the lower Colorado River.
3. Describe the role of long-term bird population monitoring in the context of conservation action and adaptive management.
4. Use long-term monitoring data to prioritize conservation actions and apply monitoring to adaptive management (Exercise 3).

INTRODUCTION

In the desert landscape of the southwestern United States and northwestern Mexico, the Colorado River forms a ribbon of life-sustaining water flanked by forests, scrubland, marshes, agriculture, and cities thriving on the use of this water. The forests and other natural communities dependent upon the river once stretched along the length of the lower Colorado River, from the end of the Grand Canyon to the river's terminus in the Gulf of California. Among the diverse flora and fauna in this region were large breeding populations of many species of birds (Grinnell 1914). Over the years, however, the lower Colorado River ecosystem has changed enormously as advancements in technology have allowed humans to store, control, and use the river's water. Logging, conversion of land for housing and agriculture, and unintentional introduction of non-native species have also contributed to the degradation of the native ecosystems of the region. Breeding populations of many native species of birds have declined in turn

(Rosenberg et al. 1991). A number of initiatives have worked to preserve the river's ecosystems and its wildlife, including bird populations, and in recent years, research, funding, and action for bird conservation in this region has increased (e.g., see Figure 1). In order for these actions to be as effective as possible, research and monitoring are ongoing to understand the impacts of past and current conservation actions and inform future plans. Such long-term monitoring[1] ensures that planners and land managers have the best possible results in restoring habitat[2] for bird populations on the lower Colorado River.

This case study focuses on the nature of anthropogenic[3] changes to this river system, the measures being taken for species conservation, and how one can determine whether or not these conservation measures are effective.

Figure 1. The Vermilion Flycatcher (Pyrocephalus rubinus) is a species covered under the Lower Colorado River Multi-Species Conservation Program. Concern for this species is largely due to a significant reduction in population numbers from current estimates to those calculated over 100 years ago. Photo credit: D. Fletcher.
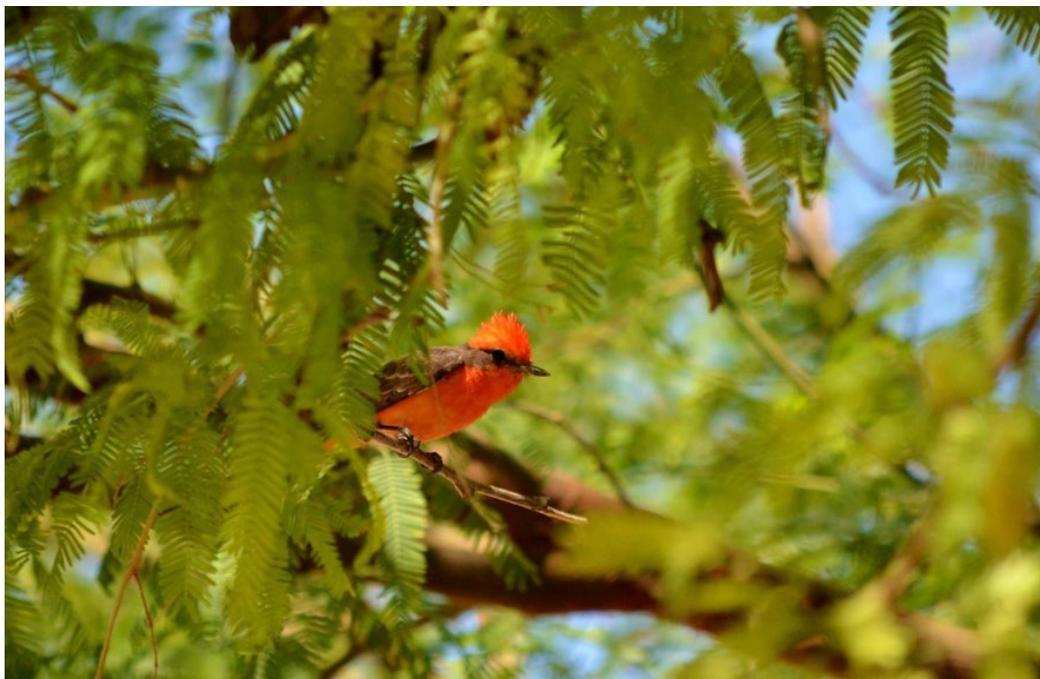
CONFLICT BETWEEN WILDLIFE AND HUMAN NEEDS

Limited water availability and a growing human population in the deserts of the southwestern United States have resulted in a conflict between the conservation of native species and urban and agricultural water needs. Historically, the Colorado River and its tributaries consisted of meandering rivers with a saturated floodplain[4] that often gave way to extensive wetlands. These wetlands were covered with muggy thickets of willows[5] and marsh vegetation, interspersed with majestic cottonwood[6] forests that depended on the river's very high water tables[7] and frequent flooding for survival and recruitment. In a desert environment, sensitive riparian wildlife depend upon these shady, cool oases. In fact, many riparian[8] bird species occur exclusively in these oasis environments (riparian-obligate[9] species).

Metropolitan areas, ranches, and agricultural fields also depend on water from the river, which provides the only large-scale supply of this limited commodity in the entire southwestern region. To accommodate water needs for development, several large dams were built in the early 1900s (including the famous Hoover Dam), which served to store river water for irrigation and municipal uses. The river was also deepened, straightened, and rip-rapped[10] (lined with rock to prevent erosion; Figure 2) to prevent flooding of settlements along the river and of the agricultural fields that had sprung up on the rich soils of the river's former floodplain. Riparian vegetation and wetlands were removed to make room for graded fields and housing. Together, these activities made much of the lower Colorado River ecosystem unsuitable for native riparian vegetation: the groundwater table became too low for their roots to reach, wetlands were cut off from the river, and regular annual flooding no longer occurred to provide its critical function in sprouting seeds of riparian plants.

Humans also introduced exotic plant species. For example, the invasive saltcedar[11] (Tamarix spp.) was brought from Asia as a windbreak tree in the 1900s, but soon spread throughout the rivers and riparian vegetation of the Southwest (Friedman et al. 2005). It now dominates large portions of all southwestern rivers, replacing native riparian vegetation in many places. This disrupted the nesting of riparian birds that previously depended on the cottonwood-willow woodlands growing in active floodplains. Saltcedar took hold in deforested areas, and turned out to be particularly tolerant of changing hydrologic conditions, as it can survive in locations where the groundwater table has dropped. However, many riparian birds, such as the endangered[12] Southwestern Willow Flycatcher (Empidonax traillii extimus), only find suitable nesting habitat in those stands that retain similar hydrologic conditions as intact cottonwood-willow forest, i.e., a high groundwater table that allows the soils to be

Figure 2. Rip-rap along the banks of the Colorado River. Photo credit: L. Harter.

saturated through most of their breeding season (Sogge and Marshall 2000, Hinojosa-Huerta 2006). Therefore, while saltcedar woodlands are abundant in many previously intact floodplain areas, many stands are unsuitable for most obligate riparian and wetland birds (Figure 3).

EFFORTS TOWARDS SOLUTIONS

Riparian bird communities have dramatically changed in the southwestern United States following the channelization and impoundment of the Colorado River for water, energy development, and flood control, all of which have caused widespread loss of riparian habitat[2]. In order to address such losses, the lower Colorado River region has become the focus of intense conservation efforts in recent years. The US Bureau of Reclamation (USBR), US Fish and Wildlife Service (USFWS), state agencies, and tribal governments are managing most of the remaining high-quality riparian areas in the region. Consequently, government agencies are leading conservation actions to mitigate habitat loss, create new habitat for threatened[13] and endangered species, and prevent new species from becoming threatened enough to be considered for protection under the Endangered Species Act.

The Lower Colorado River Multi-Species Conservation Program (or LCR MSCP) launched in 2005 with the goal of offsetting, or compensating, these losses in wildlife habitat through riparian habitat restoration and creation along the river. The LCR MSCP spans about 400 miles from Lake Mead, Nevada, to the Southern International Border between Mexico and the United States (Figure 4). The program is a multi-stakeholder partnership involving 57 different federal, state, and local government agencies; water and power users, and other interested parties. It is expected to cost over one billion dollars to complete over its 50-year lifespan (2005–2055). Thousands of hectares of cottonwood-

Figure 3. A dense thicket of saltcedar growing along the lower Colorado River. Photo credit: L. Harter.
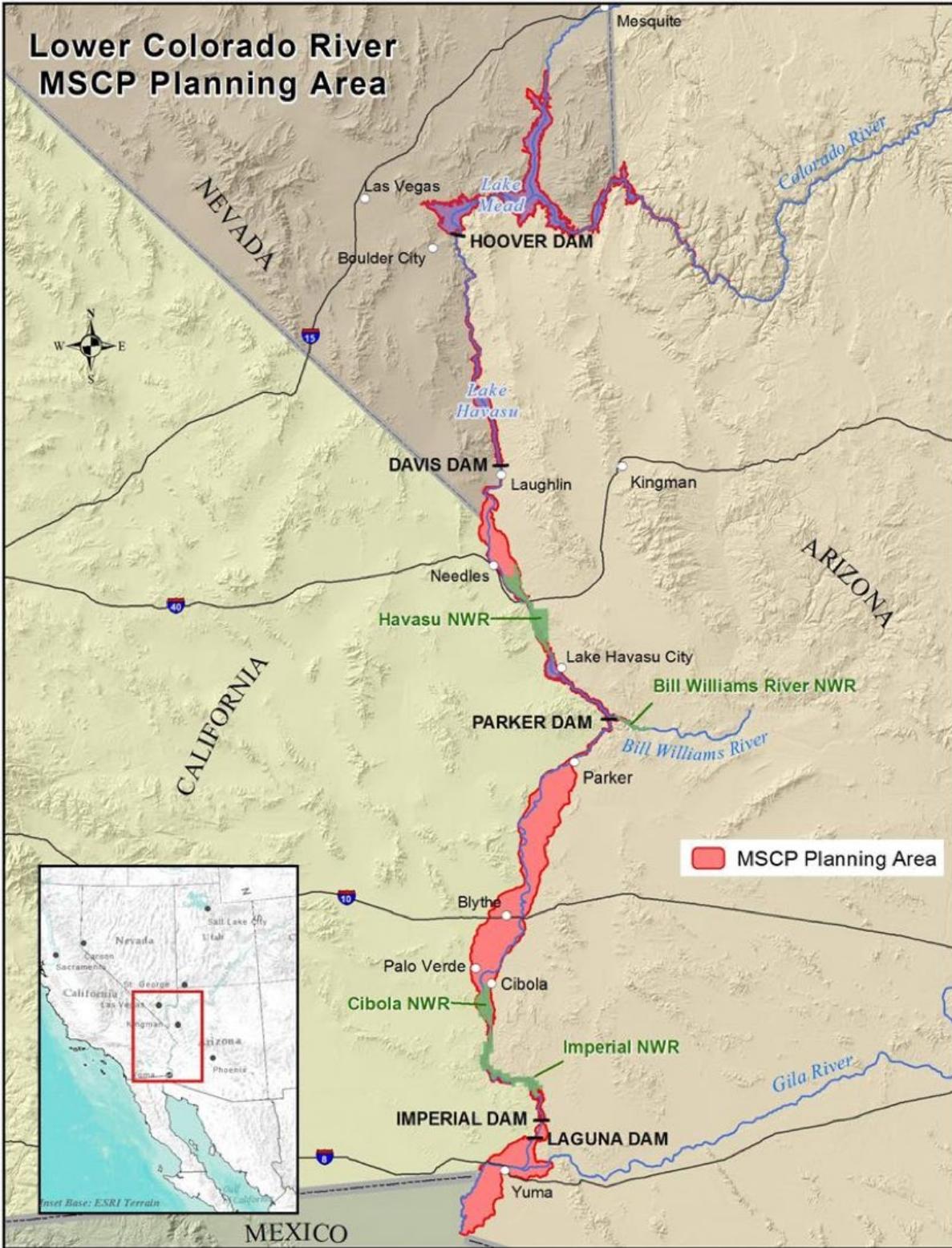
Figure 4. Map of the lower Colorado River Valley showing the LCR MSCP planning area. (NWR=National Wildlife Refuge). Image credit: Bureau of Reclamation / US government work.

willow and mesquite[14] plantings have been installed in retired agricultural fields, and existing wetlands and backwaters[15] have been enhanced to mitigate losses of fish and wildlife habitats to channelization and impoundments (LCR MSCP 2004). The participating stakeholders work together to implement this program through a steering committee to ensure that research is shared and that the program is making the best conservation choices based on the needs and goals of each group.

As part of the LCR MSCP program, riparian birds have been comprehensively inventoried and monitored since 2007 to determine the effectiveness of the program and to refine conservation actions taken. In this case study, we summarize some of these findings, their implications for local conservation action, and how large-scale bird survey data inform habitat management.

CONSERVATION PLANNING AND ACTIONS

Conservation planning under the LCR MSCP covers around 27 species, including insects, plants, fish, amphibians, reptiles, mammals, and birds (for details, see https://lcrmscp.gov/). The program works toward habitat conservation for covered species to balance human uses of water from the Colorado River with the conservation needs of species that are listed under the Endangered Species Act and other covered species that may be at risk of being listed. In this case study, we focus on the program's conservation efforts for birds.

The lower Colorado River is used by over 400 bird species during at least part of their life cycle (Rosenberg et al. 1991). The river forms a migratory corridor for birds moving between breeding and wintering areas, where these birds use riparian environments as stopover habitat to rest and refuel. At least 74 bird species use the area for breeding (GBBO 2018), 12 of which are targeted by the LCR MSCP because they are recognized under the Endangered Species Act as threatened or endangered, or else were determined by program scientists and other entities as species of concern[16], or sensitive[17], due to declining populations or loss of habitat based on information available at that time (LCR MSCP 2004). These 12 species are:
- Arizona Bell's Vireo (*Vireo bellii arizonae*),

- California Black Rail (*Laterallus jamaicensis coturniculus*),
- Elf Owl (*Micrathene whitneyi*),
- Gila Woodpecker (*Melanerpes uropygialis*),
- Gilded Flicker (*Colaptes chrysoides*),
- Least Bittern (*Ixobrychus exilis*),
- Sonoran Yellow Warbler (*Setophaga petechia sonorana*),
- Summer Tanager (*Piranga rubra*),
- Vermilion Flycatcher (*Pyrocephalus rubinus*),
- Yuma Ridgway's rail (*Rallus obsoletus yumanensis*),
- Western Yellow-billed Cuckoo (*Coccyzus americanus*), and
- Southwestern Willow Flycatcher (*Empidonax traillii extimus*).

In this case study, we focus on conservation efforts surrounding the sensitive landbirds Arizona Bell's Vireo, Gila Woodpecker, Gilded Flicker, Sonoran Yellow Warbler, Summer Tanager, and Vermilion Flycatcher.

Overview of Conservation Actions

All conservation actions come with different sets of opportunities, challenges, and limitations. The three basic forms of conservation action for this system are: 1) preservation, which involves protecting remaining functional riparian areas; 2) restoration, which involves improving existing riparian areas, so they can function better as wildlife habitat; and 3) creation, which is to create and maintain new patches of wildlife habitat. Most often, land managers decide which of these options to pursue on a given piece of land based on which lands are actually available for conservation action and what condition, in terms of habitat quality, they are in for the species targeted for conservation. Further, conservation practitioners are tasked with deciding a) how to spend a limited budget on different conservation opportunities available in a project area, and b) how to optimize their chances of a net benefit for wildlife across a landscape.

Habitat Preservation

In a few places along the Colorado River, patches of native riparian vegetation have survived and even thrived. Many of these patches are on protected land managed as riparian habitats by entities such as National

Wildlife Refuges, Tribes, state agencies, the Bureau of Reclamation, or state and county parks. Others, however, are still subject to commercial or agricultural development, or to degradation from a variety of factors. There are obvious benefits to protecting these places: it's usually the least expensive option for conservation action, and it prevents additional losses of wildlife habitat. These patches are typically characterized by high microhabitat[18] complexity. Different species might require decadent[19] trees and snags[20], large patches of riparian shrubs, marsh vegetation, or barren spots created by overbank flooding of the river. Microhabitat complexity is a critical concept in the conservation of riparian areas, because it allows for maximum species diversity.

Preservation may also be a good conservation strategy for some wildlife in areas with reduced microhabitat complexity, because such complexity may develop over time if a site is undisturbed. Preservation may sometimes be all that is needed to improve wildlife habitat quality, if certain land uses such as livestock grazing or off-road vehicle use are the primary source of habitat degradation. In addition, preservation may be used as a way to reserve the area for additional conservation actions in the future, such as restoration (see next section).

The main constraint on habitat preservation in this region is the limited amount of land that still functions optimally, or close to optimally, as riparian wildlife habitat; in other words, there is only so much land left to preserve. In other regions, preservation can also be accomplished through conservation easements in working landscapes, where agriculture, such as livestock production, can persist while minimizing livestock damage to the most sensitive wildlife habitats, and many examples of successful marriages of wildlife conservation in working landscapes exist (e.g., Charnley et al. 2014). Most historic riparian areas of the lower Colorado River, however, now consist of dry uplands that have minimal value to riparian wildlife, and landscapes on the former floodplain consist primarily of high-intensity agricultural fields. Remaining intact riparian stands (i.e., those that are dominated by wet soils and complex native vegetation) are relatively scarce and tend to be small in size (often less than 30 hectares). While even the smallest patch of native riparian vegetation is sufficient for some riparian bird species (such as the Western Kingbird and Black-chinned Hummingbird), larger patches tend to provide habitat to more species. For instance, a single pair of the threatened Western Yellow-billed Cuckoo requires patches of at least 20–40 hectares to breed (USFWS 2013). Larger preserved areas also generally have greater microhabitat complexity, since increasing microhabitat complexity requires increasingly large areas. Finally, another limitation on preserving high-quality habitat areas is that these areas are often located immediately adjacent to lakes, backwaters, or other reliable water sources, areas that are often the most valuable to developers, driving up the political and financial costs of protecting them.

An Example of Preservation Within the Lower Colorado River Region

There are four National Wildlife Refuges within the lower Colorado River region (Figure 4). Imperial National Wildlife Refuge is one example of habitat preservation on the lower Colorado River (Figure 5). While the riparian ecosystem of this site has been altered by human activity such as upstream dams and invasive species, the river bank in this 30-mile reach has not been rip-rapped. This means that water is free to flow into side channels and backwaters, supporting large stands of complex microhabitats. Among saltcedar stands, the refuge also includes healthy stands of cottonwood-willow, arrowweed[21] and mesquite-dominated desert washes, and extensive marshes. These stands support a high abundance and diversity of breeding and migrant birds, making it a success story of habitat preservation.

Habitat Restoration

Another possible conservation strategy is to restore riparian habitat in places where it is degraded, with the goal of improving its suitability for birds or other wildlife. Habitat restoration activities include managing water flows to simulate natural flow regimes, manually or chemically removing invasive species, and seeding or planting native vegetation. The costs of these interventions range from relatively inexpensive (e.g., hand-planting native trees by volunteers) to expensive (e.g., inundation with water through channel rest-oration).

Figure 5. Imperial National Wildlife Refuge. Photo credit: L. Harter.

Once restored, sites are usually preserved for long-term conservation, so restoration can ultimately have the same benefits as preservation of intact sites. In many cases, restoration is necessary to make a site valuable enough to be preserved for conservation, and it has the ultimate benefit of increasing the net area of habitat for many species that were previously not able to use the site.

Generally, restoration aims to achieve at least a simulation of the historic environments present at the site, even when it may take years for the newly restored conditions to take effect in terms of benefits for wildlife. Aside from trying to simulate historic ecosystem processes and conditions, restoration planners often adjust their project around the needs of a particular sensitive species. In these cases, it is important to begin a project with quantitative objectives and plans for how to measure success. Success is then measured with quantitative monitoring of bird populations or vegetation metrics[22] that describe habitat suitability for targeted birds, before and after restoration.

An Example of Restoration Within the Lower Colorado River Region: Managed Flooding

In a natural system, periodic flooding events are necessary for the seeding and growth of riparian plant species such as cottonwood and willow. Flooding scours areas where seeds of trees can sprout without competition and keeps the soils moist long enough for these seedlings to grow roots deep enough to reach the groundwater (Rood et al. 2003). Regular flooding also raises the groundwater table high enough to support the continued growth of healthy stands of trees (Molles et al. 1998, Merritt and Bateman 2012). Surface water also increases arthropod abundance, which is critical to the breeding success of many bird species (Gray 1993, Duguay et al. 2000, Iwata et al. 2003).

Considering the benefits to periodic flooding events, managers on the Colorado River actively manage for flooding, especially (and most effectively) in tributaries that are not rigidly managed for water delivery to meet human needs. For example, at Havasu National Wildlife Refuge, native willows are sprouting anew with additional water that is used to flood parts of the landscape. Also, when water is available, the US Army Corps of Engineers, in coordination with the Bill Williams River Corridor Steering Committee, strategically releases water from Alamo Dam upstream of the Bill Williams River National Wildlife Refuge timed to coincide with a natural flood cycle and the seeding of cottonwood and willow trees. This method has helped native trees to outcompete

Figure 6. Riparian forest on the Bill Williams River National Wildlife Refuge. Photo credit: A. Leist.

invasive saltcedar and maintain 58 kilometers of riparian forest, the largest stretch of mostly intact native riparian habitat along the lower Colorado River corridor (Figure 6; Shafroth and Beauchamp 2006). However, dams and river channelization permanently prevent flooding on much of the mainstem of the Colorado River and, thus, flood events have been all but eliminated along its lower reaches (Rosenberg et al. 1991), making this strategy of riparian habitat restoration, which is popular in other parts of the West, impractical along other parts of the lower Colorado River.

Habitat Creation

Habitat creation involves converting one landscape cover type into another, in such a way that continued human maintenance is required. Because many alterations to the Colorado River and its historic floodplain are permanent and irreversible, habitat creation can be used to mitigate for the loss of riparian areas elsewhere along the river. For example, as part of the LCR MSCP, over 1,800 hectares of different riparian habitat types[2] were created along the lower Colorado River as of 2015 (LCR MSCP 2016).

Habitat creation allows a site to be extensively redesigned and managed, from topography, water delivery, and other abiotic factors, to plant species composition.

Moreover, because habitat creation sites may be located well above the groundwater table and may not be subject to seasonal flooding, a long-term plan for irrigation is often necessary. Therefore, long-term maintenance needs to be planned, and its costs may far exceed those of habitat preservation or restoration projects. On the other hand, because habitat creation sites can be established on relatively inexpensive landscapes (such as former agricultural fields or desertified[23] floodplain areas), large swaths of land can be secured for habitat creation for a lower per-hectare cost. For example, over 500 hectares of the Palo Verde Ecological Reserve were planted between 2006 and 2013 for habitat creation (LCR MSCP 2015), and this site is large enough to support a population of the threatened Western Yellow-billed Cuckoo with 49 breeding territories confirmed in 2014 (Parametrix Inc. and Southern Sierra Research Station 2015).

An Example of Habitat Creation Within the Lower Colorado River Region

A recent habitat conservation area of the LCR MSCP, called the Laguna Division Conservation Area, pioneers a new habitat creation design that was derived from an adaptive management[24] approach (see sections below). Based on the lessons learned from earlier habitat creation sites comprised of row plantings of

native species, this newer approach attempts to provide additional microhabitat complexity, which some species may require. This large area (nearly 450 hectares!) was covered by dry upland saltcedar as recently as 2011, but is now being transformed into a patch-mosaic of native vegetation planted appropriately for the landscape contours, including transition zones of native vegetation that ties the riparian zone to the upland desert, mimicking naturally occurring riparian systems. An extensive marsh and open waterway, checked by artificial control structures that allow overbank flooding to mimic historic flood regimes, stretches through the area, flanked by cottonwood-willow patches of varying sizes surrounded by mesquite bosque[25] and other native upland cover types (LCR MSCP 2012). This area is still maturing, but very well may represent the latest improvement in maximizing a site's suitability for riparian birds through habitat creation.

The Job of a Conservation Practitioner

The job of a conservation practitioner requires integrating a complex set of issues into decision making in order to achieve conservation outcomes. When planning and managing a conservation project, the project manager must consider the biology and ecological needs of the targeted species, the ecological conditions and physical limitations of the site, the financial and political framework that overlays the project, and how to measure success, so that management is adapted based on new findings from effectiveness monitoring[26]. While daunting, it is also one of the most exciting and challenging careers for applying scientific knowledge to real-world problems.

Each of the three strategies described in this case study—habitat preservation, restoration, and creation—are chosen based on the project site's attributes and resources available for conservation action. It is the job of the conservation practitioner to determine which action is most likely to be successful in a given project. Ornithologists, such as those working for governmental agencies, bird observatories, or other non-profit conservation organizations, can provide scientific data on birds from monitoring. This allows conservation practitioners to evaluate how successful their conservation actions were after enough time

has passed for the ecosystem to respond (see below). These scientific data provide the basis for adaptive management, which allows conservation practitioners to refine their plans as needed based on results; for instance, to increase habitat suitability even further for the species targeted by the program.

On the lower Colorado River, conservation practitioners working under the LCR MSCP, have put into practice a number of conservation actions in order to preserve, restore, and create habitat for riparian birds and other wildlife dependent upon this ecosystem. Long-term bird monitoring in these areas is an example of how conservation projects can be evaluated in order to inform future projects and improve adaptive management decisions going forward.

Adaptive Management and Summary of Steps in Conservation Planning

All well-designed conservation strategies have an adaptive management plan, which takes advantage of data collected on earlier phases in the conservation project and new research. For instance, as part of their management program, the LCR MSCP conducted intensive research on the Elf Owl, Western Yellow-billed Cuckoo, and Southwestern Willow Flycatcher to learn more about each species and its habitats. The results of this research were then used to improve habitat creation designs and management, and to determine the most effective methods for species monitoring. Early phases of conservation action are monitored quantitatively in terms of achieving initial goals (e.g., particular plant densities and vigor) and in terms of target species colonization (e.g., number of Willow Flycatcher territories after conservation action compared to before). Research on what environmental factors allow a bird to nest successfully in a given habitat patch and what methods will allow researchers to quantify its occupancy and abundance in different sites are critical to achieving conservation success in the long term.

The key to successful adaptive management is the use of quantifiable data collected to determine effectiveness of particular strategies, for example, what age-class distribution of trees is most suitable for nesting of a bird species, or how far from saturated soils we

can expect a particular bird species to nest. As these habitat suitability criteria become known in greater detail and in a quantifiable way, adaptive management allows a conservation program to become more and more biologically- and cost-effective over time. But, the continual refinement of adaptive management requires ongoing monitoring to capture and incorporate new information from the dynamic and changing system. In summary, Figure 7 displays the basic steps in habitat conservation planning for bird species in the lower Colorado River.

1 Identify conservation needs: Which species need conservation action most? What are their habitats?

2 Identify lands that are available for conservation action and assess their current condition in terms of habitat integrity, hydrology, and future availability of water.

3 Determine the most biologically- and cost-effective strategy for conservation (preservation, restoration, creation of habitat).

4 Secure funding, stakeholders and partners, and required permits for conservation action.

Habitat Conservation Planning Steps

9 Use research results and lessons learned during project implementation to refine conservation action in future phases of project implementation to further optimize effectiveness.

5 Set quantitative objectives for conservation action, i.e., number of hectares preserved/restored/created, or number of birds, or breeding territories.

8 Monitor effects of conservation action to measure success, and conduct research on target species, to inform adaptive management.

7 Implement conservation action in project phases to allow for refinements in implementation.

6 Conduct surveys to establish a baseline against which success can be measured, ideally paired with appropriate control areas that can be used to measure net effects of conservation actions.

Figure 7. Habitat conservation planning steps for bird species in the lower Colorado River.

LONG-TERM BIRD MONITORING IN CONSERVATION

With millions of dollars being spent on conservation actions along the river, it is essential to document whether or not these programs are effective in meeting their goals and quantitative objectives. Monitoring serves the function of evaluating the initial "best shot" implementation plan and then continues to provide real time feedback on the effectiveness of specific conservation actions. As part of this, it is also important to monitor control sites where no conservation actions have been taken, in order to account for regional population dynamics that are independent of local conservation programs when evaluating their effectiveness.

The avifauna of the Colorado River was documented in the scientific literature during the 1860s by various explorers (e.g., Coues 1878); however, the first semi-comprehensive inventory did not take place until 1910, with Joseph Grinnell's Colorado River expedition. The Colorado River was still in a relatively undisturbed state then, prior to most dam construction (Grinnell 1914). Grinnell floated the river from Needles, California to Yuma, Arizona, and reported abundant sightings of riparian and wetland birds such as Bell's Vireo, Yellow Warbler, Vermilion Flycatcher, Yellow-breasted Chat, and Summer Tanager. This section of river was not surveyed again extensively for bird species until the mid-1970s, when researchers from Arizona State University found that the species that had experienced the most dramatic changes since Grinnell's time were those that depend on cottonwood-willow forests (Anderson and Ohmart 1984; summarized in Rosenberg et al. 1991). Species such as the Willow Flycatcher, Bell's Vireo, Summer Tanager, and Yellow Warbler had all but disappeared in many places, particularly where native vegetation was lost or replaced by saltcedar (but see Box 1).

Today, birds are often used as a tool for measuring ecosystem response to conservation action because: 1) they are comparatively easy to monitor and bird monitoring techniques are already well-studied (e.g., Sutherland et al. 2004); 2) they are considered excellent indicators of overall environmental health because, as a community, they rely on a large variety of ecosystem features and services (e.g., Wiens 1989); and 3) they are often conservation targets themselves due to population declines (Rosenberg et al. 2016). Because birding is among the most popular outdoor activities in the United States (USDA 2002), bird monitoring also provides an excellent opportunity for the public to participate as citizen scientists in collecting bird population data (Dickinson et al. 2012, Tulloch et al. 2013).

*Figure 8. Costa's Hummingbird (*Calypte costae*) recorded during surveys. Photo credit: D. Fletcher.*

Box 1: The Yellow Warbler: A Story of Resilience

*Figure 9. Yellow warbler (*Setophaga petechia*), a species that has recovered on the lower Colorado River in recent years. Photo credit: A. Leist.*

Of all the songbirds nesting in riparian areas along the lower Colorado River, Yellow Warblers experienced the most dramatic changes in population densities. In the early 1900s, Grinnell found Yellow Warblers to be abundant and estimated that approximately four males occupied every 0.4 ha of cottonwood-willow habitat in some areas (Grinnell 1914). By the late 1970s, however, only one single successful breeding attempt was documented, and only a handful of singing male Yellow Warblers were found throughout the study area from Davis Dam in southern Nevada to the Mexican border (Rosenberg et al. 1991).

It is unclear why Yellow Warblers declined so sharply while other riparian species with similar habitat requirements declined less. Most notably, these birds disappeared even from large tracts of continually intact forest along a tributary of the Colorado River, the Bill Williams River. In addition to the loss of cottonwood and willow habitats elsewhere, Yellow Warbler populations also likely experienced increased brood parasitism from Brown-headed Cowbirds, which increased regionally with the expansion of agricultural lands. Perhaps the invasion of saltcedar was the last straw for already fragile populations of Yellow Warblers. Even within relatively intact riparian forests, saltcedar was able to get a foothold and filled in gaps in the canopy and the understory layer.

Since the 1970s, Yellow Warblers have rebounded significantly; current population estimates are around 1,786 pairs for the Great Basin Bird Observatory study area. This species has returned to areas it historically occupied, and even uses breeding sites with a significant saltcedar component if there are moist soils and at least a few native trees. This rebound in numbers since the 1970s, and prior to widespread conservation action, may be an indication of the species' capacity for adaptation to habitats dominated by a newly introduced tree species.

Population monitoring takes time. Conservation practitioners need to be aware of both the length of time it takes for the conservation action to take effect (e.g., maturation of vegetation) and the time it takes for species to be able to respond. For instance, a freshly excavated wetland may only take one or two years to be colonized by invertebrates and marsh vegetation that provide habitat for wildlife; riparian woodlands, however, may take up to 15 years to mature. Some species also take time to colonize the site even after it becomes suitable. Therefore, the definition of long-term monitoring varies greatly depending on the project and the organisms involved. Strayer et al. (1986) define a study as long-term if it continues at least as long as one generation time as the longest lived organism within the study system or at least "long enough to include examples of the important processes that structure the ecosystem under study."

In the case of bird conservation on the Colorado River, the breeding cycles of most riparian songbirds are roughly annual so birds may respond to changes in available habitat within the course of a few years. Planted trees, however, require years to mature, thin out, intermix, recruit, and become decadent—all important factors in creating microhabitat complexity. Therefore, a tree planting project may attract far fewer breeding birds after two years than it would after 30 years of growth.

To account for this factor, the LCR MSCP is designed as a 50-year program.

Status of Riparian Birds of the Lower Colorado River

Beginning in 2007, the Great Basin Bird Observatory (GBBO) was contracted by the US Bureau of Reclamation to conduct surveys along the entire lower Colorado River. The purpose of this initial study was to estimate population densities and develop a program to monitor long-term population trends for riparian-obligate birds. Though all species present were recorded on datasheets, emphasis was placed on six species covered by the LCR MSCP: the Arizona Bell's Vireo, Sonoran Yellow Warbler, Summer Tanager, Vermilion Flycatcher, Gilded Flicker, and Gila Woodpecker. These were among the species that had experienced the most dramatic declines between the time of Grinnell's surveys and the mid-1970–80s.

Methods of the Monitoring Study

Between 2007 and 2015, GBBO monitored lower Colorado River riparian birds annually in both conservation areas undergoing habitat preservation, restoration, or creation, as well as in random plots throughout the lower Colorado River that can serve as control sites (Figure 10). The plots were also classified by vegetation type and, in the case of conservation sites, by amount of time since conservation action was taken. This information helps conservation planners to determine which vegetation types support which species and how long it takes those species to colonize sites after successful conservation action. Using these monitoring data, it is possible to estimate territory density for breeding birds in conservation sites and control sites throughout the project area by habitat type as a metric for bird population responses to conservation action.

Results of the Monitoring Study

The data collected since 2007 show dramatic increases in several bird species along the lower Colorado River since the 1970s, even when taking into account that different monitoring methods were used in different decades (Table 1). For example, the Yellow Warbler and Bell's Vireo, which were almost absent during the 1970s, had already begun to return to many places along the river prior to conservation action from the LCR MSCP. These rebounds can be attributed to many factors, as illustrated in Box 1. Other species appear to have

Figure 10. Trail clearing and data collection by GBBO staff. Photo credits: A. Arcidiacono, left; A. Leist, right.
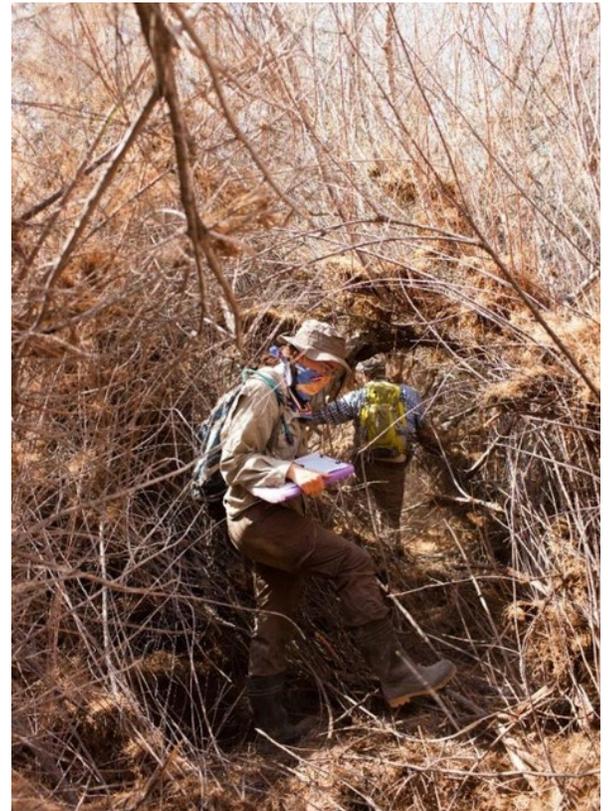
Figure 11. Cactus Wren (Campylorhynchus brunneicapillus) with nesting material. Photo credit: A. Leist.

Figure 12. Gila Woodpecker (Melanerpes uropygialis), a species covered under the LCR MSCP. Photo credit: A. Leist.

approximately the same population levels today as in the 1970s—for example the Gila Woodpecker, which relies on trees big enough for excavating nesting cavities. Still other species that were present in the 1970s have now dropped to near zero. These include the Gilded Flicker, which was historically common in parts of the study area and is now nearly extirpated[12] in riparian habitats in the region. It is unclear why some species are resilient to major environmental change, while others are not, and only continued conservation research can illuminate possible underlying causes.

Many of the LCR MSCP target species are now using newly restored and created riparian habitat, as found in recent surveys of conservation areas (Table 1). Habitat creation sites have provided several species, including the Sonoran Yellow Warbler, Summer Tanager, Arizona Bell's Vireo, and Vermilion Flycatcher, with new habitat hectares that would otherwise have been unsuitable. Many species, however, still occur in lower numbers in habitat creation than in habitat preservation sites, while other species are still absent. Long-term monitoring is needed to determine what can be done to further improve habitat suitability, whether conservation actions simply need more time to become effective, or whether other factors not related to habitat needs may

prevent the species from establishing territories in these areas.

Adaptive Management in Practice

The results of monitoring have contributed to adaptive management. For instance, starting in 2005, some of the first habitat creation sites were planted using the most cost-effective and efficient methods to achieve what was then known to be basic habitat requirements of the species covered by the program. This involved row plantings of one or two native species of trees (such as cottonwood, willow, mesquite, and Baccharis[27]) resulting in evenly spaced and evenly aged stands, which was easiest to implement and irrigate, while also having the advantage of shading out invasive species such as saltcedar. Even though this approach was effective in attracting some riparian bird species (e.g., Western Yellow-billed Cuckoo, Blue Grosbeak, Western Kingbird), other riparian bird species have not yet colonized these created patches.

Habitat models derived from monitoring data later indicated that refining the plantings would improve habitat quality. This finding resulted in new techniques for habitat creation and habitat management that result

CASE STUDY

Table 1. Historic and current population size estimates (by mated pair) for target species throughout the study area. Note that survey methods differed among studies, thus only major shifts in abundance are meaningful. Photo credits: A. Leist- Arizona Bell's Vireo, Gila Woodpecker, Sonoran Yellow Warbler, and Gilded Flicker and A. Arcidiacono- Vermilion Flycatcher.

SPECIES	GRINNELL (1910)	BIRDS OF THE LOWER COLORADO RIVER VALLEY (1974–1984)	CURRENT RESEARCH (POPULATION SIZE ESTIMATE 2011–2015)
Arizona Bell's Vireo	Abundant	57% population decline during the period covered (100 pairs and declining)	Rebounding; 1,365 pairs estimated to be present
Gila Woodpecker	Common and widespread	500 pairs estimated to be present in study area	Apparently stable; 573 pairs estimated to be present
Sonoran Yellow Warbler	Numerous in cottonwood-willow	Considered to be almost extirpated from the Lower Colorado River Valley	Rebounding; 1,786 pairs estimated to be present
Gilded Flicker	Common where saguaros[28] present	Fairly common in saguaros along the Bill Williams River, but rare elsewhere	Further declines; 22 pairs estimated to be present, only recorded nesting along the upper Bill Williams River
Summer Tanager	Characteristic species of cottonwood-willow	Considered rare to uncommon; 69 pairs estimated to be present	Possibly rebounding; 262 pairs estimated to be present
Vermilion Flycatcher	Numerous from Ehrenberg to Yuma	Drastically reduced; < 10 pairs found in the lower Colorado River Valley	Possibly rebounding; Very local, and very few in native vegetation; 112 individuals estimated to be present

in a "messier" and more complex mosaic of riparian tree plantings with mixed sizes and species composition, which studies have shown to be associated with higher bird diversity through resource partitioning than more uniform tree stands (e.g., Wiens 1989).

These considerations have informed the planting approaches used in newly created habitat sites, such as the Laguna Division Conservation Area, though monitoring will need to continue in order to evaluate the success of these "messy" habitats. It will take time for the woodland stands to mature and better reflect the habitat where targeted species naturally occur. For example, cavity-nesting species, such as the Gila Woodpecker and Elf Owl, rely on snags that occur in senescent[29] tree stands, and they are therefore expected to be among the last species that will be found nesting in created habitat on the lower Colorado River. Additionally, the system is dynamic in other ways (e.g., changing water demands and availability, climate change) and continued monitoring can help identify and address changing conditions.

Future Directions in Bird Conservation Science

Large conservation programs such as the LCR MSCP will always depend on government programs, often with many stakeholders who share both program costs and regional conservation benefits. Much like municipal and county planners seek to provide sufficient water and land for their residents, resource management agencies seek to secure and sustain natural resources including birds and bird habitats, particularly in the West, where public lands are abundant. To make conservation programs as effective as possible, government agencies and their partners focus much of their applied research effort on monitoring programs such as the one outlined here. Many times, birds and their habitats become rare before their conservation needs are fully understood, and large-scale monitoring that is paired with applied research often fills major knowledge gaps in our understanding of bird conservation.

Because of the complexity of conservation programs, as well as the ecosystems and species targeted by them, professional scientists and experienced conservation planners are needed to provide the best conservation

strategies and actions for these programs. However, much has changed in recent years that opens up the possibilities of exciting and cost-efficient ways to empower programs with more and better data than was previously possible. For instance, many monitoring and conservation planning efforts now rely on drones that collect high-resolution geo-referenced photography of conservation sites or biological hotspots (Zahawi et al. 2015). Also, methods continually improve for surveyors to collect spatially explicit data by entering these directly on a tablet or smartphone into a geodatabase while surveying in the field.

Because of these technological advances, more opportunities have also opened up for citizen scientists to get involved in collecting critical data for advancing bird conservation science by recording bird observations, often through smartphones, into global databases that can be accessed and used by the public and researchers alike. The data collected have already been used in many important aspects of bird conservation including identifying the impacts of habitat loss, pollution, diseases, and climate change on bird populations; determining bird migration paths; documenting long-term changes in the numbers of bird species; identifying geographic variation in bird behavior; generating management guidelines for birds; identifying habitats that should be conserved; and advocating for the protection of declining species (Sullivan et al. 2017).

GLOSSARY

1. **Long-term monitoring** refers to standardized measurements of ecological metrics that allow us to determine population level responses of organisms to environmental change over an extended period of time.
2. **Habitat** refers to a species' required physical and biological environment. It can be measured through physical environmental variables, such as humidity, soil type, elevation, ambient temperature, average snowfall and rain, and many others, as well as vegetation, predators, food resources, and competitors present in the areas occupied by the species. Low-quality and high-quality habitat are often distinguished by land managers to identify areas that are associated

with low productivity and survivorship of the species with those associated with high population performance. **Habitat type** is a term often used by wildlife managers to describe the basic land cover (or vegetation) type in which the species can be expected to be found. The term **riparian habitat** has become standard usage by wildlife managers to describe the idealized environment for a group of wildlife species, such as those that require a riparian setting or other easily classified habitat type.

3. **Anthropogenic** describes the influence of humans on nature.

4. **Floodplains** are the areas within a river valley that may become inundated during flood events.

5. **Willow**: *Salix gooddingii* (Goodding's willow). large, dominant tree found in southwestern riparian forests. *Salix exigua* (coyote, or sandbar, willow): understory to midstory, shrubby tree often growing in dense stands in southwestern riparian forests.

6. **Cottonwood**: *Populus fremontii.* Large, dominant tree found in southwestern riparian forests.

7. **Water table** is the level of underground water, which in riparian and wetland areas is usually a function of the river and associated water bodies.

8. **Riparian** refers to vegetation types (or wildlife associated with that vegetation) and physical environments that are directly dependent on the conditions provided by a stream or river, including their high water tables and floodplain areas.

9. **Riparian-obligate** are organisms that occur exclusively in riparian ecosystems.

10. **Rip-rap** is material used to permanently stabilize a river channel, usually rock or concrete blocks.

11. **Saltcedar**: *Tamarix* spp. Non-native, invasive tree often dominating degraded riparian areas in the Southwest.

12. **Endangered** species are listed by a federal or state agency as being in danger of extinction or **extirpation** (local extinction).

13. **Threatened** species are listed by federal or state agencies as being vulnerable to endangerment in the near future based on population trends and/or habitat disturbances.

14. **Mesquite**: *Prosopis glandulosa/pubescens.* Native, common tree often associated with more xeric edges of riparian corridors in the Southwest. Dense, spreading growth form.

15. **Backwaters** are ponding water in still areas of a stream or river, which provide important habitat for sensitive life stages of various aquatic and terrestrial animals.

16. **Species of concern** are those species listed by various federal or state agencies or groups as being of conservation concern. These are not necessarily in danger of extinction or local extinction, but may have negative population trends or be rare and/or very locally distributed.

17. **Sensitive species** may be rare, locally distributed, and/or dependent upon a specific habitat type and thus are considered sensitive to anthropogenic influences and development.

18. **Microhabitat** describes the immediate physical and biological environment of a species' life stage (measured at a finer geographic scale than a species' overall habitat requirements, see #2).

19. **Decadent** refers to senescent (see #29) plants, often featuring dead branches and dying wood.

20. **Snag** refers to a dead standing tree, which provides important nesting opportunities for cavity-nesting wildlife.

21. **Arrowweed**: *Pluchea sericea.* Understory shrub, native and common in southwestern riparian areas. Occurs as an early successional plant, often dominating disturbed areas.

22. **Metric** is defined as a standard of measurement. For instance, one may use as a metric for breeding bird abundance the number of breeding territories (as opposed to the number of individual birds) to most accurately describe breeding bird response to conservation action in breeding habitat.

23. **Desertified** areas are those that have become more arid than they previously were.

24. **Adaptive management** is a structured, iterative process of robust decision making in conservation and land management in the face of uncertainty, aiming to reduce this uncertainty over time via system monitoring.

25. **Bosque** is a deciduous woodland associated with streams, rivers, or other sources of near-surface water tables. Sometimes used synonymously with riparian gallery forest.

26. **Effectiveness monitoring** is a specific type of monitoring in which an area is monitored following

a conservation action with the particular goal of assessing the effectiveness of that conservation action.

27. **Baccharis**: *Baccharis salicifolia/salicina/sarothroides.* Understory shrub found in southwestern riparian areas, often associated with wetlands and cottonwood-willow forest associations in riparian areas.

28. **Saguaro**: *Carnegiea gigantea.* Tall, columnar cactus with a single trunk and several arms, similar to a tree.

29. **Senescent** here refers to plants that are growing old or aging.

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Bird Conservation Along the Lower Colorado River: Exploring a Complex Conservation Scenario Through Four Exercises

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EXERCISE 1: FACTORS AFFECTING RIPARIAN BIRDS AND BIRD HABITATS ALONG THE COLORADO RIVER

In this exercise, you will reflect on the *Bird Conservation Along the Colorado River* case study and consider some of the diverse anthropogenic and environmental factors that affect bird habitat and populations. You will organize information and connections presented in the case study through concept mapping. Concept maps consist of ideas, terms, or contributing factors arranged around a page/white board/computer screen, with lines or arrows to illustrate linkages. These maps help synthesize ideas, identify cause and effect, and encourage deep understanding of the material.[i] Refer to the example concept map below (Figure 1) to help you in the exercise. (Note: there is not a single correct way to structure concept map; there are multiple ways to depict relationships among the factors that affect bird habitat and populations.)

Step 1

In small groups of 2–3, list factors discussed in the case study that have affected riparian birds and habitats in the past and present, both negatively and positively. Then, create a concept map on this theme. You can create this using pencil and paper, or using concept mapping software.[ii] You should build a map that helps you answer this question: "what factors have affected and affect the status of bird habitat?" The concept map should note linkages, show hypothesized cause and effect relationships, and ultimately include effects on bird populations.

Step 2

Take the concept map a step further by considering what factors might affect birds in the future, and how those factors fit into your current concept map. For example, intensifying climate change, human demography, invasive species, or politics. If using paper and markers, this can be done in a different color.

Step 3

Your instructor will put two concepts on the board: bird habitat and bird populations. Each group will choose a volunteer to add one or more factors and appropriate linkages to the board. As a class, work together to complete the concept map.

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[i] For more information on concept maps and resources and tools see BYU Center for Teaching and Learning's webpage: https://ctl.byu.edu/tip/concept-mapping.
[ii] See Wikipedia (https://en.wikipedia.org/wiki/List_of_concept-_and_mind-mapping_software) for a description of several options.

Step 4 (Optional)

After your class-wide map has been created, your instructor may decide to hold a short "poster session", where you'll circulate silently to review the maps generated by each group. If maps were created with software, images can be shared via the course website, discussion forum, or via projector.
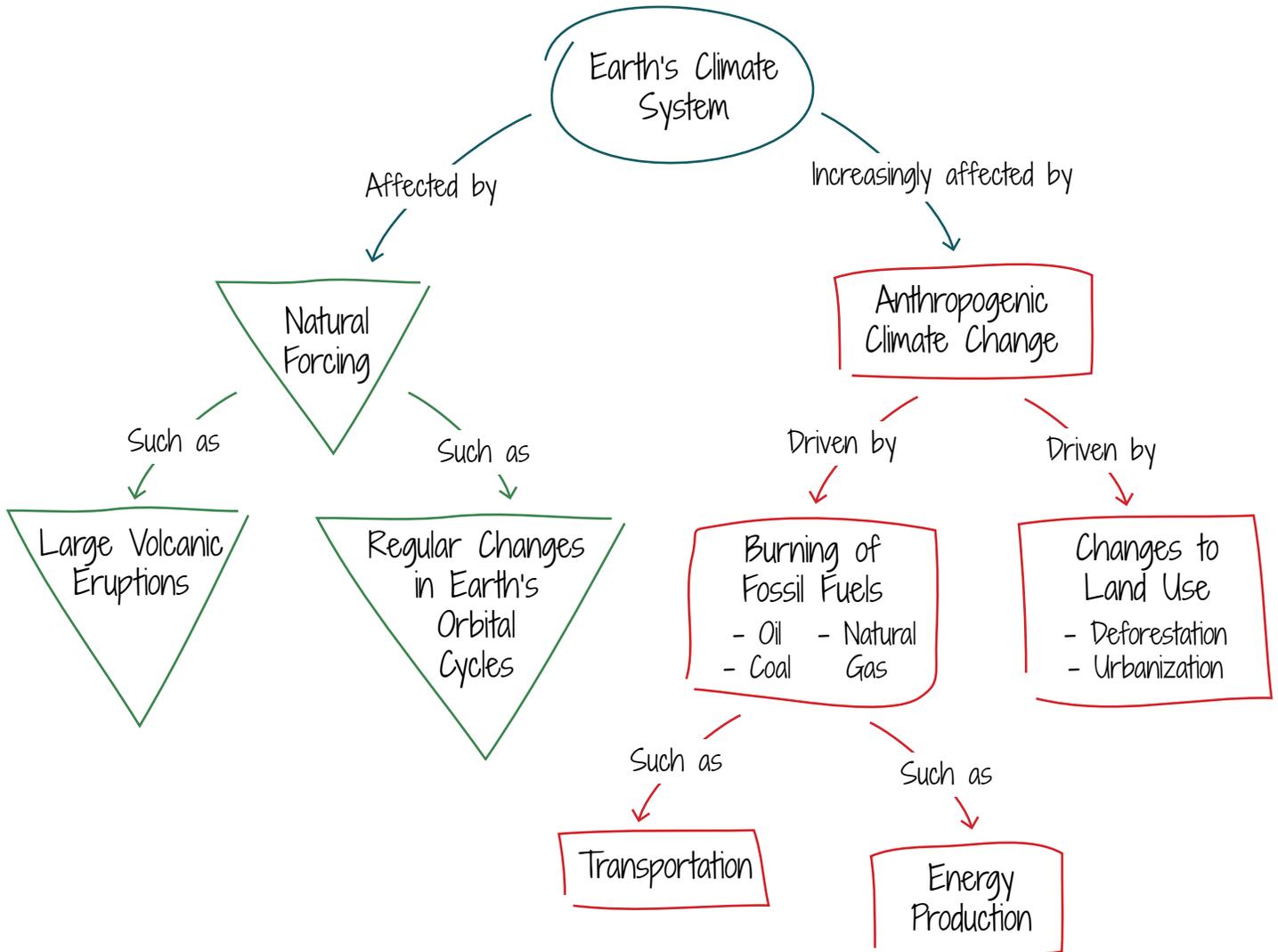
Figure 1. Example of a concept map. In this concept map, Earth's climate system is the central concept and factors that affect the system are drawn with examples and labels on the arrows. Note there are varying ways these maps can be drawn and visualized.

EXERCISE 2: CONSERVATION ACTIONS

As you've learned from the case study, conservation actions come with different sets of opportunities, challenges, and limitations. Most often, land managers decide which conservation action (in this case preservation, restoration, or creation) to pursue based on which lands are available and what condition, in terms of habitat quality, they are in for the species targeted for conservation. Further, conservation practitioners need to take into consideration issues of limited budgets and time commitments to projects weighing how best to optimize their chances of a net benefit for wildlife across a landscape.

Step 1

Using the template provided, list the advantages and disadvantages of the three primary categories of conservation actions discussed in this case study.

CONSERVATION ACTION	ADVANTAGES	DISADVANTAGES
Preservation		
Restoration		
Creation		

Step 2

Based on your understanding of the case study, explain in your own words why long-term monitoring is important in regards to these conservation actions.

EXERCISE 3: APPLYING DATA TO MANAGEMENT DECISIONS

Introduction

Wildlife managers are faced with many decisions when choosing the best conservation action for their system. Often there is not a clear right or wrong answer, as each decision comes with benefits and drawbacks. In real life, determining the best course of action requires careful consideration of a wide variety of factors, including: evaluating which species, ecosystems, or landscapes should be targeted and why; the biological effectiveness of conservation actions; any social impacts; as well as the logistics of implementation, including financial, legal, and political considerations.

To estimate the biological effectiveness (or the realistic, expected benefits) of conservation actions to riparian birds, long-term monitoring data are extremely useful. With these data, managers can 1) objectively measure the effects of the action over time, as discussed in the case study, and 2) compare and contrast different conservation benefits for different species. Here, we provide you with real bird-monitoring data from the lower Colorado River to demonstrate how you can estimate benefits from different conservation actions on native riparian birds.

In this exercise, you will play the part of a professional wildlife manager facing the choice of which conservation action to take: habitat preservation, restoration, or creation. The options provided for this exercises are only hypothetical examples of potential conservation actions. In reality, land managers face a large number of options for conservation plans. For the sake of expediency, you will focus on the question of biological effectiveness in consideration of financial constraints, but many factors could influence your decision.

Directions

Step 1. Consider the cost of each conservation action

With a $500,000 grant, you are able to implement one of three conservation actions. Use what you have learned in the case study and data from the table provided below to choose one optimized conservation plan. Be

prepared to describe your conservation plan and defend your choice to the class (see below for a complete set of instructions).

1. *Habitat Preservation*
   Identify and protect existing, high-quality riparian habitat.
2. *Habitat Restoration*
   Purchase low-quality riparian habitat and improve this area by planting with native species and restoring flooding dynamics.
3. *Habitat Creation*
   Create new riparian habitat on agricultural land.

Potential Conservation Actions

Habitat Preservation
You have identified high-quality habitat for protection on the Bill Williams River, and in this case, it happens to be available to purchase. Because this habitat includes valuable commodities such as river access, surface water, and native forest, it is fairly expensive. Although it is not under immediate threat of development, it might be in the future. With your grant, you may decide how to allocate your funds between two habitat types: forest (tall woody habitat) for $7,000/hectare, and shrubland (low woody habitat) for $5,000/hectare. Forest is limited in this area, and a maximum of 35 hectares is available for purchase. Shrubland is unlimited. The site will be protected and water rights secured as long as you own it, and no further action is required.

Habitat Restoration
With the funding available, you would be able to acquire 140 hectares directly adjacent to the lower Colorado River. The habitat is currently low-quality and dominated by dry saltcedar. Your cost for the restoration project includes two years of planting cottonwood, willow, and baccharis plants and building infrastructure for flooding to promote native-habitat growth and a diverse avifauna on the property. After two years, your land will include 25 hectares of forest (tall woody habitat) and 115 hectares of shrubland (low woody habitat). Maintaining

this site will require a small amount of work beyond this two-year window, with management of water levels and maintenance of water flow infrastructure. These future costs are not included in the initial budget, therefore consider that you will need to apply for additional funding in the future to maintain this site for perpetuity.

Habitat Creation
Your budget for this project could cover the purchase of a block of 160 hectares of agricultural land (currently very low-quality habitat for breeding birds) including water rights and watering infrastructure. Also included in this budget are three years of plantings with native trees, shrubs, and other plants. Because you have much more control over created habitats than other types of conservation actions, you can distribute the area however you wish among three habitat types: cottonwood-willow, mesquite, and mixed. All three vegetation types require the same initial investment, so there are no restrictions in planting. However, consider that mesquite requires less water to maintain in the future. The created habitat is above the floodplain and will require continued maintenance and flooding to persist. These costs are not included in the initial budget, therefore consider that you will need to apply for additional funding in the future to maintain this site for perpetuity.

Step 2. Consider the species you are trying to protect

As a project manager, you have to justify your decision on what conservation action you plan to implement. Stakeholders, funders, and regulatory agencies need to be convinced that this is the best use of precious resources. Therefore, for this exercise, we ask you to calculate the benefits of your actions to your target species. The data in the table included below are derived from actual survey data obtained by the Great Basin Bird Observatory and other groups performing long-term monitoring on the Colorado River. You can use these to estimate how many territories you will preserve or create through your conservation action.

Questions to consider when choosing a species-oriented conservation action:

1. Which species do you want to target with this conservation action, and why?

2. Will this conservation action also more broadly improve the diversity of riparian bird species in the area, and if so how?
3. What is the longevity of this project? Will you be able to maintain this area into the future?
4. What will this conservation action not allow you to do on your site?

Step 3. Calculations

Use the Table 1 to calculate the species diversity and total number of bird territories that can be supported with your conservation action and different habitat types. Use these calculations to justify your decisions about how you will carry out your conservation plan. Because there are many possible outcomes depending on which conservation action you choose, and how much of each habitat type you plan to buy/plant, you don't need to perform each possible calculation to determine your conservation action. However, you should consider multiple potential choices (at least five) to strengthen your argument for your chosen action.

1. Calculate the total number of bird pair (breeding) territories by multiplying the territories/hectare by the number of hectares you will provide with your conservation action within that habitat type. *Read all below steps first to ensure you calculate correctly.*
2. *For the habitat preservation option*, use Region 7 (the Bill Williams River). Note that numbers of each species are different for tall woody and low woody habitat types, both of which may be present in your conservation area.
For the habitat restoration option, use Region 11 (areas along the Colorado River near Imperial National Wildlife Refuge). Note that numbers of each species are different for tall woody and low woody habitat types, both of which will be present in your conservation area.
For the habitat creation option, use habitat creation data. Note that numbers of each species are different for cottonwood-willow, mesquite, and mixed habitats; it is up to you to decide how much of each habitat type to include in your conservation area, and which makes the most sense given your target species.

3. Because birds require a certain amount of space to breed, they will only use a patch of habitat if it is large enough for an entire territory. Therefore, when calculating number of territories, you must round *down*. For example, 1.3 Yellow Warbler territories gives you a total of 1 territory (2 birds). A calculation of 0.8 Summer Tanager territories gives you a total of 0 territories (0 birds). If you want more territories, you need to dedicate more hectares to that habitat.

4. However, you need to consider all habitats within your conservation area together to calculate total number of territories. Thus, if you have 0.3 Black-tailed Gnatcatcher territories in tall woody and 1.8 Black-tailed Gnatcatcher territories in low woody, you can add these together to get 2.1 territories, and round down to a total of 2 territories.

5. Note: Yellow-billed Cuckoos require a large patch size of at least 20 hectares to begin establishing territories. Any patch of suitable forest habitat smaller than 20 hectares will not support Yellow-billed Cuckoos for the purpose of this exercise. (Note that other species may require larger patch sizes than their territory sizes as well, but this is particularly evident with the Yellow-billed Cuckoo.)

Step 4. Defend your Decision

In at least 200 words, explain the following:
- Which conservation option did you choose and why?
- Which species did you select as target species and why?
- Include at least five alternative options that you considered for your conservation plan, with calculations to indicate why that option wasn't chosen.
- What is the expected longevity of your conservation action?
- Downsides to your conservation plan; what you will not achieve?
- Include your calculations of number of hectares of each habitat and total cost, and numbers of territories (for a pair of birds) of each species.

Step 5. Present your Decision

Following the exercise, each group will briefly present their conservation project plan (about 5 minutes each), describe the highlights, and explain why they made this decision. Your instructor then may facilitate a discussion based on the your experience.

Key for Table 1

Region 7	Bill Williams River (intact riparian)
Region 11	Mainstem section of the Colorado River (degraded riparian)
TW	Tall woody habitat type
LW	Low woody habitat type
HC	Habitat creation sites
CW	Cottonwood-willow habitat type
SCC	Species of Conservation Concern in the United States

Federally Threatened is a US Fish and Wildlife Service designation of a species that is likely to become endangered within the foreseeable future throughout all or significant portions of its range.

State Endangered although not recognized as endangered throughout the species' range by the federal government (i.e., Federally Endangered), the species is considered to be in danger of extinction within that particular state.

Species of Special Concern (SSC) or *Species of Greatest Conservation Need (SGCN)* is any species that does not meet the criteria of an endangered or threatened under federal standards, but is particularly vulnerable, and could easily become an endangered, threatened, or extirpated species in that region due to restricted distribution, low or declining numbers, or specialized habitat.

No Status means the species is not of conservation concern.

Table 1. Bird species in the Lower Colorado River, their habitat requirements for a pair of birds (in territory per hectare) and conservation status. See Key for Table 1 for more information.

SPECIES (TERRITORIES/ HECTARE)	PRESERVATION		RESTORATION		CREATION			CONSERVATION STATUS
	REGION 7 TW	REGION 7 LW	REGION 11 TW	REGION 11 LW	HC CW	HC MESQUITE	HC MIXED	
Western Yellow-billed Cuckoo[1]	0.01	0.00	0.00	0.00	0.09	0.00	0.00	Federally Threatened
Arizona Bell's Vireo	0.14	0.11	0.00	0.03	0.03	0.00	0.05	SCC, State Endangered (California)
Gila Woodpecker	0.04	0.08	0.01	0.01	0.00	0.00	0.00	State Endangered (California), SCC
Lucy's Warbler	0.39	1.59	0.00	0.00	0.04	0.15	0.04	SCC, California SSC
Sonoran Yellow Warbler	0.65	0.78	0.05	0.00	0.04	0.00	0.01	Regional SCC, California SSC
Summer Tanager	0.04	0.10	0.00	0.00	0.01	0.00	0.00	California SSC
Yellow-breasted Chat	1.12	1.27	0.09	0.49	0.06	0.02	0.11	California SSC
Crissal Thrasher	0.01	0.03	0.00	0.00	0.02	0.03	0.03	California SSC
Abert's Towhee	0.15	0.37	0.04	0.12	0.25	0.35	0.33	Arizona SGCN
Common Yellowthroat	0.54	1.49	0.48	3.05	0.19	0.15	0.45	No status
Song Sparrow	1.51	2.66	0.41	2.12	0.06	0.06	0.29	No status
Black-tailed Gnatcatcher	0.05	0.26	0.05	0.42	0.07	0.33	0.13	No status
Verdin	0.18	0.41	0.07	0.46	0.15	0.49	0.41	No status
Marsh Wren	0.00	0.00	0.20	0.40	0.00	0.00	0.00	No status
Bewick's Wren	0.61	0.91	0.00	0.00	0.00	0.00	0.00	No status
Black-chinned Hummingbird	0.06	0.26	0.04	0.10	0.12	0.05	0.07	No status
Anna's Hummingbird	0.00	0.00	0.01	0.07	0.06	0.06	0.08	No status
Ash-throated Flycatcher	0.04	0.15	0.02	0.03	0.02	0.03	0.04	No status
Blue Grosbeak	0.03	0.05	0.00	0.00	0.22	0.11	0.25	No status
Bullock's Oriole	0.01	0.00	0.01	0.00	0.11	0.02	0.10	No status
Western Kingbird	0.00	0.00	0.00	0.01	0.07	0.02	0.04	No status
Ladder-backed Woodpecker	0.10	0.11	0.03	0.07	0.12	0.04	0.10	No status

[1] From Parametrix, Inc., and Southern Sierra Research Station. 2015. Yellow-billed Cuckoo Surveys and Population Monitoring on the Lower Colorado River and Tributaries, 2014 Annual Report. Submitted to the Bureau of Reclamation, Boulder City, Nevada. Prepared by S.E. McNeil and D. Tracy, Southern Sierra Research Station, Weldon, CA; and J. Lisignoli and T. Hurt, Parametrix, Inc., Albuquerque, NM. March 2015. All other data from the Great Bird Basin Observatory (GBBO), unpublished data.

EXERCISE 4: BEYOND THE CASE STUDY: CONTRIBUTE TO LONG-TERM MONITORING THROUGH CITIZEN SCIENCE

Introduction

In the United States, the popularity of birdwatching is growing, with roughly 47 million (approximately 20% of the population) people considering themselves birdwatchers (USFWS 2011). In addition to recreation, birdwatchers can participate in citizen science programs where bird observations are entered, often through smartphones, into global databases that can be accessed and used by the public and researchers alike. Generally, birders who practice citizen science this way already have some birding skills. However, even beginning birders can engage by reporting the birds that they already know how to identify.

The most important bird citizen science programs are the following:

1. **eBird** (www.ebird.org): Most birders are already familiar with this online hub for all bird observations. This online database allows amateur birders and researchers can submit their bird observations in real time using the eBird app on smartphones. The resulting database provides scientists and naturalists access to real-time data about bird distributions and abundance. Some areas also have "avicaching" programs, which encourage birders to visit a particular location of interest in areas with little or no data. The program also actively encourages the collection of standardized count data[i], which specially trained observers can use to make valuable contributions to a conservation project. This program rewards birders for birding by keeping their individual birding lists (checklists[ii] for particular visits, as well as life lists), but also allowing them to see what other birders have reported and where. All eBird data are publicly available free of cost. For more information on eBird and how this data can be used: http://ebird.org/content/ebird/about/.

2. **The Christmas Bird Count** (https://www.audubon.org/conservation/science/christmas-bird-count): This annual survey has been conducted nationwide every year for over 100 years during the three weeks around Christmas. Each region has established areas to survey with a Christmas Bird Count, and local birding clubs, Audubon chapters, or online birding groups coordinate the volunteer effort each year.

3. **North American Breeding Bird Survey** (https://www.pwrc.usgs.gov/bbs/): More advanced birders can participate in this annual survey, which adheres to strict protocols and requires excellent birding skills. Breeding Bird Survey (BBS) routes have been surveyed by volunteers nationwide for the past 50 years, and thus, they are the reason we even know which birds are declining and which ones are not. This database will also allow us to assess the impacts of climate change on birds. BBS surveys are coordinated by one person or organization in each state, and contact information can be found on the above-mentioned website.

Directions

This exercise will either be conducted as part of a class field trip, or completed individually.

Go to a location within your town or city and create and submit a checklist to eBird (see description above). The location may be assigned, or you may be allowed to choose a place. The location chosen will depend on your local area, but could be any natural or semi-natural area, or even on your school's grounds or campus! Try using published field guides or apps such as Merlin to identify birds.

Scientists can use these observations, along with millions of others around the world, to track bird movements and populations over time. Even a short checklist, such as a 10-minute count at a feeder or water source, is useful. With citizen science, anyone can contribute

[i] Counts can be stationary, or walks up to five miles; typically from five minutes to five hours.
[ii] A checklist includes counts of all species identified at a specific location, date, and time.

valuable data to long-term monitoring of birds and other organisms.

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Exploring the Social and Ecological Trade-offs in Tropical Reforestation: A Role-Playing Exercise

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ABSTRACT

This exercise introduces students to the complexities of conservation in rural tropical landscapes. It introduces the concepts of payments for environmental services (PES), trade-offs and synergies between agricultural land-uses and society's needs, and introduces students to tropical land-uses and common rural stakeholders in the tropics. The exercise has two main parts. In Part 1, students learn about a new reforestation program in the fictional country of Nueva Puerta and must debate how to direct the reforestation program: towards poverty alleviation, export production, water protection, or habitat connectivity. In Part 2, students break into small groups to negotiate the placement of PES in a tropical land-use simulation game. The land-use simulation is designed to show students some of the realities and limits of tropical conservation. In the final phase of the exercise, students reflect on their experiences through discussion questions. Optionally, they can write a reflective essay and/or vote which real-world reforestation project they are interested in supporting as a class.

LEARNING OBJECTIVES

After this debate and land-use simulation game, students will be able to:

1. Understand how the impact of policies to promote ecological services will differ in areas with distinct social and ecological contexts.
2. Describe the ecological services associated with reforestation.
3. Make a persuasive and evidence-based argument (written or oral) about the relative importance of ecological services and other social values.
4. Appreciate the distinct perspectives of stakeholders in rural tropical landscapes.
5. Evaluate the impact of real world reforestation projects (optional).
6. Identify/infer trade-offs associated with different kinds of reforestation.
7. Negotiate cooperatively to find compromises to resolve stakeholder conflicts.
8. Identify and appreciate the limitations facing conservation programs.

INTRODUCTION

The Promise of Tropical Reforestation

People increasingly recognize the benefits of forests, especially tropical forests, in providing environmental services (also known as ecological or ecosystem services). Environmental services are benefits that humans receive, typically for free, from ecosystems. Some examples of environmental services are crop pollination by native insects (e.g., bees), water purification and denitrification in wetlands, food provision from fisheries, and recreation opportunities, such as in parks. Forests provide many environmental services: they store carbon, prevent erosion, provide wood and other products for people, improve hydrological cycling, provide habitat for threatened or endangered species and more.

Historically, we have received environmental services for free and taken for granted that ecosystems would provide them. However, environmental change means that some of these services are becoming scarce. For example, due to deforestation, the amount of carbon being stored by tropical forests is declining. Now, conservationists and natural resource managers are looking for strategies to protect these ecosystems and ensure that nature continues to provide these services. One such strategy is payments for environmental services (PES) programs, systems in which "beneficiaries of nature's goods and services pay owners or stewards of ecosystems that produce those services, with payments contingent on service provision" (Naeem et al. 2015). Some examples of PES programs are: biodiversity protection (e.g., conservation donors paying to set aside land to create a biological corridor), watershed protection (e.g., downstream water users paying to

promote upstream land use that prevents erosion and improves water quality; Wunder 2005), and carbon sequestration and storage (e.g., an electricity provider paying for tree planting to pull carbon dioxide (CO_2) out of the atmosphere). While some conservationists object to putting a monetary price on nature, or worry about the impacts or risk involved (e.g., Silvertown 2015), supporters of PES programs argue that they can be effective in changing drivers of biodiversity loss, and provide valuable additional funding for conservation (e.g., Ferraro and Kiss 2002).

Tropical forests are important providers of environmental services. Tropical forests account for 50 percent of the world's existing forests (Pan et al. 2013), and they store large amounts of carbon: more than double the amount of carbon per hectare than temperate and boreal forests (not including soil carbon; Malhi et al. 1999). Tropical forests harbor most of the world's tree species (Fine et al. 2008), and are also the forests most threatened by deforestation and land-use change (FAO 2010). Reforestation in tropical forests thus has the potential to provide multiple benefits in tropical landscapes (Locatelli et al. 2015). It contributes to climate change mitigation and biodiversity conservation. In highly deforested landscapes, reforestation can improve connectivity and create biological corridors, enhancing some species' abilities to move across landscapes. In addition, tropical reforestation has the potential to provide economic benefits to landowners in the form of timber production, and other local benefits such as erosion prevention and water regulation.

Tropical reforestation can take many different forms, and the benefits stemming from these also vary. If reforestation can occur naturally, or with some assistance (ecological restoration), the resulting natural ecosystems are called secondary forests. Alternatively, landowners can establish tree plantations, which can be monocultures or polycultures (depending on how many species are planted) and can be composed of native species or non-native (exotic) species. Monocultures are the simplest plantations to manage, with uniform production and uniform species characteristics, such as harvest time. In the tropics, non-native timber plantation species are often the best understood by foresters, easy to grow and with large markets for their wood.

But neither monocultures nor non-native plantation species have many benefits for local biodiversity (Brockerhoff et al. 2008). By contrast, highly complex native-species polycultures have high biodiversity (Nájera and Simonetti 2010). With moderate amounts of biodiversity, agroforestry is a type of polyculture where trees are grown alongside agricultural crops or animals. For example, coffee agroforestry with a shade overstory has more species of birds than sun-grown coffee monocultures without trees, but fewer species than complex native tree polycultures (Nájera and Simonetti 2010). Thus, the benefits associated with reforestation vary based on the type of reforestation. The location of reforested land can also play a key role in the types and quantity of benefits accrued. For example, reforestation on steep slopes may best help prevent erosion, while reforestation near existing forests may best help promote connectivity.

Perils, Pitfalls, and Problems in Tropical Reforestation

Due to its potential to remove CO_2 from the atmosphere and provide other benefits, many conservation organizations and local governments have been promoting tropical reforestation. By attaching payments to this type of land-use, PES programs can provide the necessary incentive so that landowners choose reforestation over other land uses. However, developing a PES program for reforestation is complicated by the many different, and sometimes conflicting, interests of stakeholders in tropical landscapes. A persistent question is where to conduct these programs in order to both maximize benefits for local communities and issues of global conservation importance. A local farmer may be more interested in growing grain for their family than in sequestering carbon for foreigners.

Planting a tree has myriad environmental benefits, no question. But it also has economic opportunity costs. You have committed that space, and the shadow it casts, to growing a tree for the next several years to decades to centuries. If that is a farm field that you planted your tree in, you can no longer grow dense, productive crops that need full sunlight. If you have the money and live in one of the few suitable areas where they grow, you may be able to switch to lower-density, shade-loving

crops like coffee or cacao (chocolate). But for most of the world's "poor" (i.e., low-income) tropical farmers, switching crops isn't an option because it would cost too much money. Neither is waiting twenty years to harvest wood they planted—they might go hungry in the meantime, with nothing to sell or eat. Wealthy farmers with money saved up are better able to wait for slow-growing trees to yield timber and fruit—they can bear the opportunity costs. Even when farmers can afford to plant trees, having all of your wealth standing in trees is a risk—a single fire could wipe them out.

Depending on which species you plant, and where you plant it, reforestation may also come with environmental costs or ecological costs. In dry areas, planting non-native trees can lower the water table and dry up wells (Le Maitre et al. 2002), or, in the case of *Eucalyptus*, cause an increase in forest fires with their flammable dry leaves. Certain non-native species are invasive, and will spread out rapidly from a plantation—for example, the invasive tree *Casuarina equisetifolia* was once widely planted for erosion control and is now responsible for choking the habitat of endangered species on nearby beaches (Global Invasive Species Database 2017). Plantation species grown in orchard monocultures, like oil palm in southeast Asia, often have little to no value for biodiversity (Nájera and Simonetti 2010)—and when they replace diverse rainforests, secondary forests, and polyculture house gardens, populations of orangutans and rhinos go locally extinct (Fitzherbert et al. 2008). Once oil palm has expanded to cover most of the landscape, as it is doing in many parts of southeast Asia, South America, and Africa, whole species will go extinct (Vijay et al. 2016).

THE ASSIGNMENT

To help you better understand the trade-offs implicit in choices about reforestation, you are going to learn about and role-play two related scenarios. In Part 1, you will make an informed argument based on the assigned reading, recommending which region of a country should receive PES payments from the national government. Your instructor will think critically about the recommendations from the class and use them to determine which region will receive the PES money. In Part 2, you will break into four stakeholder teams:

reforestation program representatives, local town council, small farmers (i.e., small farm landholders), and large farmers (i.e., large farm landholders). The different stakeholder teams will need to work together to decide the fate of the reforestation program in your region: where incentives will be offered, to whom, and for what kinds of reforestation.

PART 1. TRADE-OFFS IN CONSERVATION AND DEVELOPMENT: A DECISION-MAKING AND DEBATE EXERCISE

You are a young, ambitious official (representative) in a national government program that administers payments for environmental services (PES) to fund reforestation on private farms. Farmers that sign up for this program receive $5,000 to plant trees or allow natural reforestation on their land, and may harvest and sell the wood twenty years later. The program has increased forest cover in many regions of your country, Nueva Puerta, but critics of the program say it is a waste of money because the forest cover increase has not been targeted to achieve real benefits in terms of habitat connectivity, wood production, environmental services, or poverty reduction. Your job is to improve the targeting of reforestation by selecting which *one* region in Nueva Puerta will receive a PES program in the next year.

Your supervisors have requested a short report that outlines and supports your choice with logical arguments. Depending on your supervisor, this may be a verbal or written report—ask them for the format and length. Because this is a political matter, you must be ready to debate and support your choice with arguments in favor of your chosen region, but also directly address why your choice is better than another region.

You have four regions of Nueva Puerta to choose from (Figure 1). Read about each region before making your decision and starting your report.

The first region, Monte Azul, is high in the central mountains, near the capital city. Most of the landowners in this region live in the big city and run large cattle ranches or coffee farms ("large farmers"). A few small farm landowners ("smallholders" or "small farmers") run low-income coffee farms on the least fertile hill soils. Forest

Figure 1. Map of Nueva Puerta
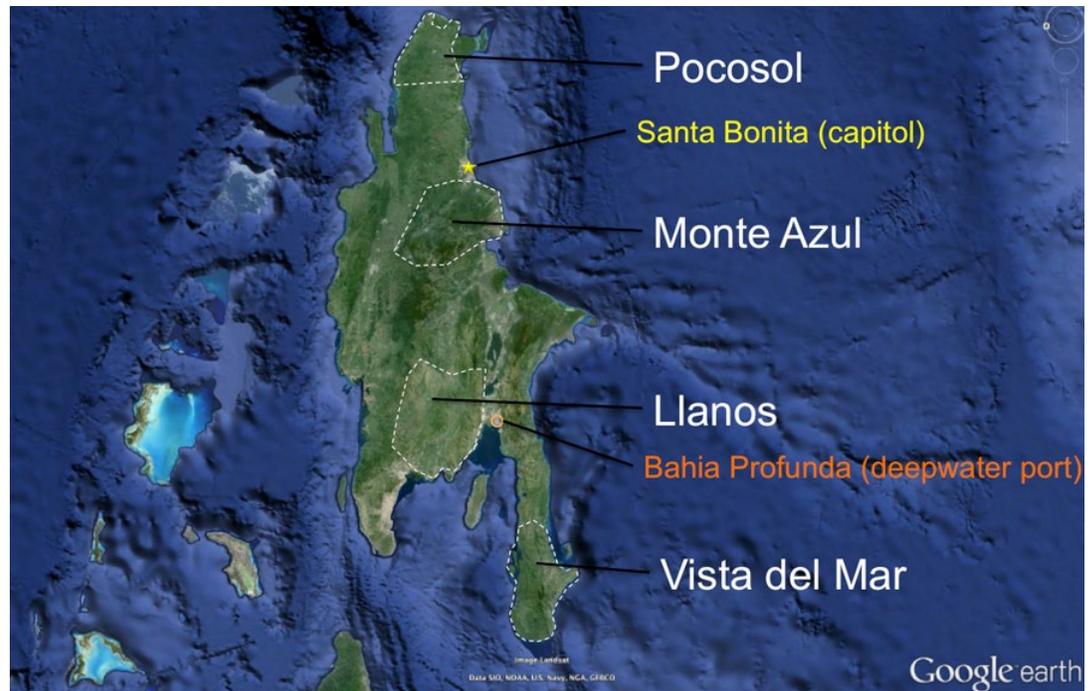
is abundant on the high steep slopes, but overgrazed cattle pastures and coffee predominate everywhere else. Regional forest cover is 40 percent. The high mountains here are a main source of water for the city reservoir, and in recent years there has been concern about soil erosion and water quality in the reservoir. Possible reforestation options in this region include:

- Agroforestry: planting trees in coffee farms (shade coffee),
- Timber: planting monocultures of cypress (a non-native conifer with low invasive potential and valuable wood), and
- Conservation: planting native trees to accelerate natural regeneration in pastures.

The second region, Vista del Mar, is the poorest region of the country and has the lowest forest cover (<10%). It is far from the main cities and is mainly accessed via coastal ports and poor-quality roads through the hilly terrain. The landowners in this region are almost entirely low-income small farm holders on the edge of extreme poverty, running small subsistence farms or cattle ranches. There are a few larger-land owners along the coasts growing bananas for export. Tropical dry forest used to cover the region, but now forest is quite rare, with most trees along rivers and scattered through fields. Even the steepest slopes are mostly grassy pastures kept open by skinny cattle and escaped fires. High soil

erosion degrades water quality and farm fertility during the brief rainy season. The soil is of decent quality, but the low annual rainfall slows the forest regrowth and the recovery of land after overgrazing. Possible reforestation options in this region include:

- Agroforestry: planting economically valuable trees in pastures (a silvopastoral system),
- Timber: planting monocultures of *Leucaena leucocephala* (a non-native, nitrogen-fixing tree with high invasive potential, good fire resistance, and valuable firewood), and
- Conservation: fencing riparian areas to encourage forest regeneration along rivers.

The third region, Pocosol, is located in the flat rainy lowlands between two large rainforest parks, relatively far from the capital. The two parks protect the last two large populations of the endangered Puertanuevan Ant-thrush, a forest-dependent, highly mobile bird that is disappearing from isolated forest fragments around the region. The Ant-thrush is incredibly popular among bird-watchers, with a scarlet body and striking green wings. Remaining forest cover is at 30 percent, but the forest outside the parks is highly fragmented and restricted to swamps, hill slopes, and riversides. In this region, the large landowners are primarily focused on planting sugarcane, raising cattle, or conducting bird-watching eco-tourism, while the smallholders are focused on

cattle and logging. Possible reforestation options in this region include:

- Agroforestry: planting wood rows of valuable native trees along the edges of cattle fields ("green fences"),
- Timber: planting monocultures of teak (a non-native tree with highly valuable wood and low invasive potential), and
- Conservation: planting polycultures of trees (a diverse mixture of twenty native tree species with low economic return but good habitat value).

The fourth region, Llanos, is a flat cattle-ranching region with poor-quality soils and good road access to Nueva Puerta's deep-water port. The country has been trying to establish a fruit or timber industry there for years, and has discovered through trial and error that there are a few varieties of trees that grow well in the acidic soils of the region. There is great interest in establishing plantations for export among the large cattle ranches in the region, to increase the national income and reduce international debt. The eastern rolling hills are where the remaining forest cover is concentrated (15%) and are dominated by smallholders raising cattle, with 5–50 cows per ranch. Possible reforestation options in this region include:

- Agroforestry: planting oil palm in open orchards,
- Timber: planting monocultures of *Gmelina arborea* (an incredibly fast-growing non-native tree with good wood for shipping pallets), and
- Conservation: planting monocultures of mountain ash (a native, slow-growing species with valuable wood that is the chief nesting tree of the migrating Montezuma Parrot).

Use the remaining space on this page to outline your report.

PART 2. STAKEHOLDER NEGOTIATION EXERCISE: BASIC INSTRUCTIONS

Congratulations! Your region has been selected to receive payments for environmental services (PES) to fund reforestation on private farms. What's more, your town has been selected as the test pilot case for the first year of the PES program. Posters have gone up around the village, pointing out that farmers who sign up for this program receive a cash payment per hectare. Participation will entail either A) planting timber trees to harvest in 20 years, B) practicing agroforestry for 20 years, or C) putting your land into conservation for 20 years. A town meeting has been called to discuss and negotiate the new program.

Pick a Stakeholder Team

Decide which stakeholder team you want to represent in this town meeting: one of the reforestation program representatives, the local town council, a small farmer, or a large farmer. There must be at least one person for each team, so a group of four people will have one person for each stakeholder role.

Examine the Regional Map

Take a moment and think about the viewpoint you would have, growing up in the area described in Part 1. Then take a look at the map of your region (provided by your instructor; Appendix I), which includes towns and the surrounding agricultural land. Towns (in red) and properties belonging to the large farmers (dark yellow, four square clusters) and small farmers (light yellow) are pictured on the map, along with forested areas (green) and rivers (blue)[i]. Areas in light green are farmers and ranchers who didn't make it to the town meeting, and are thus not eligible for PES. Red roads connect the towns.

The Negotiation

You are about to enter a negotiation with the other stakeholders living in your region, and how your team performs may affect your grade. Each of you will negotiate the placement of PES contracts in your township. You will have the opportunity to decide if each eligible square of property in the township will either stay in agriculture or be converted to one of the three options for reforestation: agroforestry, timber, or conservation. Your score will depend on how you negotiate to locate reforestation and agriculture in your township. Understand your own incentives well, and be prepared to make reasoned arguments. Yelling won't help, but careful negotiating and a solid grasp of the background reading will. If you play nice, and don't stick up for your own interests, be prepared to lose this negotiation. *Read your stakeholder team's scoring instructions for your region carefully.* Optionally, you may keep it secret from opposing teams! If they see it, they may have a negotiating advantage over you.

The Objective

Your objective in the simulation game is to accumulate more points than the other stakeholder teams in your group by the end of the negotiation. Different players

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[i]A grayscale version of this map might be distributed (Appendix II), if that is the case, the shades of gray are defined in the legend.

Table 1. Scoring

BASE SCORING:	
Farm square	1 point per 10-hectare square
PES SCORE MODIFIERS FOR FARMERS:	
Agroforestry (yellow-colored marker*)	+1 point to farm income
Timber (blue-colored marker*)	+0 point to farm income
Conservation (green-colored marker*)	-1 point to farm income
FINAL SCORE:	
Base score + PES score modifiers for farmers + Bonus points	
*colors may depend on your instructor's set-up.	

earn points in different ways. For large and small farmers, points come from farm square income and some bonus points, which represent your personal preferences and desires. For town council members, points come from road trade and farmer income (your constituents). For the reforestation program manager, points come from giving out PES contracts.

The Rules: How To Play

1. To start, each player should count the farm squares to know their stakeholder team's starting base points; each farm square is ten hectares. Farmers make a base number of points per ten hectares (a large farm is forty hectares in size, or four squares = 4 points).

2. Review your stakeholder team's possible bonus point scenarios for your region. Optionally, these detailed scoring rules for different stakeholders may be kept a secret from other players.

3. Before you start negotiating, take a moment to think about what type of PES payment you want on the farms, and where you might want it. Your instructor might ask you to fill out a blank map sheet with your ideal outcome. This may be collected but, regardless, it's a good idea to make one anyway.

4. The game begins when the PES program representative team makes an offer to a farmer team to alter one or more agricultural square's income with a PES payment. If accepted, the representatives will have a bag of colored tokens or pins to mark what type of PES that property receives. After the first offer, negotiations can be initiated by any team. Offers agreed to a majority of members are binding on a team.

5. This is a free-for-all negotiation: farmers can say no, town council can counter-offer, and so on. All contracts are final only after the last PES contract has been given out.

6. The entire negotiation is over once 15 colored PES markers are on the board, you reach an impasse, or the instructor calls time.

7. Once the negotiation is over, use the group scoring sheet tally up your score. You will score points for your final base score and for any bonus point modifiers you have earned through PES contract negotiation (see your stakeholder scoring sheet).

8. If possible, take a photo of your region's completed board for later reflection.

Frequently Asked Questions:

1. Q: Is bribery permitted?
   A: This is up to your instructor. But side deals, secrets, cartels, cabals—all fine.
2. Q: Can the town council veto my offer/deal?
   A: Yes. The town council has five vetoes.
3. Q: What do the points mean, really?
   A: Points are an approximation of economic utility: how much something benefits you, either monetarily or otherwise.
4. Q: Is this game a good approximation of reality in the tropics?
   A: That's a great question. This game is an over-simplified model of stakeholders, policies, and incentives, designed to highlight some common trade-offs associated with tropical reforestation. Where is it least realistic? Hmm, that would make a great discussion question afterwards...
5. Q: Is "Nueva Puerta" a real island?
   A: Yes.
   Q: Is "Nueva Puerta" a real place or country?
   A: Nope, not at all.

HANDOUT 1: STAKEHOLDER SCORING INSTRUCTIONS: REFORESTATION PROGRAM REPRESENTATIVE

This is your big promotion! And keeping it just depends on keeping the international NGO (non-governmental organization) donors to your national government happy while convincing the people you grew up with to adopt the PES program. You have two objectives: you want to enroll properties in the PES program, and you want to do as conservation-friendly reforestation as possible.

Scoring and Rules:
1. Base points: You get one point for every square you enroll in the PES program.
2. PES points: You get additional points if the selected PES option is conservation-friendly:
   - Agroforestry (+0 bonus)
   - Timber (+1 bonus per square)
   - Conservation (+2 bonus per square)
3. Bonus points: You get one bonus point per square if the PES properties are adjacent to (i.e., touching) natural forests. Note, touching is referring to the entire side of a square, not just a corner. Extra bonus points can be earned according to your region (see below).
4. Non-completion penalty: You only have enough program money to pay to enroll 15 property squares in PES. Choose wisely. If you do not enroll 15 properties, subtract the remaining number of PES contracts from your final point score. It is possible to put PES on town squares, with town council permission.

Guide to Regions

REGION	REFORESTATION OPTIONS	SPECIAL REGION-SPECIFIC RULES FOR BONUS POINTS
Monte Azul	A: Shade coffee T: Cypress plantations C. Natural regeneration	Creating forests to border and protect the rivers is especially important for water quality. You get one extra bonus point for *timber or conservation* PES that touch *water* squares.
Llanos	A: Oil palm T: *Melina* plantations C: Native mountain-ash plantations	Establishing farms that will export products easily is valuable. You get one extra bonus point for *agroforestry or timber* PES in squares that touch *roads*.
Pocosol	A: Green fences T: Teak plantations C: Diverse native plantings	Creating wooded habitat to connect and buffer isolated forests is valuable. You get one extra bonus point for *conservation* PES that touch *forest* squares.
Vista del Mar	A: Silvopastoral systems T: *Leucaena* plantations C: Fencing riparian forests	Reaching small farms that lack access to infrastructure is important. You get one extra bonus point for *agroforestry or timber* PES in squares that *don't* touch roads.

Personal Scoring Guide

BASE SCORE	PES SCORE	BONUS AND PENALTY POINTS	TOTAL
# PES squares placed =	(# conservation×2) + # timber =	One point per square of PES adjacent to forests = See your region's special rules for bonus points = Subtract one point for each PES payment you do not place	

HANDOUT 2: STAKEHOLDER SCORING INSTRUCTIONS: SMALL FARMERS

You are barely making ends meet each day. The PES program may or may not benefit you, and the large farmers and the town council may or may not negotiate in your best interest. Work with your fellow smallholders to achieve a profitable and just solution for yourselves! You have one objective: maximize the return for small farms across the entire board (the total *small* farmer's points at the end of the negotiation is the key to your success).

Scoring and Rules:
1. Base points: You receive one point for each square small farmers collectively own.
2. PES points: You can gain or lose additional points from certain types of PES reforestation contracts:
   - Agroforestry (+1 point per square)
   - Timber (+0 points per square)
   - Conservation (-1 points per square)
3. Conservation bonus points: You support conservation, especially when other people do it at no cost to you. Collect one bonus point for each large farm square that has a conservation PES at the end of the game.
4. Completion bonus: At the end of the game, if all 15 of the PES contracts are assigned, you get a completion bonus of 5 points. This reflects an increase in your reputation for supporting conservation: ecotourism money begins to flow to your small farmers.

Personal Scoring Guide

	BASE SCORE	PES SCORE	BONUS POINTS	TOTAL
Small farmers	20 points	(# agroforestry on small farms) – (# conservation on small farms) =	# conservation on large farms = If all 15 PES contracts placed, add 5 points.	

Reforestation Options

REGION	AGROFORESTRY	TIMBER	CONSERVATION
Monte Azul	Shade coffee	Cypress plantations	Natural regeneration
Llanos	Oil palm	*Melina* plantations	Native mountain-ash plantations
Pocosol	Green fences	Teak plantations	Diverse native plantings
Vista del Mar	Silvopastoral systems	*Leucaena* plantations	Fencing riparian forests

HANDOUT 3: STAKEHOLDER SCORING INSTRUCTIONS: LARGE FARMERS

As wealthier members of your community, you are pro-conservation and welcome the PES program, as long as it doesn't detract from your profitable business as usual. You have two objectives: maximize the PES enrollment while maximizing the profit from large farms across the board (the total large farmer's points at the end of the negotiation is the key to your success).

Scoring and Rules:
1. Base points: You receive one point for every ten hectares you own, and there are four ten-hectare plots per farm.
2. PES points: You can gain or lose additional points from certain types of PES reforestation contracts:
   - Agroforestry (+1 point per square)
   - Timber (+0 points per square)
   - Conservation (-1 points per square)
   PES contracts can be placed on any ten-hectare plot within your forty-hectare farms.
3. Bonus points: You support conservation, especially when other people do it at no cost to you. Collect one bonus point for each small farm that has a conservation PES at the end of the game.
4. Non-completion penalty: At the end of the game, if all 15 of the PES contracts are not assigned, you receive a non-completion penalty of 5 points. This represents a decline in your reputation for supporting sustainable agriculture and conservation. You large farmers have benefited from recent fertilizer subsidies from the national government and if the new national PES program fails here, that fertilizer support from the government will go somewhere else.

Personal Scoring Guide

	BASE SCORE	PES SCORE	BONUS POINTS	TOTAL
Large farmers	40 points	(# agroforestry on large farms) – (# conservation on large farms) =	# conservation on small farms = If fewer than 15 PES contracts placed, subtract 5 points.	

Reforestation Options

REGION	AGROFORESTRY	TIMBER	CONSERVATION
Monte Azul	Shade coffee	Cypress plantations	Natural regeneration
Llanos	Oil palm	*Melina* plantations	Native mountain-ash plantations
Pocosol	Green fences	Teak plantations	Diverse native plantings
Vista del Mar	Silvopastoral systems	*Leucaena* plantations	Fencing riparian forests

HANDOUT 4: STAKEHOLDER SCORING INSTRUCTIONS: LOCAL TOWN COUNCIL

Oh no! Commerce is your town's livelihood, and change is often a threat to that livelihood. The new PES program may or may not be a help in that process, but you worry the program's eco-friendly conservation options will lower agricultural productivity and take money out of your constituent's pockets. You have one objective: to maximize the income of farmers in your area.

Scoring and Rules:
1. Base points: You must advocate for all your constituents: your final point score is the *lower* of either the large or small farmers' total base points + PES modifiers. This does *NOT* include their additional bonus points.
2. Trade bonus: Having economic resources that are accessible to the town is good. At the end of the negotiation, you get two bonus points for each farm that receives an agroforestry or timber PES that touches a city or road. Note, the selected PES land squares must share an entire side to be considered touching, not just a corner.
3. Permitting: If the PES program creates political ill will by hurting the local economy, it matters for your well-being and job security. Therefore, if the town council doesn't agree with a PES contract location, they can revoke its agricultural tax permit: that is, you have veto power and can veto up to five PES placements. When you veto the PES placement, you have 1–2 options, depending on your instructor:
   1. Let the farmers and PES coordinator work out a new farm location;
   2. (or, under optional bribery rules) Offer the PES program coordinator the ability to place their vetoed PES contract on a town square. You receive three points per PES contract placed on a town square, which effectively is a bribe to the town council. It is your choice whether you wish to be honest or corrupt as a local government. While government corruption can exist in any country, its effects can be particularly harmful in less developed countries.

Personal Scoring Guide

	BASE SCORE	PES SCORE	BONUS POINTS	TOTAL
Town council	Lower score of (large or small) farmers' (base + PES) =	Not applicable	# agroforestry or timber touching road x 2 = *Optional*: # of PES payments on towns x 3 =	

Reforestation Options

REGION	AGROFORESTRY	TIMBER	CONSERVATION
Monte Azul	Shade coffee	Cypress plantations	Natural regeneration
Llanos	Oil palm	*Melina* plantations	Native mountain-ash plantations
Pocosol	Green fences	Teak plantations	Diverse native plantings
Vista del Mar	Silvopastoral systems	*Leucaena* plantations	Fencing riparian forests

HANDOUT 5: GROUP SCORING SHEET:

NAME OF REGION: _____

Fill in this table to summarize the placement of PES programs on the map:

NUMBER OF PES	AGROFORESTRY	TIMBER	CONSERVATION	TOTAL
Small farms				
Large farms				
Total				

Fill in this table to calculate or record each stakeholder's score:

	BASE SCORE	PES SCORE	BONUS POINTS	TOTAL
Large farmers	40 points	(# agroforestry on large farms) – (# conservation on large farms) =	# conservation on small farms = If less than 15 PES contracts placed, subtract 5 points.	
Small farmers	20 points	(# agroforestry on small farms) – (# conservation on small farms) =	# conservation on large farms = If all 15 PES contracts placed, add 5 points.	
Town council	Lower score of (large or small) farmers' base + PES =	Not applicable	# agroforestry/timber touching road x 2 = (*Optional*) # of PES payments on towns x 3 =	
PES program representative	# PES squares placed	(# conservation ×2) + # timber =	One point per square of PES adjacent to forests. See your region's special rules for bonus points. Subtract one point for each PES payment you do not place.	

POST-GAME QUESTIONS FOR DISCUSSION IN YOUR GROUPS (OR HOMEWORK)

Please discuss and then answer here in one sentence per question (some have multiple questions):

1. How well did you do in this game? How could you have done better?
2. If multiple regions were played, how did the maps end up differing between the different parts of the island? Look at final maps for other regions, and talk to the players in each region to learn why.
3. How did the town council and its vetoes affect your game play?
4. If bribery had been permitted for all stakeholder groups, how different would your discussion have been? How fair and legitimate would the contract process have seemed to you? What would you have thought about conservation?
5. If government corruption was rampant and enforcement of laws and contracts poor ("weak governance"), what would be the fate of the PES program over the long term?
6. How likely would a farmer with weak land tenure (i.e., no formal, enforceable land title) be to join this program?
7. Small farmers in rural areas often have the least power and money in developing countries. Do you think the negotiation game you completed reflected that reality? How might a small farmer increase their profitability or ability to affect government policy?
8. In the game, small and large farmers act together as a group. In the real world, some farmers do act as groups, forming co-operatives. But most farmers do not. Why would a farmer, large or small, who is not part of a larger co-operative ever choose conservation PES as an option?
9. How might an influx of eco-tourists into Nueva Puerta change the national economy? Do you think ecotourism money might change the local attitudes of both farmers and townsfolk in your region towards conservation PES?
10. In the real world, how does access to roads and markets change the farming economy—would each farmer make more or less? How does road access change the ability of farmers receiving PES to plant trees and extract timber and agroforestry products? In general, how has road access affected deforestation around the tropics? Please research your answer to the last question.
11. Hilly and mountainous areas are harder to access. How likely, do you think, are hilly and mountainous areas to be under agriculture? Are they more or less likely to be abandoned and left to reforest than flat areas the same distance from a road? Where does coffee grow?
12. If you had to come up with one new game rule, what would it be?

REFLECTION QUESTIONS

These are intended as homework, and the starred questions may be assigned as optional reflection essays(**). Your instructor will give you additional instructions.

1. Tell a quick story about how your region's negotiation map got created. Why did the pins fall where they did? Include the photo of your game board in your answer.
2. What did you like most about the game? What did you like least?
3. Give two examples of ecological trade-offs (ecological benefits and drawbacks) for a specific type of reforestation. Remember that reforestation includes secondary forests, timber plantations, tree crops, and agroforestry.
4. What would a successful PES program look like, twenty years down the road? How much would it cost, relative to the starting cost? Pretend for a moment that you are pitching the PES program to a small country: how are they going to pay for it?
5. Conservation is not equal everywhere. Why would conservation payments be better targeted by forests, or by rivers, or on steep slopes? Research the definition of an ecological buffer zone, and of forest connectivity. Do you think it would be easier to put a conservation payment in a hilly region with low agricultural productivity, or in a flat region with high agricultural productivity? Why?
6. Winning, in the game, is hard to define. How would you define winning the game—individual success, or a successful regional outcome? In the real world, which region would be the most likely to receive

PES, in your opinion? Which region would be most likely to achieve the PES objectives?

7. From Part 1, which region did you vote for reforestation money, and why?

8. **What social and ecological trade-offs exist when tropical conservation or reforestation projects to capture carbon or preserve wildlife directly benefit global human well-being, but only bring limited local economic benefits and may decrease local control over land? Research whether conservation projects (e.g., protected areas) are always beneficial for local people; in your opinion, is benefiting local people a necessary requirement for successful conservation projects?

9. **PES systems are complex, and the success or failure of specific PES programs depends on the policies and benefits and costs to each stakeholder. What do you think are possible characteristics of a successful PES program? How might local attitudes towards a PES program differ A) in the capital city of the donating country (e.g., Norway) and B) in a low-income rural region receiving the PES?

10. **Do you feel the game is realistic? Why or why not? What biases or assumptions in the rules of the game created this realism or lack of realism? For example, small farmers worked together in groups in the game, but in the real-world farmer co-operatives are rare. Also, in this game, conservation schemes entailed no benefits for farmers, but under a different set of rules, they could provide cultural and food services to local and indigenous landowners.

11. **This game glosses over complexities that are very important: there are other kinds of incentives than cash, and tradeoffs both locally and globally. A game mindset discourages collaboration and encourages "fend for ourselves" and "get as much money as possible" behavior. Research how have PES programs performed in the real world—what challenges do they face? Examine a couple examples we didn't discuss in class. The Wikipedia page for "Payments for ecosystem services" is a good jumping off point: bonus points for non-Wiki examples.

12. **If Exxon Mobil (or a company of your choice which you disapprove of) offered to pay for a massive PES program for the next ten years in Nueva Puerta, would you, as the government, accept their money? Why or why not?

13. **You are the environmental minister of a small developing country. Recently, a large nonprofit approached you and offered to fund a PES program in your country for the next 20 years, and potentially longer. However, you have heard there are criticisms of PES programs, and you want to know more. Research critiques of PES programs and summarize them here. This video is a good jumping off point: http://www.bioeconomies.org/enterprising-nature/.

OPTIONAL EXERCISE: VOTE FOR REFORESTATION NGO

There are many reforestation projects in tropical forests around the world. Just like in the game you played, these projects need to take into account global and local conservation priorities and competing concerns, desires, and incentives of different stakeholders. Below, you'll find a list of reforestation projects in various countries around the world. Please feel free to find other examples of reforestation projects for the class to support, as well. Read about each project on its website. Then, in the context of what you learned through this exercise, pick your favorite project and explain why you think it's the best. As a class, you can discuss and vote on the best project.

After looking at each project, as a class, vote on the project that you think best integrates and balances conservation and environmental goals with local stakeholder priorities. If your instructor chooses, either they or the class can donate some funds to the organization that students favor.

- http://www.caminoverde.org/who-we-are
- http://weforest.org/projects/Restoring-Atlantic-Rainforest
- http://weforest.org/projects/india-empowering-women-entrepreneurs-land-restoration
- http://www.edenprojects.org/
- https://www.carbonfund.org/reforestation-and-avoided-deforestation
- http://www.treeswaterpeople.org/programs/reforestation/reforestation.html

- http://www.arkive.org/reforestation/
- https://www.paulmitchell.com/our-story/caring-for-our-planet/reforestaction/
- http://www.plowhearth.com/about/reforest_america.htm
- https://www.reforestemospatagonia.cl/en/
- http://www.reforestingscotland.org/

(Please note that websites do change, and you may need to do an online search of the names of these organizations to find the specific projects referenced above.)

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APPENDIX I: REGIONAL MAP

Legend

■ *Forest* ■ *Farms not eligible* ■ *Rivers*

■ *Small farms* ■ *Large farms* ■ *Towns*

EXERCISE
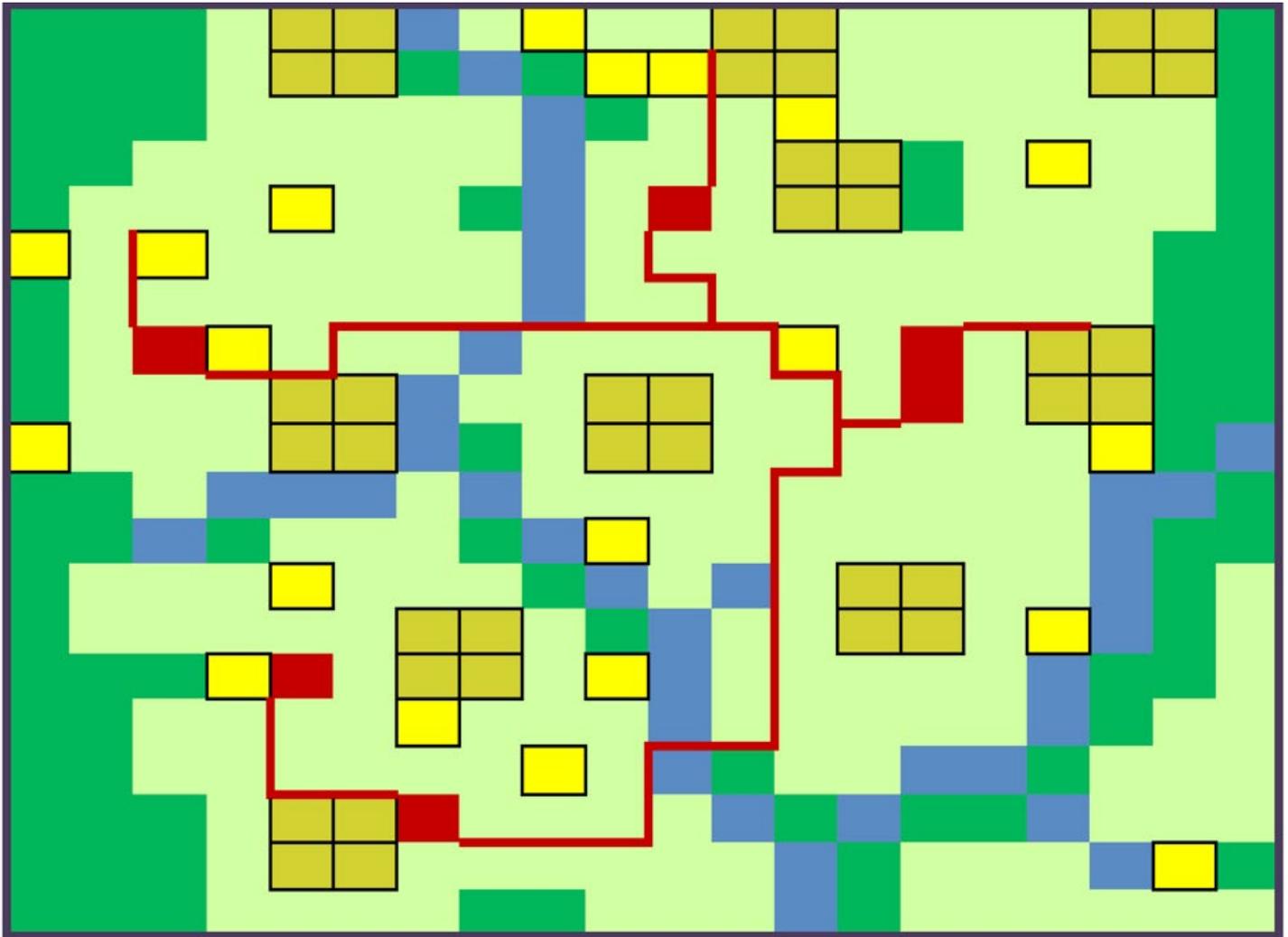
APPENDIX II: REGIONAL MAP (GRAYSCALE)
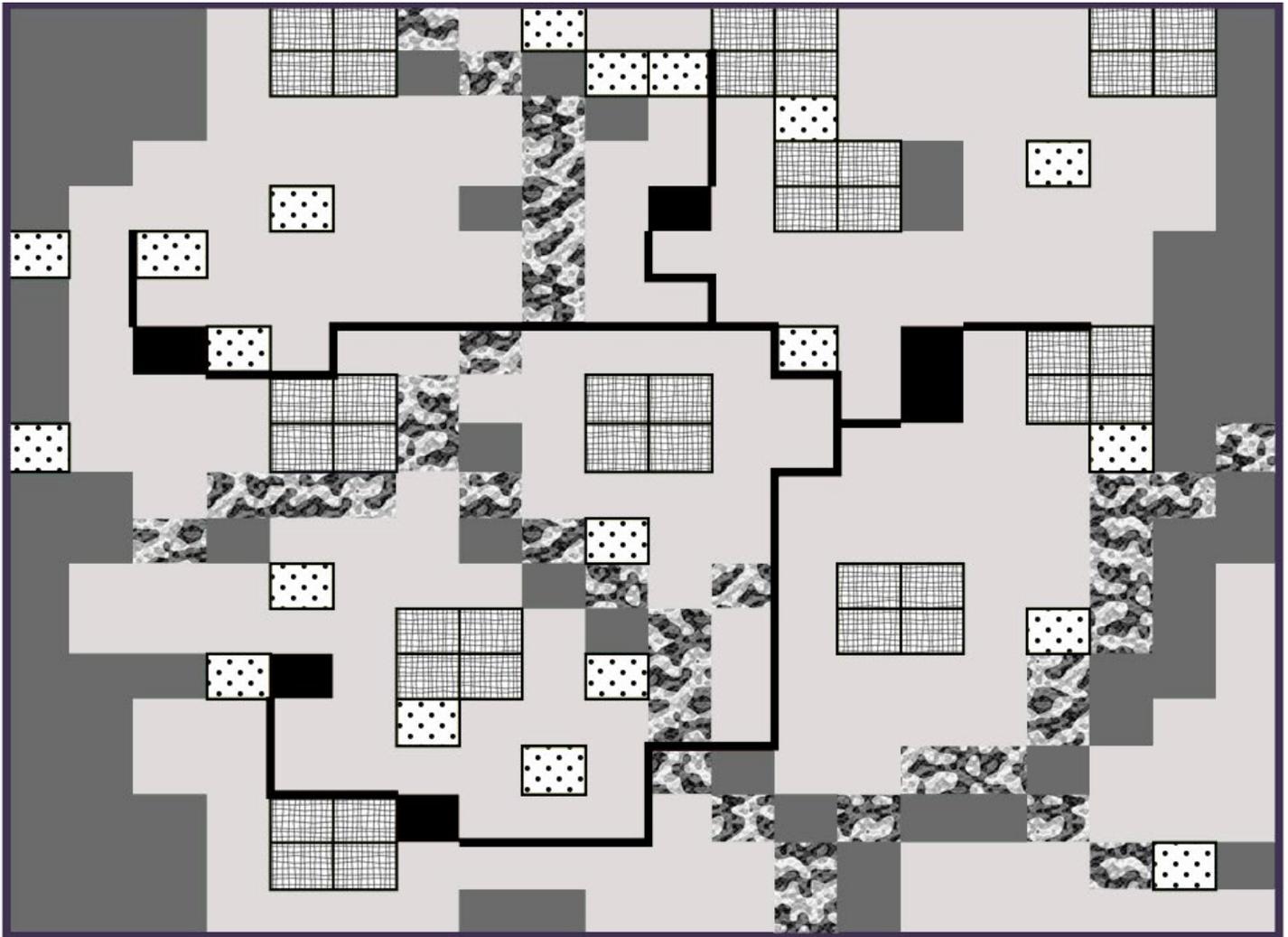
Legend

	Forest		Farms not eligible		Rivers

	Small farms		Large farms		Towns

Biogeography in Conservation: Tools to Explore the Past and Future of Species in a Changing World

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ABSTRACT

Humans have now altered essentially every natural ecosystem in the world, and among the numerous consequences of anthropogenic global change, many of the Earth's species are currently living under drastically different environmental and ecological conditions. On one hand, many species that once thrived in the wild are now threatened by extinction, while at the same time, species that were historically benign are becoming invasive in different parts of the world. To address this major challenge, it is critical that conservation practitioners understand the multiple short- and long-term climatological, geological, and evolutionary mechanisms that have resulted in the current distribution of species; understanding how these same mechanisms interact is also key in predicting species distributions—and possible extinctions—into the future. Using the Global Biodiversity Information Facility (GBIF), an open-access worldwide database of species occurrences, this research project exercise is designed to guide teams of students through the process of: a) identifying and researching characteristics relevant to understanding species distribution (e.g., age of the group, habitat requirements, dispersal capabilities); b) representing the present and historic species distribution; c) critically assessing the quality and amount of information available; d) using that information to understand species history and potential future challenges the species may either face or impose on the ecosystems; and e) sharing the results with peers and learning from that experience.

LEARNING OBJECTIVES

After completing this research project exercise, students will be able to:

1. Understand the methods used to study both current and historical species distributions;
2. Use open-access biodiversity databases to record, map, and model the distribution of selected taxa;
3. Use basic database management tools to analyze, interpret, and communicate scientific data on species distributions graphically, orally, and in written reports;
4. Interpret and apply biodiversity data in the context of informing biodiversity conservation planning and policy; and finally,
5. Critically evaluate the potential use and limitations of open-access biodiversity databases, in understanding species historical and current distributions.

BACKGROUND

Biodiversity Conservation in the Anthropocene

The fate of animals, plants, and arguably entire ecosystems or biomes, is in the midst of unprecedented change as a result of human action (Ladle and Whittaker 2011, Pachauri et al. 2014). Currently, scientists, environmentalists, policy-makers, and citizens recognize that the structure, function, and composition of many habitats worldwide have been completely destroyed or severely damaged by human activity (Richardson and Whittaker 2010). Of the numerous impacts humans have had on the natural world, among the most prominent are both deliberate and accidental changes in the composition of species across all taxonomic kingdoms.

At the same time, anthropogenic climate change now threatens to completely redraw the geographic map of life on this planet. Increasingly, scientific evidence suggests that these massive, global anthropogenic changes in the composition of ecosystems are unique on geological timescales, which is one of the reasons our current geological era—the "Anthropocene" or the "Era of the Human"—is becoming more widely acknowledged as a distinct period of Earth's history (Crutzen 2002).

While some species are able to thrive in the Anthropocene, evidence suggests that the vast majority of species face a higher degree of susceptibility to anthropogenic changes, which in turn results

in: a) reduced local or global population numbers; b) increased rates of local or global extinction; and ultimately, c) increased likelihood of species compositional change in essentially all ecosystems globally (McKinney and Lockwood 1999). From a strictly human perspective, the consequences of such changes for ecosystems services that people directly rely on, such as clean air or water provisioning, are difficult to predict (Millennium Ecosystem Assessment 2005).

Integrating Conservation Biology and Biogeography

Conservation biology—a term first coined as recently as 1978 (Douglas 1978)—is an applied field of scientific study that focuses on understanding spatial and temporal patterns in the Earth's biodiversity, with the aim of managing species, their habitats, and ecosystems, in order to prevent their extinction (Soulé 1985, Soulé 1986). To predict the fate of key species and ecosystems, and ultimately prescribe solutions, conservation biology draws on tools and methods employed in many fields of study including fundamental taxonomy-based sciences, such as botany and zoology, as well as more quantitative predictive sciences, such as population and community ecology. Because potential solutions to prevent biodiversity loss must be implemented by people at different scales (e.g., local, regional, global), conservation biology is structured as an interdisciplinary and active research field, with critical participation from biologists, social scientists, economists, policy-makers, and engaged citizens.

Complementary to conservation biology, is biogeography: the field of study focused on understanding the processes that give rise to the spatial distribution of species. While biogeography and conservation biology undoubtedly share certain elements, biogeography focuses more specifically on how changes deeper in the Earth's geological history have given rise to the diversity of life we see today. For instance, key themes in biogeography include an understanding of how plate tectonics and/or historical shifts in the global climate have influenced biological diversity through: a) the shaping of species' dispersal patterns; b) immigration and emigration of individuals into and out of ecosystems; and c) the physiological and

reproductive fitness of different individuals or species in response to climatic change. Such factors in turn exert major controls on species demographics and effective population sizes, and the commonness or rarity of species (Sahney et al. 2010). At the same time, anthropogenic influences are creating scenarios (or "natural experiments") where biogeographers can observe in real-time how species arise, the conditions of global change under which different species flourish or decay, and the key determinants of speciation, dispersal, and extinction (Kueffer 2015).

While the principles of biogeography tend to relate to "bigger picture" changes in the Earth systems, its conceptual tools and methods are widely applied to address real world conservation problems. Indeed, the principles of biogeography inform the conservation of species globally and are now well reflected in the emergence of the sub-discipline of "conservation biogeography" (Whittaker et al. 2005). For example, the "Island Theory of Biogeography" is arguably one of the most important guiding principles in conservation biology to date, as can be seen in the debate as to whether single-large or several-small conservation areas are the most effective in conserving biodiversity (commonly referred to as the "SLOSS debate"; e.g., Tjørve 2010). Additionally, new tools are improving our capacity to link conservation biology with biogeography, including: a) global databases on species occurrences (e.g., the Global Biodiversity Information Facility (GBIF); Box 1), climate data (e.g., WorldClim), and geography and geomorphology (e.g., the Shuttle Radar Topography Mission (SRTM)) and b) free computing software that has high computational power (e.g., R Statistical Software, Maxent species modeling software). Coupled with rapidly expanding Internet access, these tools continue to increase our capacity to analyze and interpret current biogeographic trends, and use this information to inform conservation policy and practice. Furthermore, the open-access nature of such resources presents key opportunities for students (and citizens) to perform in-depth analyses that may be useful for conservation initiatives (Moritz et al. 2011).

OBJECTIVES

In this exercise, you will: a) explore the spatial dis-

Box 1. Global Biodiversity Information Facility (GBIF)

The Global Biodiversity Information Facility (http://www.gbif.org) is a global species occurrence database that relies on a large number of museums, universities, and research centers that publish information either collected or gathered by them, on the worldwide occurrence of species. A species occurrence is a record of: a) an individual of a species that has been observed; b) the method used to observe the particular individual and species; and c) the time and location of the observation. There are definitely sources of uncertainty surrounding species occurrence data. For instance, before satellite-based GPS coordinates were available, most of the records relied simply on qualitative descriptions of the location where samples were observed. Similarly, taxonomic identifications also present challenges. Some species can be identified and recorded under multiple scientific names (i.e., "synonym names"), and species identification is always challenging (e.g., some species are morphologically identical, and in other cases two individuals of the same species can be extremely different).

Accounting for such errors is critical in preventing systematic over- or underestimates for the total number of species. In addition to these challenges, another important limitation of species occurrence databases, such as GBIF, is that they contain "presence-only" information. This has two main implications. On one hand, GBIF and similar databases do not contain information about the abundance of the species, so the observation of one or two individuals of a species (i.e., "singletons" or "doubletons", respectively) has the same weight as the presence of hundreds or thousands of individuals. On the other hand, occurrence data present an intriguing challenge, in that we often want to believe that such data also implicitly tell us something about the absence of species from certain locations.

Unfortunately, absences must be interpreted carefully since the absence of a species record in one location does not necessarily mean the species is not there. Researchers must consider why an area on the map has no records, and this can be either because: a) no biodiversity survey was ever conducted there; b) data from that location have not been uploaded to a particular database; c) the species may have been present in the location during a biodiversity survey, but was simply not observed; or d) the species is actually absent from that particular location and would not be observed even under the most intensive biodiversity sampling efforts. Other strengths and limitations of biodiversity databases have been discussed in the literature and include incomplete information, inaccurate locations, incomplete and/or biased sampling, among others (e.g., Otegui et al. 2013, Beck et al. 2013, 2014).

tribution patterns of one selected taxonomic group; b) examine the biogeographical changes this taxonomic group has experienced through geologic time; c) identify potential threats related to the conservation or spread of this taxonomic group; and d) identify and evaluate opportunities for conserving or managing this taxonomic group. In doing this, you will first review the core concepts of biogeography and then apply them to understand your group's distribution using a global species distribution database. Additionally, you will explore the primary literature to expand your understanding of the processes that have led to the current species distribution patterns, and think critically about the possible conservation biology implications for your specific taxonomic group. Fundamentally, these goals will be met through the hands-on creation of species distribution maps, which will provide the most up to date information on your selected taxonomic groups along with the creation of an oral presentation and written report.

OVERVIEW

For this assignment, the class will be divided into

teams of 3–4 students. During the next four weeks, each team will gather information via the GBIF species distribution database and create distribution maps for a given taxonomic group—hereafter referred to as your "taxon" (singular), or "taxa" (plural). Your taxon incorporates all the species within a particular taxonomic family or order. If information is available, you will also explore distribution maps of fossils for your taxon. All of these maps, along with information collected from primary literature, will help your team to form a number of testable hypotheses. Specifically, your team will derive hypotheses on: a) the geographical origin of your assigned taxon; b) the current distribution of the assigned taxon; c) the leading conservation risks for your assigned taxon; and d) the conservation mechanisms (including management) that can possibly address the current threats in the Anthropocene. At the end of the project, each team will share their results with the class in an oral presentation, and each team will submit a written scientific report based on their project (see rubric and Appendix I for more information on the report instructions). Over the course of the next four weeks, each team will be expected to work on their report outside of class time.

By Week 3, your explorations will allow you to answer the following questions from Box 2 (see below). As you proceed through the week activities, keep in mind that your answers to these questions will be included in the discussion section of your final report. Additionally, be aware that there are several leading journals in the fields of biogeography and biodiversity, including *PLoS ONE, Frontiers of Biogeography, Diversity & Distributions, Global Change Biology, Conservation Biology, Biological Conservation,* and *Journal of Biogeography.* These resources will also be helpful in developing the discussion for your report on the biogeography and conservation of your taxonomic group (also see the references).

ACTIVITIES WEEK-BY-WEEK

1. Week One: Biogeography Data Acquisition From GBIF

During the first week of the assignment, your team will need to accomplish the following: a) choose your taxon from the list provided; b) download your dataset from GBIF; c) import your data into a working database (e.g., Microsoft Excel); and d) use the working database to derive a map of your taxon's global distribution. In doing so, you will also e) begin to document and explore the limitations of the data available on GBIF for your taxon.

1.1 Select a Taxon

First, your team should select a taxon for your project and report your decision to your instructor. Based on

Box 2. Questions for discussion

Section A: Understanding current distribution (*answer all* the following):
1. Describe the present distribution of your taxon in terms of biomes and habitat requirements. Also list the continents/regions where your taxon is present or notably absent; are there areas where the contrast-taxon is found but your focal taxon is absent? Or areas where both are absent?
2. Using your GBIF occurrence data, and your peer-reviewed literature review, speculate on which geographical area this taxon might originate from.
3. How might this taxon have arrived at its present distribution? Specifically, discuss what are the barriers and dispersal pathways that might have existed, which explain your taxon's current distribution. If fossil information is available in your maps, use it to discuss your observations. (Remember that barriers and continents may change in the time span of your taxonomic group. Compare the geographical history of your taxon with geological history. Take into consideration invasive species that can blur other patterns.)
4. Are there problems with the taxonomy for this taxon that limit or confound the understanding of its distribution? Explain your answer (e.g., consider the approaches in identifying species from your focal taxon and revisions made to its taxonomic classification).

Section B: Conservation biology of the taxon (*answer only two* of the following, based on which are most relevant for your taxon group):
1. Are there any endangered species in your taxon? Explain why or why not, based on your GBIF data and/or your literature search.
2. Is endemicity a major factor that would affect the conservation status or potential management options for your taxon? Why or why not?
3. Would you expect the present-day distribution of your taxon to shift under climate change? How?
4. Does your taxon include any number of invasive species? Why or why not, and what are the likely mechanisms of invasion?

Section C: Conservation into the future (*answer only one* of the following):
1. Identify one region that you think should be protected, as a means to ensure the conservation of your taxon. In that area, identify two processes that threaten the survival of your taxon, and suggest mechanisms to deal with these threats (here, you may incorporate any real ongoing projects that may be in this area). If the threats that you are analyzing only apply to a subset of your taxon (e.g., one or a few species of a genus or family), then explain why you chose this particular species and region.
2. Identify one region where your taxon is considered a threat to an ecosystem. In this area, identify why a particular species from your taxon is a threat to the other species in the area, and suggest at least two mechanisms to manage and mitigate these threats (here, you may incorporate any real, ongoing projects that may be in this area). If only a subset of your taxon is a threat for the ecosystem/region, then explain why you chose this particular species and region.

Section D: Data limitations
1. Explain any major limitations associated with the methods that you used in this assignment.

a number of factors, including sufficient data coverage in the GBIF database, conservation importance, and public knowledge of these species, the following taxa have been identified as recommended options for this exercise:

1. Spine crawler mayflies (Ephemerellidae)
2. Pond turtles (Emydidae)
3. Narrow-mouthed frogs (Microhylidae)
4. Boa snakes (Boidae)
5. Viper snakes (Viperidae)
6. Megabats (Pteropodidae)
7. Horses (Equidae)
8. Beavers (Castoridae)
9. Opossums (Didelphimorphia)

After you have made your selection, you will begin by gathering general information about your taxon. In particular, you will need to focus on the types of ecosystems and habitats your taxon is associated with. How far does your taxon travel and disperse? Are there habitat types or environments that the taxon cannot cross, posing as dispersal barriers? Altogether, this information will help you to understand how your taxon might have become distributed throughout different parts of the world.

1.2 Download Your Data

Once your taxon has been selected and confirmed by your instructor, you will then download and process data on that taxon from the GBIF website (http://www.gbif.org/). Copy the suggested citation for your downloaded data from the GBIF website. Appendix II outlines these technical aspects and the step-by-step data acquisition process.

You will find that your GBIF dataset includes occurrence data for your taxon. Each row in the downloaded spreadsheet corresponds to an occurrence record with information about the observed species' taxonomy (order, family, genus, species), where the occurrence was observed (i.e., latitude, longitude, altitude, country, state), when the occurrence was observed (i.e., date of the record), and how that occurrence was recorded (e.g., live animal field observation, information from a museum collection, fossil collection). Re-read Box 1 for a

review of information about GBIF data.

Note here that GBIF occurrence data may be representative of the current distribution for a species, and/or a historic distribution (if fossil observations are available). Because the assignment is at a global scale, the distribution map you create from GBIF information will be reliable only if there have been enough chances (or adequate sampling effort) to allow for reliable surveys and records of the occurrence of your taxon around the globe. "Good sampling" implies many samples distributed widely across the expected distribution, without a strong sampling or reporting bias (such as intensive sampling only in one small part of the world).

1.3 Make a Map of Your Taxon

Your downloaded GBIF dataset is a snapshot of the information on the distribution of your taxon, made available from several museums, universities, and research centers around the globe. A key task is now to create maps that can help you to understand, and more importantly, visualize the distribution of your taxon (and the species in it) around the globe. These distribution maps that you are building do not intend to describe the probability of finding a given species, although some modern algorithms (e.g., Maxent, ENFA) can produce those types of maps using data from GBIF or similar sources. In this exercise, your group will be building maps similar to the maps used in the published biogeography literature, which are based on known distributions of the species (while also acknowledging information gaps in the process).

Computer templates that will help you build these maps are provided (see Appendix III), but first your team will need to organize your downloaded data in order to keep only the relevant pieces of information. Furthermore, in addition to a map that simply shows the occurrence data for your taxon, you will need to create supporting information. This will include: a) a secondary map showing the number of species of your taxon occurring in different parts of the world; b) a table that includes the names of the species in your taxon, along with information on the extent of their distribution, measured as the number of squares or grid cells each species occupies (each of which represents

a 10º latitude by 10º longitude area), and lastly c) a table that relates valid species names in your taxon with their synonyms. Appendix III explains in detail how to use a simple database management program (namely, Microsoft Excel) to summarize the thousands of records you downloaded from GBIF, into a smaller dataset that contains only the required information to build the maps and tables.

1.4 Using a Contrast Map to Document Sampling Bias

This is a good stage in the assignment to begin documenting some of the limitations of biogeographic data. Specifically, at this stage you may start to notice evidence of sampling bias, something very common in biodiversity and biogeography data (Zhang et al. 2014). Presence-only data make it hard to distinguish sampling bias from real absences (see Box 1). With respect to sampling bias then, your group must think critically as to whether or not the occurrences in your downloaded GBIF database are truly representative of the global distribution of the species.

For example, it is often the case that areas further from roads are harder to sample, developed countries have more resources for reliable sampling, and countries more interested in connecting to the GBIF are better represented. Also, sampling bias certainly occurs across taxa, with charismatic species generally having larger and more consistent sampling efforts. Consider the panda bear, *Ailuropoda melanoleuca* (Ursidae), as an example: a great deal of resources are available for protecting this species, and there are intensive monitoring programs in place. In contrast, the red panda, *Ailurus fulgens* (Ailuridae), is a less charismatic species and as a result receives less funding and support for monitoring. In turn, the red panda is considerably less well evaluated in biodiversity databases as compared to the panda. Additionally, zoo records can commonly be included in databases which can bias your datasets, and even subtle spelling mistakes in species names or typos in coordinates may lead to data biases. For example, if you find an elephant living in Toronto or a polar bear in the Caribbean, they are likely taxonomic or coordinates typos or specimens in zoos.

One way to distinguish areas with real absences, vs. areas

with no sampling effort, is to look for species that can be sampled using methods similar to the ones used for the taxon of interest. For instance, if you are studying a particular group of bats (such as vampire bats), how can you use information collected for other bat species? One way is by assuming that bat sampling methods (such as mist nets) are likely to capture most bat species, but not other species with different characteristics such as mice or cats. Therefore, a contrast map, a map showing the distribution of all the bats recorded in the database will provide a rough estimate of the distribution of "samples" (places where bats have been collected). For example, an area that has both a high density of bats (i.e., an area with several samples) but is lacking in vampire bats would indicate a real absence of vampire bats: in other words, no species occurrence records despite a large sampling effort are much more likely to be real absences. The contrast map will provide a contrast to compare with the distribution of your taxon of interest.

Since this assignment is at a fairly coarse spatial and taxonomic scale, the presence-absence sampling pattern should be good enough to give an idea of potential sampling bias. In any case, the conclusions gathered from the map will be revisited during the second and third week. Discuss with your team and your instructor which taxon may be a good option to use as a contrast group to compare with your species of interest.

1.5 Week One Outcomes

At the end of week one, your group should have:
- a brief note about the primary habitat requirements and common dispersal characteristics of species representative of your taxon;
- a table of occurrence for your focal taxon, obtained from the GBIF database (file occurrences.csv);
- a table that relates valid species names in your taxon with their synonyms (Appendix III, Step 3);
- maps of your taxon's distribution as obtained using the "map" spreadsheet in the Excel file "dataFrame. xlsx";
- two secondary maps showing the locations of a) the number of extinct (fossil) species and b) extant species of your taxon, both created using the "map" spreadsheet in file "dataFrame.xlsx" (for the fossil map, choose the tag "richness" and fossil

"TRUE" in the top selectors in the spreadsheet, for the extant species use the same tag but fossil "FALSE");

- a table with the scientific names of the species in your taxon, along with information on the number of squares where each species is represented (created using spreadsheet "taxaAbundance" in spreadsheet "dataFrame.xlsx"; where each square represents a 10º latitude by 10º longitude area);

- contrast map obtained directly from GBIF showing the distribution of the extant taxon that will be used to assess the sampling bias (Appendix II, Part 2), and your team's assessment of the level of bias likely to apply to your taxonomic group.

2. Week Two: Data Exploration

For the second week, your group should come prepared with the outcomes from the first week and be ready to: a) explore your data; b) evaluate its consistency; and c) gather additional information you may need to answer the questions of this assignment (outlined above in Box 2). In general, by addressing these questions, you will begin to link ideas about how multiple different ecological, evolutionary, and landscape-level processes may have shaped the distribution of your taxon. Review the third weeks' activities to have a better idea of the type of information you will need and then distribute the tasks among your group members accordingly.

2.1 Exploring Your Data

Now that you have your basic study tools from Week 1, you can start creating distribution maps for the different species in your group. In this step, use your curiosity to create some questions and answer them. The first questions can (and perhaps should) be focused on exploring and learning Excel functionality in order to map the taxonomic distributions you compiled in Week 1. Specifically, how can you use the filters to map fossils and living specimens?; How can taxonomic richness be mapped?; Where are the actual continents in your coarse resolution map?; Or where are the archipelagos? Once these more technical questions are addressed, you can start exploring whatever scientific ideas catch your interest: for example, which species have larger latitudinal range? Which species occupy a greater area in the world? Are these species distributed across the entire world? Are the species with smaller ranges constrained to a particular geological/geographical part of the world? Also, you can now examine the richness maps that indicate the number of species (either fossil or extant) in different parts of the world and ask yourself whether they show similar patterns.

2.2 Evaluating Data Consistency

Start by identifying potential gaps in your occurrence table downloaded from GBIF. For instance, if there is an area in South America with no occurrences of your taxa, and no occurrences of your contrast group either, search the scientific literature for papers focused on your taxon in those countries, and use these sources to confirm that your taxon is indeed not likely present in these areas. Also, by this stage your group should have evaluated whether or not your taxon has synonyms; if synonyms were identified, review the scientific literature and evaluate the distribution of those synonymous species. If you cannot find any scientific literature on your taxon within a region that your GBIF data also suggest does not contain your taxon, you have indeed identified a likely real absence in the distribution of the taxon. If you find a paper about your taxon (or synonym) in a particular region, you will have to add this record in your Excel database. Before adding the information, make sure that the species name you are adding is indeed valid (remember to consult your list of valid taxon names and their synonyms obtained by the GBIF database during the first week). These gaps should be included in your final report, along with the additional literature you have found.

2.3 Gathering Relevant Information

Different taxa have widely different evolutionary histories and face a variety of conservation problems. Use the discussion questions in Box 2 to direct your readings. The first piece of relevant information that you will want to document is the evolutionary history of your taxon. Specifically, attention should be given to the 'age' of your taxon, the current understanding of its evolutionary origins, the possible pathways it followed to disperse into its current distribution, potential extinction events that occurred in the past,

or other events that led to the isolation of a once wide-spread species (i.e., a need for your taxon to retreat to refugia). In sum, this information collectively should give your team an idea about how your taxon's current-day distribution patterns came to be. Use your map in dataFrame.xlsx to generate fossil maps and explore the information obtained from GBIF.

In addition to your taxon's evolutionary history, your team should also document patterns of your taxon's endemicity: any major restrictions on the distribution that confine your taxon to a particular geographical area. This is highly relevant for some taxa (especially those that do not disperse particularly well) and can be very helpful in understanding the origin of a taxon. Your team should also note whether or not your taxon contains any invasive species; identifying invasive species, particularly those facilitated by human movement, is important since such species can introduce complexity when interpreting spatial patterns and their mechanisms. Your team should attempt to discern instances of endemism or invasiveness, by using the table that counts the number of squares (each of which represents a 10º latitude by 10º longitude area), the taxon of interest occupies in the Excel map (see "taxaAbundance" spreadsheet in the "dataFrame.xlsx" file); endemic species should occupy a disproportionately small number of cells, while invasive species should occupy a disproportionately large number of cells. You may wish to reproduce these Excel maps for specific species to show the scale at which they are endemic or invasive to a region. Organize your findings of this and the previous week in a text that can be used later for the introduction of your final report.

2.4 Week Two Outcomes

At the end of week two, your team should have:
- a compilation of literature addressing the age (or hypothesized age) of your taxon, and of any particular subgroup you may find important to explain how the focal taxon arrived at its present-day distribution;
- all the data products from week one (see Section 1.5), supplemented with the data acquired during this week, including notes on the data consistency and invasive/endemic species; and
- an expanded written description of the taxon to

include in the final report—this should provide you and the reader with an understanding of the potential habitat requirements and barriers, including the dispersal mechanisms involved.

3. Week Three: Data Analysis and Questions

At the beginning of the third week, your team should come prepared with complete background descriptions of your taxon, including data tables, distribution maps, and written background information. You should begin to organize these data in such a way that they are useful for answering the discussion questions (see Box 2). Each member of your team will come to this week's session with your initial ideas surrounding potential answers and any questions you may have for your instructor to the discussion questions and questions for your instructor.

During the third week, your team will begin to prepare your final report, will answer the specific questions (see Box 2), which should be addressed in the report's discussion section, and will prepare your 12-minute presentation (note: time requirements may be altered based on your instructor's discretion).

3.1 Discussion Questions

The questions in Box 2 are designed to summarize the biodiversity and biogeography information that you have compiled on your focal taxon and are a guideline for the discussion section of your report (GBIF occurrence data, distribution maps and other tables, literature review). The questions are divided into three sections; the first section (A) focuses on biogeographic patterns, in particular the distributional map, as well as guidelines to understanding your map. The second section (B) introduces questions that may or may not be relevant to your particular taxon. Your first task in section (B) is to *identify and answer two* of these questions relevant to your taxon. In the third section (C), you will *identify and answer only one* of the questions to integrate the information collected previously into the context of conservation threats faced by your taxon. Finally, in the fourth section (D) you will discuss the potential limitations of your study. See the rubric for some extra details on each question. Drawing upon the Excel results and skills you developed in Week 1, create maps and

tables than can help you to answer those questions, and present them in the results section, with a brief description of the most important patterns you observe that are relevant to answering the discussion questions (refer to the rubric and Appendix I). In the discussion, provide detailed and fully developed answers and reference scientific literature as appropriate.

3.2 Preparing Your Presentation

Each team member will be required to speak, and provide information that gives either background, answers specific questions or summarizes the overall report on this taxon, as appropriate. As a team, you are free to choose your presentation format, but it is expected that your presentation will cover the assignment topics (in particular the discussion questions) and integrate your understanding of your focal taxon's distribution and ecological requirements. If you do not think you will have enough time to explain everything, choose the most relevant points of each question that you want to share or discuss; for instance, you may choose to explain distribution patterns for a smaller number of the most representative species within your taxon that are poorly represented, endemic, or highly threatened species. Whatever you choose, make sure to explain why they were chosen briefly your decision. Detailed guidelines on the presentation are in the rubric and Appendix I.

3.3 Looking Ahead

During the fourth week each team will: a) present their results to the whole class in a 10-minute presentation; b) receive feedback and suggestions to improve their report; c) incorporate that feedback into their report; and d) submit one single team final report for their assigned taxon. It is also advisable to contextualize and discuss the findings of the other teams compared to the findings of your team in your final written report. Specific guidelines for the report (length of each section, requirements, etc.) can be found in the rubric and Appendix I.

3.4 Week Three Outcomes

At the end of the third week, your team should have:
- a working draft of your report that demonstrates:

- a clear understanding of the distribution of your taxon
- a clear understanding of the processes that shaped your taxon distribution
- a clear understanding of potential implications of your taxon's distribution for conservation
- a discussion section that addresses the questions selected from Box 2.
- A 10-minute presentation which will be presented in Week 4

4. Week Four: Project Presentations

At the beginning of the fourth week, your team should come prepared with your presentation, as well as a draft of your final written report. The final class period will be devoted completely to presentations, where each team's analysis and recommendations will be presented to the class.

4.1 Week Four Outcomes

At the end of week four, your group should have:
- presented your analysis to the class
- a clear understanding of the strengths and weaknesses of your analysis
- a plan to incorporate student and instructor feedback received during your presentation, into your final report prior to its final submission.

Final Report

You will have some time after your presentation to make any last-minute revisions or changes in their answers/report based on information raised during the final presentation. Review the schedule provided by your instructor.

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RUBRIC

Team members (initials):

TITLE PAGE (1 PAGE)					
Indicate primary responsibility of each student (sections and questions). Each group member must sign the report beside their name accepting the division of labor as indicated.	Mandatory				

INTRODUCTION (400 WORDS; ~1.5 PAGES)					
Criteria	**Absent or irrelevant**	**Present and relevant**	**Relevant, concise, and well documented**	**Mark**	**Comments**
The topic of the study and primary research questions are well presented and easily flows for an academic reader.	0	1.5	3		
The main characteristics of the taxon (habitat, dispersion, age, etc.) are neatly and succinctly explained.	0	1	2		
Conservation issues of the species are discussed, if needed, with emphasis in particular areas.	0	1	2		
An overview of the data analysis is explained.	0	0.5	1		

MATERIALS & METHODS (500 WORDS; ~2 PAGES)					
Criteria	**Absent or irrelevant**	**Present and relevant**	**Relevant, concise, and well documented**	**Mark**	**Comments**
The approach to obtain the data and the sources is clearly presented.	0	1.5	3		
General explanation of how every single map and table in the document (including appendices if present) was constructed.	0	1.5	3		

RESULTS (INCLUDING TABLES, FIGURES, MAPS; ~3-4 PAGES OF TEXT; ~1000 WORDS)

Criteria	Absent, irrelevant, or inaccurate	Partly relevant or partly accurate	Fully relevant and fully accurate	Mark	Comments
Figures/tables: It is easy to understand the message from the figures and tables (figure is appealing, units are present, properly labeled and captioned).	0	3	5		
Figure/table: The figures and tables help to support the message in the document.	0	3	5		
The most important patterns presented in the figures and tables, and relevant to the discussion, are properly described.	0	2	4		
The results are easy to read and no more tables or figures seem required to supplement the message of the document.	0	2	4		

DISCUSSION: (~1800 WORDS; ~7 PAGES MAX)

Criteria (by lettered parts)	Absent, irrelevant, or inaccurate	Partly relevant or partly accurate	Fully relevant and fully accurate	Mark	Comments
A. Description of the current distribution of the taxon.	0	4	6		
A. Discussion of the area of origin of the taxon.	0	3.5	5		
A. Discussion of the potential dispersal patterns and barriers of the taxon and how them leads to the current distribution.	0	4.5	8		
A. Discussion of the challenges in the taxonomy of the group.	0	2	3		
B. *Two questions selected from B list help to understand the challenges faced by the taxon.*	0 (Irrelevant questions)	1 (Partially relevant questions)	2 (Two relevant questions)		Not needed to explicitly address this point.

B. The reasons behind the presence or absence of endangered species are discussed.	0	3	4		
B. Endemicity patterns are used to logically analyze conservation priorities.	0	3	4		
B. The potential impacts of climate change on the taxon are analyzed.	0	3	4		
B. Different mechanisms of invasion are analyzed in the particular context of these species.	0	3	4		
C. An area of the world is identified, described and the reason for its selection explained.	0	1	2		
C. Two threats and two solutions for them are justified, described and discussed.	0	3	4		
D. Limitations: The limits of the study are clearly presented and the implications for the results briefly described.	0	2	3		

CONCLUSION (~250 WORDS; ~1 PAGE)

Criteria	Absent, irrelevant, or inaccurate	Partly relevant or partly accurate	Fully relevant and fully accurate	Mark	Comments
Complete and succinct characterization of the distribution of the group, potential origin, barriers and pathways, conservation challenges and relevance for conservation.	0	4	6		

REFERENCES CITED (~250 WORDS; ~1 PAGE)					
Criteria	**Absent, irrelevant, or inaccurate**	**Partly relevant or partly accurate**	**Fully relevant and fully accurate**	**Mark**	**Comments**
Citations used throughout the document are in a consistent and recognized format.	0	1	2		
All sources cited in report are listed in References section using a consistent and recognized format.	0	1	2		
FORMAT					
Criteria	**Absent, irrelevant, or inaccurate**	**Partly relevant or partly accurate**	**Fully relevant and fully accurate**	**Mark**	**Comments**
Typed, 1.5 or double-spaced & appropriate length. Clear & concise presentation of text (i.e., text flows logically and is coherent, correct spelling, proper grammar and structure overall).	0	1	2		
DATABASE					
Spreadsheet file used to analyze the data.	Mandatory for report to be marked and for results to be verified				
GROUP REPORT (TOTAL)	**0**		**85**		

ORAL PRESENTATION (INDIVIDUAL - 15 POINTS)	MAX	STUDENTS (INITIALS)				
Presentation is easy to follow with clear organization (i.e., specific intro and conclusion), no ideas "out of place", and no irrelevant information.	3					
Content is directly relevant to the assigned topic, and all supporting evidence is accurate, high quality, and directly used to evaluate specific research questions.	2					
Students display a complete understanding of the subject matter, clearly explain the research questions, supporting evidence, and end with a clear and comprehensive take home message.	3					
Delivery makes the presentation compelling, speakers are confident, language is clear and easy to follow.	2					
Presentation includes clear, relevant, and aesthetically pleasing aids which are directly related to topic; all slides have appropriate text and precise, relevant info.	3					
Timing is appropriate and allocated sufficiently across all different parts of the presentation.	2					
	Total					

APPENDIX I. WRITTEN REPORT

You will write your report following standard scientific paper guidelines. Below are some general suggestions, but review the rubric for specific requirements. For more information on scientific writing, see the NCEP module *Scientific Writing*, available for download at ncep.amnh.org.

Introduction Guide

The *Introduction section* must give the reader basic knowledge to be able to understand the whole purpose of the paper. You must make the introductory statement clear, giving the context for the study and explanation of the perspective. What are the key questions you ended up exploring with these data? Why did you take this approach? What information is already out there (what literature) to help you understand the knowledge that you are building?

The introduction should also describe the most important characteristics of the taxon you are working with, where it is and has been found, what types of habitats and the climatic conditions necessary for its survival. Also, some mention of its dispersal capabilities would be important to mention to allow the reader to understand your rationale and discussion below. If appropriate, you may also wish to briefly build a case for conservation of your focal taxon by presenting some of the threats that may limit its survival.

Methods Guide

The *Methods section* is a succinct and brief description of the most important steps that you took to get your results, so that anybody can understand how you obtained your results and, if they wanted to, could replicate the study. Here, you have to explain how you got the results that you are presenting, without specific details of the steps you used to get them. For instance, you have to refer to the fact that you used GBIF data information, and you have to cite it following their suggestion, but you don't have to explain how to download the data.

Results Guide

In the *Results section*, you should write about and highlight the major results that you identified from your data analysis. In addition to summarizing your results within the text, the data should be presented in the form of maps, tables, charts, graphs, figures, histograms, or any other tool that can help to synthesize and visualize the most important findings that you are trying to communicate. You may want to include a map describing the number of species (within your focal taxon) in each area of the world, and also some maps for those species that show the most interesting distribution patterns (those patterns that you will most likely discuss in your next section). Don't forget to include a legend (e.g., color scale) in your maps and captions to describe your figures and tables.

Discussion Guide (Questions To Address)

The *Discussion section* should include answers to the specific questions previously provided in Box 2, along with the implications of the results. These questions should be answered in scientific writing format rather than short answer format (e.g., don't list the questions/answers, but instead write a narrative that provides a detailed and fully developed discussion of your answers). Discuss possible explanations for biogeographic distributions and potential issues related to conservation. Finally, what gaps existed in the literature or in your data that present limitations to your analysis? In some cases, you may need to restate some of the ideas that you presented in the results, which is okay, but in this section you will need to add references to put your comments in context of previously published literature.

Optional: If you prefer and receive approval from your instructor, you may write a section combining results and discussion. In that case, you can link to one of your figures or tables that can help answer the particular question you are addressing. Be aware that some questions will need specific results, while others may require a more comprehensive analysis of your general results.

Conclusions Guide

The *Conclusions section* will address the overall importance of your taxon, its origins, past and present distributions, ecological challenges (barriers/pathways), and significance for conservation.

Reference Guide

All references used to support the introduction, methods, and discussion sections of the paper must be cited in proper order at the end. Only appendices (optional, if you decide to not embed figures and tables within the text) will appear after this section. Try to limit your literature to peer-reviewed journals. If you are unsure of the reliability of sources, consult with your instructor.

Each reference source should be listed alphabetically by author and provides sufficient information on it so that any reader will be able to retrieve it and verify the statements made in the paper. The format of the reference section is less important than the requirement to be consistent in formatting throughout. One suggested way of proper referencing is to use the standardized APA or similar format: www.apastyle.org/learn/tutorials/basics-tutorial.aspx.

APPENDIX II. RETRIEVING DATA FROM GLOBAL BIODIVERSITY INFORMATION FACILITY (GBIF)

GBIF is organized in four sections: Occurrences, Species, Datasets, and Data Publishers. The four sections are linked, but you will work only with the first two ones.

1. Downloading occurrences:
    a. Go to http://www.gbif.org.

    b. Select occurrences.
    c. The screen is now divided in three main parts, the menu on the top, the filter menu on the left, and the occurrences report on the right. While you apply your filters (left menu), you will notice that the number of records that match the result changes ("search occurrences" in top middle section) will change.

d. Add a *Scientific name* filter: Search for your taxon (order, subclass, superfamily, genus, species, etc.). Tip: use the dropdown list (you may need to do an internet search to figure out which groupings to select at each level). BE CAREFUL! A same genus, species, or family name can be used in different kingdoms.

e. Add a location filter, to filter out the occurrences without coordinates.
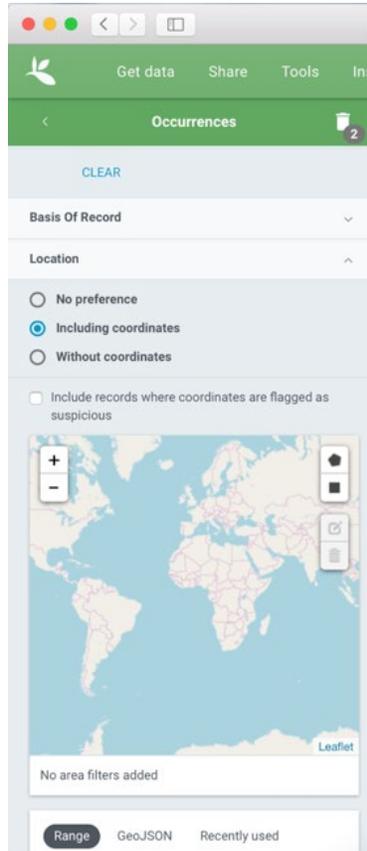
f. Add other filters that you might consider useful.
g. Press the download button in the top-center. To download the data, you will need to create an account. Follow the steps indicated in the webpage.
h. Once your account is created and you press the download button, you will be able to choose the format. Simply press the CSV button. Take some time to review the information provided in the webpage.

i. After you press the download button, the server (the computer at GBIF) will begin to gather information from the different servers around the world that can contain relevant information for your query. Once it is ready, you will receive an email saying that you can download your file. The email contains a link and a reference! Keep that email to add the reference later to your report.

j. Click on the provided download link in the email and automatically the file will download (often as a zip file). Unzip and save it with this name: *occurrence.txt* (the default name will be *occurrence.csv*, try to change to *occurrence.txt*. See suggestions below. Talk with your instructor if you have problems doing it). You may receive a prompt from your computer warning you that you are changing the extension of your file. Ignore the warning and continue.

2. It may take up to 15 minutes for the data to download from the servers, so take this time to review the general information of your taxon from GBIF by clicking on the other categories in the top section (e.g., map). These sections are especially useful to determine what your contrast group will be.

   a. Repeat steps (a) to (f) from the previous section, using another taxon (e.g., your contrast group, anything that interests you). Feel free to explore other orders, families, genera, species or any other taxonomic levels.

   b. With your contrast taxon, browse through GBIF information as you did with your focal taxon. There is no need to download the GBIF data for the contrast taxon.
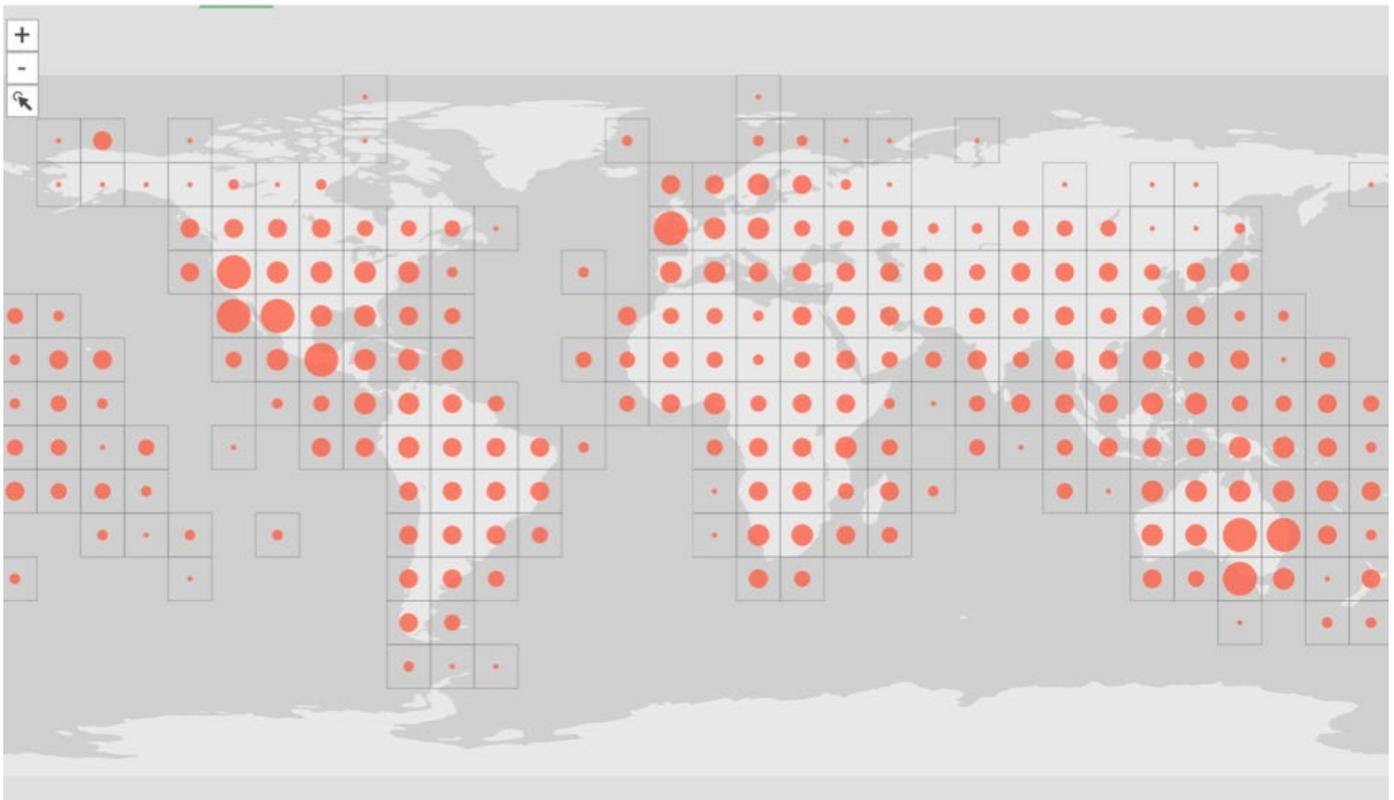
c. At least for your contrast taxon, select the map view, take a screenshot and save it for future inclusion in the final report.

APPENDIX III. IMPORT YOUR DATA INTO A DATABASE (EXCEL AND R)

Excel Instructions (Adaptable to Other Similar Software)

The following instructions have been developed in Excel for Mac 2011, so certain details may differ. All of the functions are likely available in more recent versions but may be located in different menus or ribbons. Similarly, alternative programs such as LibreOffice, Numbers or Google Sheets will likely offer the same capabilities, but the location of the functions will differ compared to the steps detailed here.

Warning: Early versions of MS Excel (i.e., Excel 2003 and earlier) are unable to handle more than 65,536 rows of data. Newer versions can handle up to 1,048,576 rows. When you query GBIF, if you have more occurrences than the maximum number of rows permissible through the version of Excel being used, then another software may need to be used with the file.

Before using this document, be aware that you need:
-   The *occurrence.txt* file downloaded from GBIF (see Appendix II). This file provides the species distribution information.
-   The *dataFrame.xlsx* file provided by your instructor. This file contains a simplified base map of Earth and formatting information that will allow you to superimpose your data on to it at later stages of the assignment.

Tips: General suggestions when dealing with large datasets
-   Keep a backup of your raw data.
-   Never sort the raw data: if you don't do it properly, you will shuffle your data and it will no longer make sense.
-   Save different versions of your file with each of your intermediate steps.
-   Confirm the results you obtain in each step: it is very hard to track the source of data issues at the very end following extensive analysis, so confirming results at each step is advisable.

Step 1. Open the occurrence.txt file downloaded from GBIF

This is likely the least interesting step, but can potentially be the most frustrating and discouraging because of the small computer formatting-related details. Specifications at this stage may also change from computer to computer owing to (for example) your browser configuration. At this stage, do not hesitate to ask for help if you cannot open the file. It is expected that you may need a bit of assistance during this step.

From Finder (on Mac OS x) or Explorer, you can try this option:
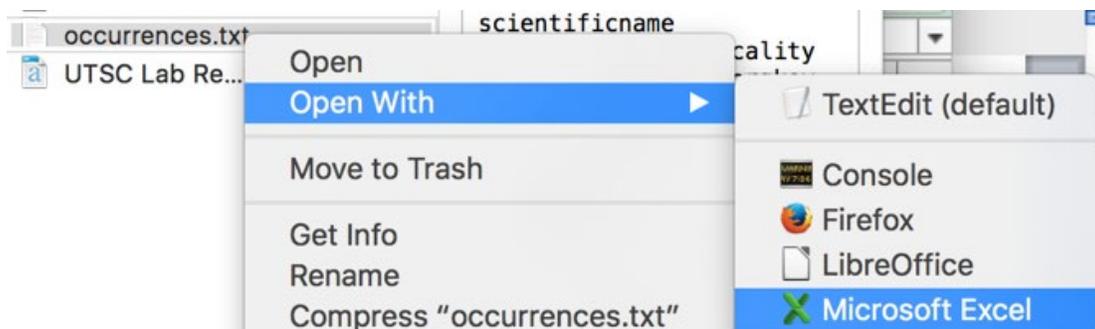
From Excel, use the following command: File > Open > Choose your file.

Since your GBIF data is downloaded as a text file, it is likely that you will see the "Text import wizard" window:

In this case, select "Delimited", press "Next >".

Now you have to choose the character that will be used to delimit (or separate) the cells from one another. Despite the file extension originally being ".csv" (which means "comma separated values") when you downloaded it from GBIF, the values are actually delimited by tabs. So check that option only in the "import wizard".

You should be able to see the columns properly separated in the data preview. Press Finish.

Tip: Confirm proper structure of your data
Sometimes Excel does not automatically recognize the format of the GBIF data, and it will open the file and show something like:

If your data appears like this, then there is no clear distinction among cells and the data will visually seem very disorganized. In this case, you have to rename *the extension* of your file (to ".txt") and force Excel to read the downloaded file as a plain text file. Important: Sometimes changing the extension of a file is very tricky in MS Windows. If you cannot do it, contact your instructor as soon as possible.

Finally, review and familiarize yourself with your file to be sure everything is displaying properly in different columns. It is usually a good idea to freeze the first row. (In Excel, follow this command: Layout > Freeze panes > Freeze top row.)

Step 2. Cleaning the data

Keep only the useful columns that include information about what was collected (taxonomy), how, when, and where it was collected. You may not use all of these columns, but they may help you to understand your results later. In summary, your working data should retain only the following columns:

TYPE OF DATA	WHAT WAS OBSERVED?					
Column	A	B	C	D	E	F
Field	family	genus	species	infraspecificepithet	scientificname	
Content	Taxonomy (Family)	Taxonomy (Genus)	Currently valid scientific name	Taxonomy (infraspecies level)	Scientific name as originally reported	Leave this column empty

Note: If the data in the columns entitled "species" (Column C) and "scientificname" (Column E) do not match, it means that there may be a synonym that you must be aware of. You will identify these in the next step.

TYPE OF DATA	WHERE WAS IT OBSERVED?				WHEN WAS IT OBSERVED?	HOW WAS IT OBSERVED?
Column	G	H	I	J	K	L
Field	countrycode	locality	decimallatitude	decimallongitude	year	basisofrecord
Content	Country	First territorial level inside a country	Latitude	Longitude	Year when the sample was collected	Fossil, direct observation, unknown?

You can delete the other columns (i.e., anything other than columns A-L above). Be aware that sometimes GBIF changes the field names or format. Also, hereafter, the below instructions will assume you have your columns in the described order and position.

In your dataset, certain rows without any species or genus name may exist. You can delete such rows once you are sure you will not need them for later analyses. This can be done by adding a filter (see below), selecting the species with (blank) names, and then deleting those rows. You may also decide to keep the genus level record (e.g., to keep as many fossils as possible). If you decide to keep them, you can just replace the empty species cell with the value in the genus column. If the genus is unknown, then the information is most likely irrelevant, and you can just delete those rows.

Tip: How to create a filter?

First, go to a cell in your table (e.g., cell A2 in the example), select all your table pressing command and A buttons, (Ctrl and A buttons for PC) and then click on Data > Filter.

The filter will allow you to show only certain rows without having to change the order of the table through sorting. To do this, go to the column you want to work with (e.g., column genus in the figure below) and press the triangle at the right side of cell. You will see a box with some options and the list of values in your column.

When the filter is applied, you can then select all the rows that are to be removed, by selecting the numbers in the left side of your screen. Then, once highlighted, delete all of these rows by selecting the option "delete" in the menu "edit". Then, clear your filter to see the remaining data.

Step 3. Finding synonyms

Synonyms are a common problem in taxonomy and occur when species thought to be different at first, are later found to be the same. Your GBIF dataset reports both the species as originally assigned to that particular record (column *scientificname*) and the current valid name (column *species*). The original scientific name column may include other information also, such as the subspecies (if any) or the authority information (the name and year the species was proposed). On the other hand, if the author of the occurrence (not of the species) was unable to identify the species, only the genus or even the family may be reported. To easily spot synonyms in your database use the F column and title it "Synonyms" and write this Excel formula below:

=(LEFT(E2,SEARCH(" ",E2,SEARCH(" ",E2)+1)-1))<>C2

as in

| | LEFT | | ⊗ | ⊘ | | _fx_ | =(LEFT(E2,SEARCH(" ",E2,SEARCH(" ",E2)+1)−1))<>C2 |

	A	B	C	D	E	F
1	family ▼	genus ▼	species ▼	infraspeci ▼	scientificname ▼	Synon ▼
2	Equidae	Equus	Equus niobrarensis		Equus alaskae (Winans, 1989)	-1))<>C2

This formula looks at the first two words (delimited by spaces) in the cell E2 (where the original scientific name is; column *scientificname*) and compares the result with the cell C2 (where the valid species name is; column *species*). If the scientific names in both the column *species* and column *scientificname* are different, you may have a synonym and the formula will return TRUE. If both of these columns match one another, the formula will return FALSE. Use the formula builder function in Excel to explore a bit more how it works, and remember, instructions inside brackets are solved first.

Tip: Copying formulae into other cells
To copy the function to all the cells below it, move your cursor to the right bottom corner of the cell that contains the formula. The cursor will change in appearance to a black +. Double click on the bottom right corner and your formula will be copied to every cell below it. Excel will automatically copy the formula until it encounters an empty cell (either below, or in the cell adjacent to the left).

Tip: Fast movements in the table
To move quickly through the table and identify breaks in the data that might prevent the complete copying of the formula, hold the Command key (Ctrl key in PC) and press the different directional arrows on your keyboard. That will allow you to jump through quickly, because it will look for changes between empty/non-empty cells. If you want to select all of these cells, then hold Shift and Command (Ctrl in PC) simultaneously, and then press the directional arrows.

Your table should like this:

| | LEFT | | ⊗ | ⊘ | | _fx_ | =(LEFT(E2,SEARCH(" ",E2,SEARCH(" ",E2)+1)−1))<>C2 |

	A	B	C	D	E	F
1	family ▼	genus ▼	species ▼	infraspeci ▼	scientificname ▼	Synon ▼
2	Equidae	Equus	Equus niobrarensis		Equus alaskae (Winans, 1989)	-1))<>C2
3	Equidae	Equus	Equus conversidens		Equus conversidens	#VALUE!
4	Equidae				Equidae	#VALUE!
5	Equidae				Equidae	#VALUE!
6	Equidae	Equus	Equus conversidens		Equus conversidens Owen, 1869	FALSE
7	Equidae				Equidae	#VALUE!
8	Equidae	Equus	Equus simplicidens		Equus occidentalis (Leidy, 1865)	TRUE

You will find different values that represent different situations:
- No synonym (Synonym value is FALSE), as in row 6 in picture above.
- Real synonym (Synonym value is TRUE), as in row 8 in picture above.
- The classification was done to genus or family level only (Synonym value is #VALUE!), as in rows 4, 5 and 7 in picture above.
- Incomplete information (Synonym value is #VALUE!), for instance, the authority information is not present in the column *scientificname* as in row 3 in picture above.

Using the filter in the column *Synonym*, select only the rows that are not FALSE; in other words select only empty cells, TRUE values, and errors such as #VALUE!. Once you decide a criterion is no longer needed (for instance, empty

cells are only caused by incomplete classification), you can update the filter by deselecting the particular value from the list.

In order to focus in on the actual synonyms, select only the TRUE values in the synonyms column filter. Now, you can copy the rows that can be observed in a new spreadsheet, and remove every column except for *family*, *genus*, *species*, *scientificname*, and *synonym*. Name the new spreadsheet "synonyms.xls", remove the duplicates, and explore the synonyms in more detail. To remove duplicated rows, simultaneously hold Command (Ctrl in PC) and the letter "A" in your *synonym* spreadsheet and use the ribbon to perform the following: Data > Remove duplicates tool.

Save this spreadsheet—it will guide your exploration of the literature. For instance, when you are filling gaps using literature, you must use the new taxonomic name to be consistent with your table, but older papers may still be using synonyms of the species. This table can also help you to understand potential problems of classification that sometimes are explained in papers. Be aware that some of these problems are not fully solved by experts in the field.

Step 4. Getting the species, coordinates, and the fossils

Now you will move back to the original spreadsheet, because you need to recover the genus only information if available, the spatial information stored in the columns *decimallatitude* and *decimallongitude*, and you also need to distinguish fossils from extant specimens. First, we need to deactivate the Excel filter in order to ensure we are using our entire dataset. To do so, use your cursor to select any cell in your original spreadsheet (in order to make the spreadsheet "active") and go to Data > Filter, and click on the filter button again to deactivate the filter.

Species and genus information:

Identifying species in the field or in the fossil records is hard, so you may find that sometimes genus information is the only information available. With your contrast taxon, browse through GBIF information as you did with your

focal taxon. There is no need to download the GBIF data for the contrast taxon. For your purposes, it is better to combine the genus and the species information in a single column. First, label the column *M* (that should be empty) as "SpeciesName". Then, you will see if the information in the column species is empty. If it is empty, it means the species name is unknown, so we will try to get the genus name. The next formula will do these tasks for you:

=IF(ISBLANK(C2),B2,C2)

copy this formula to the column *M*.

Hint: Review the previous tips to quickly copy formulae.

Your table should look like this:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
													IF	fx	=IF(ISBLANK(C2),B2,C2)			
1	family	genus	species	infraspecific	scientificnam	Synonyms	countr	localit	decimal	decimal	year	basisofrecord	SpeciesName	
2	Equidae	Equus	Equus caballus		Equus caball	FALSE	US	Bosto	42.301	-71.1		PRESERVED_SPECIMEN	=IF(ISBLANK(C2),B2,C2)	
3	Equidae	Equus	Equus hemio hemionus		Equus hemio	FALSE	MN		43.106	106.9	2013	HUMAN_OBSERVATION	Equus hemionus	
4	Equidae	Equus			Equus quagg	TRUE	KE		-1.48	35.06	2014	HUMAN_OBSERVATION	Equus	
5	Equidae				Equus quagg	TRUE	KE		-1.298	34.85	2014	HUMAN_OBSERVATION	0	
6	Equidae	Equus	Equus quagga		Equus quagg	FALSE	KE		-0.197	37.01	2014	HUMAN_OBSERVATION	Equus quagga	
7	Equidae	Equus	Equus grevyi		Equus grevyi	FALSE	KE		0.263	36.91	2014	HUMAN_OBSERVATION	Equus grevyi	

See in row 4, that the genus information is retained. If there are no genus or species information as seen in row 5, Excel will return a "0" value.

Fossils:

Fossils represent the historic distribution of species and can also provide information about their distribution before humans started to have an impact on the Earth's ecosystems. To distinguish between fossils and other type of occurrences, you will use the information in the column *basisofrecord.* First, you will label the column *N* (that should be empty) as "Fossil". Then, you will look for those records that are explicitly identified as fossils (i.e., basis of record is "fossil_specimen"). To do that, in the column *N*, use the formula:

=L2="FOSSIL_SPECIMEN"

Now, rows with TRUE values on column *N* represent fossils. Conversely, FALSE values in column *N* should represent non-fossils records, but GBIF is far from perfect and sometimes the basis of a record for an extinct species is recorded as "unknown". So, if you have independent information that states a species went extinct before any direct observation of the specimen was possible (e.g., more than 30,000 years ago), then you must manually change the cell value of the column *Fossil* from FALSE to TRUE. Of course, you will need to do some background research on your focal taxon and identify species that are known to have gone extinct.

At the end, the right side of the table should look like:

	IF				fx	=L2="FOSSIL_SPECIMEN"	
	I	J	K	L	M	N	O	P
1	decimallatitude	decimallongitude	year	basisofrecord	SpeciesName	Fossil		
2	42.301069	-71.100285		PRESERVED_SPECIMEN	Equus caballus	=L2="FOSSIL_SPECIMEN"		
3	43.106121	106.935609	2013	HUMAN_OBSERVATION	Equus hemionus	FALSE		
4	-1.48011	35.064852	2014	HUMAN_OBSERVATION	Equus quagga	FALSE		
5	-1.298103	34.851533	2014	HUMAN_OBSERVATION	Equus quagga	FALSE		
6	-0.197487	37.011887	2014	HUMAN_OBSERVATION	Equus quagga	FALSE		
7	0.263024	36.908709	2014	HUMAN_OBSERVATION	Equus grevyi	FALSE		

Coordinates:

You will summarize the information available into species present in squares of 10˚x10˚. This will help to: 1) focus on global distribution patterns and 2) control for unequal sampling.

To summarize the information, you will round the latitude and longitude of each occurrence record to the closest multiple of 10. To do so, you can use some math and the function "round" that, as its name suggests, returns the closest integer. For instance, if the coordinate is 17.3, the latitude should be transformed into 20. To do so using the function round, you divide the number by 10, (17.3/10=1.73), then you round the result (round(1.73)=2) and you multiply the result again by 10 (2*10 = 20). The Excel formula for this will be:

　　=ROUND(I2/10,0)*10

where "I2" refers to the second cell in the column *decimallatitude*. You can type this formula in the column O, and name it "Latitude".

Do the same for longitude in the column *P*: "Longitude". In this example the formula for this column will be:

　　=ROUND(J2/10,0)*10

Now, the right side of the table should look like:

	ROUND				*fx*	=ROUND(J2/10,0)*10				
	I	J	K	L		M	N	O	P	Q
1	decimallatitude	decimallongitude	year	basisofrecord		SpeciesName	Fossil	Latitude	Longitude	
2	42.301069	-71.100285		PRESERVED_SPECIMEN		Equus caballus	FALSE		40	=ROUND(J2/10,0)*10
3	43.106121	106.935609	2013	HUMAN_OBSERVATION		Equus hemionus	FALSE	40	110	
4	-1.48011	35.064852	2014	HUMAN_OBSERVATION		Equus quagga	FALSE	0	40	
5	-1.298103	34.851533	2014	HUMAN_OBSERVATION		Equus quagga	FALSE	0	30	
6	-0.197487	37.011887	2014	HUMAN_OBSERVATION		Equus quagga	FALSE	0	40	
7	0.263024	36.908709	2014	HUMAN_OBSERVATION		Equus grevyi	FALSE	0	40	

Step 5. Summarizing the information

The previous step will link each of the species to a 10˚x10˚ square representing an area on the Earth. If more than one species occurs in a single location, then you will have more observations than are needed for your analysis, and is one of the first reasons to generate a table with only one record per species per square. When you plot the map (see below) for each species, you will be able to easily identify its global distribution. The second reason for generating a table with only one record per species is that, as you may recall, you will also need to review the global distribution of the number of species from this taxon present on Earth (so that you can discuss whether the taxon is primarily tropical or present only in the Americas, etc.).

To do so, copy the four columns we created in your most up-to-date table with occurrences (step 4) into a new spreadsheet, and paste it using Paste Special option (or clicking on the clipboard once pasted) and select the option "values only".

And now it will look like

Now you can remove every column except for these: *SpeciesName, Fossil, Latitude,* and *Longitude.*

Select all the cells with values in your table and choose Data > Remove duplicates. You should get a table that looks like this:

Press "remove duplicates" and see the results. Copy the results to the spreadsheet, sppData, in the file *dataFrame.xlsx* provided by your instructor. Visually *confirm that the order of the columns is consistent* in both tables. If the column order is not consistent, reorganize the columns accordingly by cutting and pasting the columns into their proper positions.

As previously mentioned, some records do not have genus or species information. In those cases you will find a "0" in the SpeciesName column. You should delete those records as they provide little or no relevant information. To do that, add a filter and select with the filter the records with value "0" only. Then, press the row number selectors on the left and use the delete rows function in the edit menu, or right click and select the delete rows option. Finally,

remove the filter so that you can see all the records again.

Step 6a. Understanding the data to map species distributions

Now, let's take a look on the spreadsheets that represent the spatial distribution of oceans and species in the world. You can find the map in the spreadsheet *map* in *dataFrame.xlsx*, and the information used to create that map in the spreadsheet data. As you can see in both, the information in the spreadsheet data is a coarse resolution map of the world (10° latitude by 10° longitude grid), and it is linked to the spreadsheet *map* in the same file.

In the *data* spreadsheet, the column *A* (tag) indicates what that particular row refers to (species name, richness, ocean/non-ocean), column *B* (*Fossil*) indicates whether the report is a fossil or not, and columns *C* and *D* (*Longitude* and *Latitude*) represent the coordinates. For instance, a value "Ocean" in the column tag in the second row of the data spreadsheet means that everything in the second row in that spreadsheet contains information about the oceans. However, Column *E* (*Value*) is the actual value you will be storing, the other columns are often referred as identifiers. In the case of oceans, a number -1 indicates an ocean is there, while a number 0 represents a continent or island.

The ocean and continent information contained in *tag* and *value* columns in the data spreadsheet are needed to draw the map of the Earth. Excel will take the maximum value in the *value* column (Column *E*) that is present for any combination of latitude and longitude values, and color the cell accordingly. In other words, Excel will take into account if, for a given latitude and longitude, there is a value of -1 which denotes oceans, or a value of 0 which denotes continental areas, and will color your map accordingly. After you add your taxonomic data (instructions detailed immediately below), these colors will be further refined. Species presence or richness will have values that are larger or equal to one, therefore the maximum value for that coordinate will be larger than 0, and the color in that cell that will change accordingly. Now, take a look at the map and the data spreadsheets before you add your own data to make sure it looks correct.

Step 6b. Building the data to map each species distribution

Now we will add your species data in order to add taxonomic information to this background map of oceans and continents. To add your data, copy your results from the spreadsheet entitled *sppData* to the bottom of the table in the spreadsheet titled data that is in the file *dataFrame.xlsx*. Paste in your *sppData* beginning at row 705. Do not copy the row with the titles, just the data.

When copying the information to the spreadsheet data, be careful with the order of the columns, the columns must be in this order: *species, fossils, latitude, longitude*. In the *E* column (*value*) located within the spreadsheet data, add a number 1 for every single cell of the table that you just copied (do not add more cells than needed, only until the end of the table that you just copied here). This value of 1 that you just added to the column *E* corresponds to a presence of the species; this presence is then linked to a specific *latitude* and *longitude* which is reported in columns *C* (*latitude*) and *D* (*longitude*), respectively. This report of a taxon being present corresponds to either a current or historical distribution, as specified in the column *Fossil* (*B*). Your table should look like this:

	A	B	C	D	E
1	tag	Fossil	lat	long	number
702	ocean	NA	-90	160	0
703	ocean	NA	-90	170	0
704	ocean	NA	-90	180	0
705	Equus caballus	FALSE	40	-70	1
706	Equus hemionus	FALSE	40	110	1
707	Equus quagga	FALSE	0	40	1

Step 7. Building the data to map the species richness distribution

In this step, you determine the number of species in each one of the 10°x10° squares to find areas with a high density of species. You will also be able to distinguish between extinct and extant populations. To do this, you will work with the summarized information stored in the spreadsheet *sppData*.

First, let's go back for a minute to the spreadsheet *sppData*. Name column *E* (that should be empty) "fossil_coordinates". Then copy and paste this formula and fill down for each row to combine the fossil, longitude, and latitude information in a single cell (be sure that the row number match the respective row):

=B2&" ("&C2&","&D2&")"

Select all the data in the spreadsheet *sppData* and build an automatic Pivot Table (Data > Pivot table, or Insert > Pivot table in newer versions of Microsoft Excel). In the Pivot Table window, first click on the word "fossil_coordinates" located in the "Field name" section and drag this column into the "Row label" section. Then, click and drag the word "species", also located in the "Field name" section, into the "Values" section. In doing so, the word "species" will change to read, "Count of species". Do not enter anything into the "Column labels" field. This will give you the
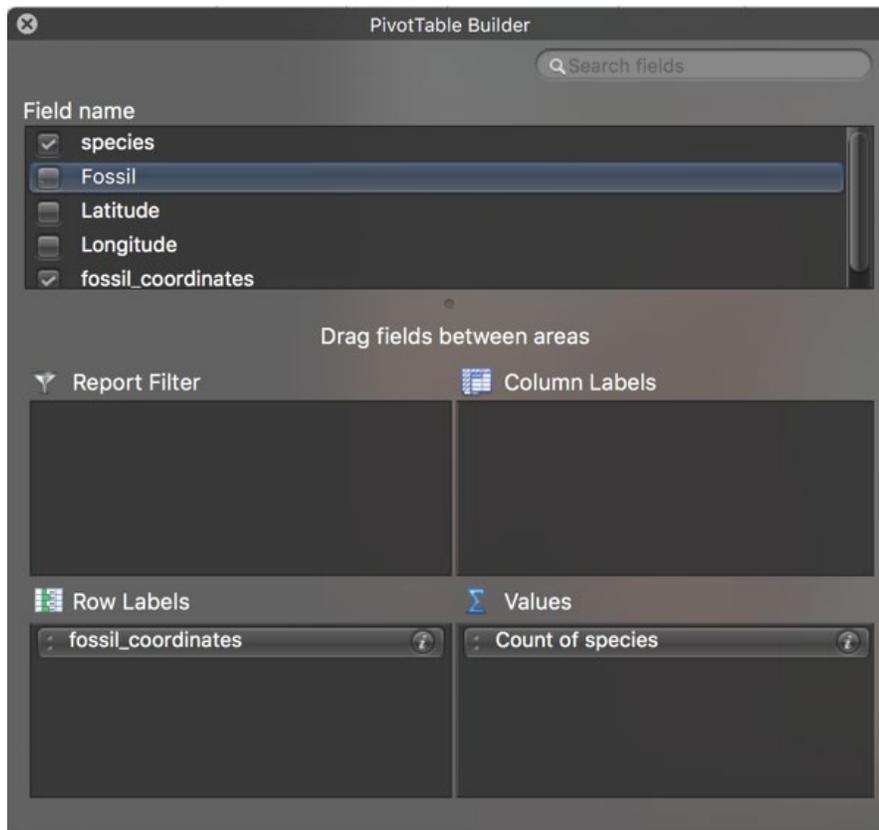
number of extant and extinct species per 10˚x10˚ grid. Now you will need to split the coordinate info again to get a table that you can append to the one in the data spreadsheet. To do this, copy the following formulas next to the result of the Pivot table in the cell indicated (we will assume that the Pivot table has the first column located as "A", and the first row with values located at row number 5, as in the screenshot below):

    Tag (cell D5): richness
    Fossil (cell E5): =LEFT(A5,1)="T"
    Lat (cell F5): =MID(A5,SEARCH("(",A5)+1,SEARCH(",",A5)-SEARCH("(",A5)-1)+0
    Long (cell G5): =MID(A5,SEARCH(",",A5)+1,SEARCH(")",A5)-SEARCH(",",A5)-1)+0
    Value (cell H5): =B5

Now, fill in the formula for each column (D to H) for the remainder the Pivot table.
Your results should appear as in the figure below:

	A	B	C	D	E	F	G	H
1								
2								
3	Count of species							
4	Row Labels	Total		Tag	Fossil	Lat	Long	Value
5	FALSE (-10,-170)	1		richness	FALSE	-10	-170	1
6	FALSE (-10,-70)	1		richness	FALSE	-10	-70	1
7	FALSE (-10,10)	2		richness	FALSE	-10	10	2
8	FALSE (-10,130)	3		richness	FALSE	-10	130	3
9	FALSE (-10,140)	1		richness	FALSE	-10	140	1
10	FALSE (-10,20)	1		richness	FALSE	-10	20	1
11	FALSE (-10,30)	2		richness	FALSE	-10	30	2
12	FALSE (-10,40)	2		richness	FALSE	-10	40	2
13	FALSE (-20,-40)	1		richness	FALSE	-20	-40	1
14	FALSE (-20,-50)	1		richness	FALSE	-20	-50	1

Copy the results (columns D to H from the first row of data—in above example, row 5—until the last row with information in your table), and paste (using paste special, values only) this pivot table data at end (bottom) of the spreadsheet data.

Step 8. Building the maps

At this point, you have all the information you will need in your spreadsheet data, and this should be linked to your spreadsheet *map* (be sure that there are no empty spaces in between the tables you just copied into the spreadsheet *data*). Now you can go to the map. The map is actually a pivot table linked to the spreadsheet data, using the ocean cells to give you an idea of the global distribution of your taxa, with latitude as rows and longitude as columns. Because each square represents a 10˚x10˚ grid the continents appear a bit distorted. The sheet "map template" has a map of the Earth in a similar projection to give you an approximate idea the location of each square. You can copy the figure on top of your map and stretch it a bit, but it will never be perfect because Excel is not designed for these types of tasks.

The top portion shows an Excel pivot table:

Max of Value	Column Labels		
Fossil	NA		
Tag	ocean		

Row Labels	-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	Grand Total
90	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
80	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	0	0	0	0	0	0	-1	-1	0	0	-1	-1	-1	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	-1	-1	0	-1	-1	0	0	0	0	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	-1	0
40	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0
30	-1	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0
20	-1	-1	0	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	0
10	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	0	0	0	0	0	0	0	-1	0	0	-1	0	0	0	-1	-1	-1	-1	-1	-1	0		0
0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0	-1	0	0	0	0	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1	0
-10	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0
-20	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	0
-30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	0	0	-1	0	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1
-40	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	0	0	-1	0	0
-50	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	-1
-60	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-70	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Select any cell on the map and refresh the Pivot Table (Pivot Table > Refresh). The filters on the top use fossil and tag columns to decide what you want to plot, and the map will look for the largest value recorded for that particular coordinate, among all the tags that have been selected in the filter. The "NA" Fossil option and the 'ocean' tag must ALWAYS be selected. If there is nothing else for a particular combination of latitude and longitude, then either an ocean (with a value of -1) or a continent (no-ocean, so a value of 0) will be the value retrieved by the map. If you select everything, then the largest value will be the one provided by richness (which is always 1 or more if there is at least one species present in a particular square), so everything and richness will generate the same result. If you select one or more species, then the map will show a number 1 in every cell where the selected species exist.

The lower portion shows a map grid:

	-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
90	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
80	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	0	0	0	0	0	0	-1	-1	0	0	-1	-1	-1
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	-1	-1	0	-1	-1	0	1	1	1	0	0	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	-1
40	-1	-1	-1	-1	-1	-1	1	1	1	0	1	0	0	-1	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1
30	-1	-1	-1	-1	-1	-1	1	1	1	1	1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1
20	-1	-1	0	-1	-1	-1	-1	0	1	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1
10	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	-1	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0	-1	0	0	0	0	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1	-1
-10	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	0	-1	-1
-20	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	0	0
-30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1	-1	-1	0	0	-1	0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
-40	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	0	0	-1	0	0
-50	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	-1
-60	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-70	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

To improve the readability of the map, the cells that belong to the map have been formatted using conditional coloring (Home > Conditional formatting). There are two conditions: gray for ocean and yellow-green for any value above 0. The yellow-green scale uses a continuous gradient between light yellow and dark green. The greater the value, the darker the green color. The formats are already set, so there is no need to change them. But just in case, here is the format used:

Now you can use the filter selectors (click icon in the cells *B1* and *B2*; see above figure) to choose what you want to see (fossils? extant? one or more species, richness). In the map, -1 means ocean, 0 means continental areas without any record of the taxa, and any other value indicates that one or more species are present. Remember, to be able to see the map properly, you have to mark both i) the "ocean" in the tag filter, and ii) "NA" in the fossil filter.

Step 9. Ranking the species distribution

The final thing you may wish to do is to use your database to rank your species in terms of the number of squares each species occupies. The more squares occupied, the larger a species' range; in other words, the wider the species' distribution. A species distributed everywhere in the world may be either: a) an invasive one (e.g., black rat); b) a species with a high dispersal capability (e.g., migratory birds); and/or c) a species possibly transported by humans (e.g., dogs). Conversely, the fewer squares a species occupies, the more endemic it is.

To get this ranking, you can go back to your spreadsheet *sppData* and create another Pivot Table in a new spreadsheet. This time, use the fossil column as "report filter", species name as rows, and the combined coordinates as value. Now you can see the number of squares occupied by each species and can sort your Pivot Table to find the most widely distributed fossil or extant species, or the least. Here the first few rows for our example. Rename this spreadsheet as "taxaAbundance".

EXERCISE

Step 10. Errors in the data

Cleaning a dataset is an important process, and it often requires several iterations. For instance, in this example, the most abundant species is *Equus caballus*, i.e., horses. However, horses and donkeys have been moved by human activities, so they are misleading when trying to understand geographic patterns. Therefore, it is better to map them, to keep track of the changes you are doing, and then remove them from the analysis. Since you have summarized all your data in the sheet *sppData* of the file *dataFrame.xlsx*, any update of your data (fixing a species name, updating the fossil status, adding or removing a line with data), have to be done in that table: the sheet *sppData* of the file *dataFrame.xlsx*. After you do it, you may have to repeat steps 6b-10.

Other ideas:

This is where your creativity begins. You can use these spreadsheets that you just created and the same tools to answer other questions that can help you in your assignment. But, this will depend on your specific taxon, as well as on the optional questions you choose to answer. Here are some ideas:
- How did the fossil record of species distribution change for your taxon over time? If you have a large number of fossils, can you create a timeline representative of the history of your taxon?
- How many countries has your taxa been found in? How can you infer "endemicity" using the number of countries and squares your taxon is present in?
- Can you infer endemicity using latitude and longitude? Do they give you the same answers?

R Instructions (optional alternative to using Excel)

Below are instructions to process the information partially using R software. This section assumes you, the student, have some expertise in the usage of Excel and R, so the instructions are not as detailed as they are in the Excel version. Also, note that the logic of the steps are described in the Excel version of the instructions only, and not replicated here:

Step 1. Open the occurrence.txt file downloaded from GBIF
```
# read the data
oc <- read.delim("occurrences.txt", stringsAsFactors = F)
```

Step 2. Cleaning the data
```
# filtering columns
oc2 <- oc[,c("family", "genus", "species", "scientificname",
        "countrycode", "locality", "decimallatitude", "decimallongitude",
         "year", "basisofrecord")]
```

Step 3. Finding synonyms
```
# To find the synonyms, use a filter
synonyms <- oc2[(grepl("^[[:alpha:]-]+ [[:alpha:]-]+",oc2$species) &
        (oc2$species !=
        sub("^([[:alpha:]-]+ [[:alpha:]-]+).*$","\\1",oc2$scientificname))),
        c("species","scientificname")]
synonyms <- unique(synonyms)
names(synonyms) <- c("valid","synonym")
write.csv(synonyms, "synonyms.csv", row.names=FALSE)
```

Step 4. Getting the coordinates and the fossils

```
# building the 10˚ squares
oc2$longitude <- round(oc2$decimallongitude/10)*10L
oc2$latitude <- round(oc2$decimallatitude/10)*10L
oc2$fossil <- oc2$basisofrecord == "FOSSIL_SPECIMEN"

# if there is no species information, fill with the genus
oc2$species[is.na(oc2$species) | oc2$species == ""] <-
        oc2$genus[is.na(oc2$species) | oc2$species == ""]
```

Step 5. Summarizing the information

```
# simplifying the table
sppData <- unique(oc2[,c("species", "fossil", "latitude", "longitude")])
sppData$q <- 1
#  occurrences has now the information needed to paste
#  on the "sppData" sheet of dataframe.xlsx.
#  so you will export it as a csv file
write.csv(sppData, "sppData.csv", row.names=FALSE)
```

Step 6. Building the data to map the species distribution

```
# getting the data
data.spp <- sppData[,c("longitude", "latitude", "fossil", "species"),]
# removing rows without species
data.spp <- data.spp[!is.na(data.spp$species) & (data.spp$species != ""),]
# forcing species number to be 1, and changing the name of the species column
data.spp$number <- 1
names(data.spp)[4] <- "tag"
# exporting the data in csv format
write.csv(data.spp, "data.spp.csv", row.names=FALSE)
```

Step 7. Building the data to map the species richness distribution

```
# building the richness
richness <- aggregate(number ~ longitude + latitude + fossil, data.spp, FUN=sum)
richness$tag <- "richness"
richness <- richness[,c("longitude","latitude","fossil","tag","number")]
write.csv(richness, "data.richness.csv", row.names=FALSE)

# building the richness and spp data file
write.csv(rbind(data.spp, richness), "data.csv", row.names=FALSE)
```

Step 8. Building the maps

You can now import your file into Excel (because R will format your data in the .csv file formal, which Excel recognizes. Therefore, you should be able to open your R output directly in Excel, by simply double clicking on the file in your file browser). At this point, if R output file (with the .csv file extension) opens seemingly in Excel please proceed to Step 8 of the Excel instructions presented above to build the maps, and then to Step 9 in R to build the next table.

Step 9. Ranking the species distribution
      # count the number of squares where a species occurs.
      spp.rank <- aggregate(number ~ fossil + tag, data.spp, FUN=length)
      # rank them and
      spp.rank <- spp.rank[order(spp.rank$fossil, -spp.rank$number),]
      # export the file
      write.csv(spp.rank, "rank.csv", row.names=FALSE)

Similar to the previous step, you can now import your file into Excel. After importing your data in Excel, paste it in an empty spreadsheet and analyze as suggested in Step 9 in Excel.

Step 10. An error in the data
If you find an error in your data, then you have to review the key table in your process, namely the table sppData. Because this is already in a csv file called "data.spp.csv" (see step 6), you can just open the file in Excel (or even with notepad), fix it, and read it again into R using:

      data.spp <- read.csv("data.spp.csv", stringsAsFactors=FALSE)

After you read this file, go back and repeat steps 7 to 9, including updating your Excel file if needed.

Genetically Modified Crops and Biological Conservation on Farmlands

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ABSTRACT

The human population is forecasted to approach 11 billion people by 2100 and increased demands for agricultural production are expected. A sustainable approach to agriculture will need to balance increased production with conservation of biodiversity and ecosystem services. Genetically modified (GM) crops designed for pest resistance and herbicide tolerance, among other traits, have been rapidly adopted since their introduction in 1996. Their widespread use represents a profound change in global agriculture. This case study explores how GM crops may influence agricultural management practices, and the subsequent effects on diversity and ecosystem function on farmlands. The case study describes the distinguishing features of GM crops, what GM traits and crops are available for commercial use, and adoption patterns. The exercise then presents the following three hypothetical scenarios taking place on a corn farm in Iowa in which users are asked to infer potential effects on biological conservation: 1) converting natural areas to farmland; 2) adopting insect-resistant Bt corn; and 3) adopting herbicide-tolerant corn. The exercise poses questions that require interpretation of data and critical thinking skills to address complex issues. Upon completion of the exercise, users should have a more nuanced understanding of GM crops and their role in biological conservation.

LEARNING OBJECTIVES

In light of the rapid changes in agriculture due to advancements in plant biotechnology, completing this exercise will allow you to:

1. Identify the factors that distinguish GM crops from other crops.
2. Describe how management practices change when GM crops are introduced into an agro-ecosystem.
3. Consider how GM crops and associated management practices influence biological diversity and ecosystem services and think critically to make a decision based on the evidence provided.

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 (Rhodes 2010). Throughout this exercise you will be asked to apply your critical thinking skills in the context of genetically modified crops and biological conservation on farmlands.

INTRODUCTION

Genetically Modified Crops: A New Revolution In Agriculture

In the mid-20th century, widespread changes in agricultural practices led to what was known as the Green Revolution. During this time, advancements in farm management techniques, development of high-yielding crop varieties, and distribution and use of fertilizers and pesticides increased agricultural production worldwide, greatly reducing hunger (Tilman et al. 2002). Since then, the global human population has more than doubled from approximately 3 billion to 7 billion people, due in part to these advancements in agriculture. However, it is estimated that about 14% of our population is malnourished (Sanchez and Swaminathan 2005), and the number of people facing chronic food deprivation has increased to nearly 821 million as of 2017 (FAO et al. 2018). In addition, the United Nations (2017) predicts that the human population is expected to continue to grow and possibly exceed 11 billion people by the year 2100.

Meeting the energy and food demands of such a large human population will be one of the main challenges of this century. However, these needs must be balanced with the wise management of biodiversity[1] and ecosystem

services[2] that are essential to our own survival. Since more than one third of the usable land on the planet is already appropriated for human needs (Vitousek et al. 1997), agricultural expansion will need to be increasingly aligned with conservation efforts and make use of scientific advances in farm management practices that are more sustainable and less intensive with regards to environmental impact (Godfray et al. 2010).

Recently there has been a new revolution in agriculture—the development of genetically modified (GM) crops. Using advancements in biotechnology, scientists have been creating GM crops that are resistant to pests and disease and are more tolerant of adverse environmental conditions, in addition to other traits related to improved nutrition and storage capabilities. When these GM crops are introduced into an agro-ecosystem[3], they can influence farm management practices, such as tillage[4] of the soil or pesticide use, which may indirectly or directly affect biodiversity (Amman 2005). GM crops may be attractive to many farmers, as they can often simplify the pest management process, which can be difficult and time-consuming (Hellmich and Hellmich 2012). Indeed, since their commercial introduction in 1996, GM crops have been widely and rapidly adopted in the US and elsewhere.

What Are GMOs?

Nearly all of the food crops we enjoy today have undergone extensive genetic modification over many years. Traditionally, these crops have been modified over time through selective breeding for desired traits. For example, consider an ear of sweet corn that you buy in the store: It has a large cob covered in many soft sweet kernels. However, the ancestor of modern corn—a type of wild grass native to Mexico, called teosinte—has hard small seeds and virtually no cob (Figure 1). By selectively breeding plants with desired traits, a process known as artificial selection, the evolution of corn occurred quite rapidly and involved relatively few genetic changes (Beadle 1980).

In addition to selective breeding[5], other crop modification techniques are also used (Figure 2). Mutagenesis[6] involves exposing seeds to radiation or chemical mutagens in order to produce a greater number of genetic mutations from which new traits can arise and be selected. The deep red color associated with some popular cultivars of ruby red grapefruits is actually a trait produced by exposure to radiation (Broad 2007). There is no way to know how many genes are affected by mutagenesis and extensive safety testing is not always required for these

Figure 1. The evolution of corn occurred through artificial selection. Image credit: Nicolle Rager Fuller, National Science Foundation (Flickr/US government work).

CROP MODIFICATION TECHNIQUES

BIOLOGY FORTIFIED
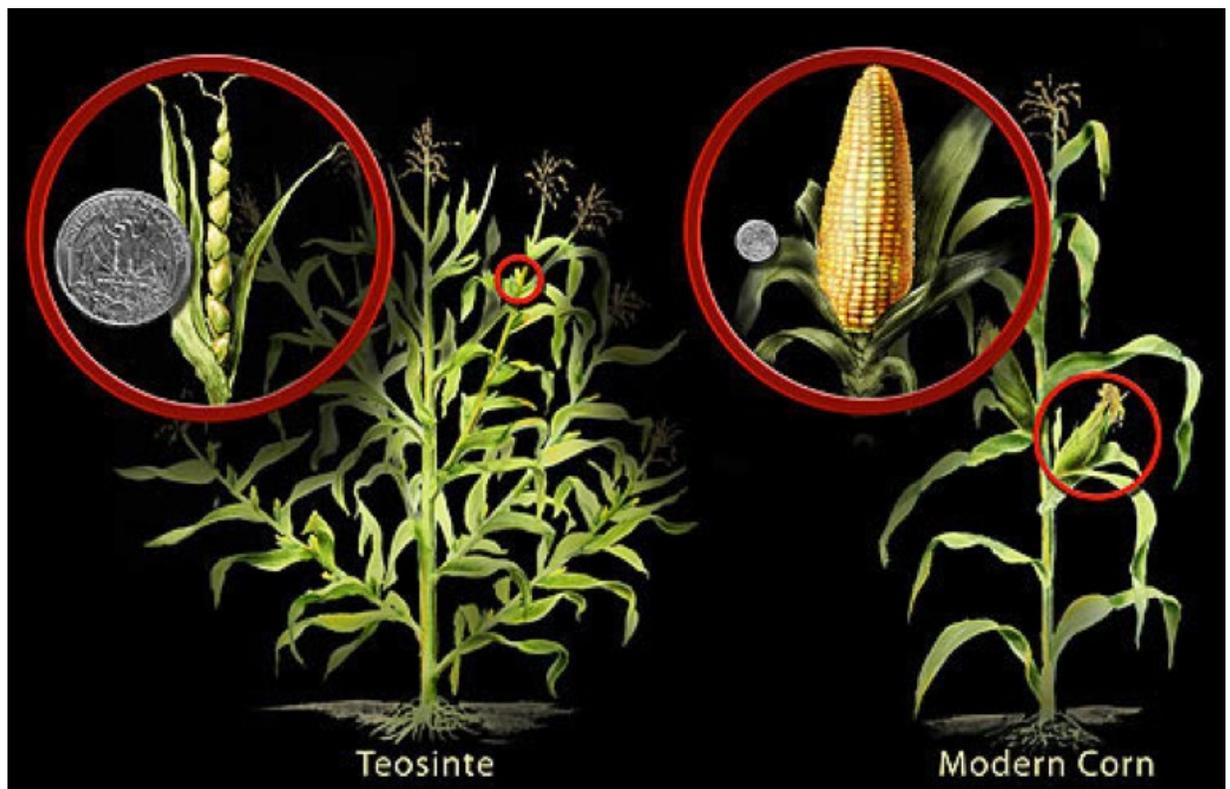
Mutagenesis

Use of mutagens such as radioactivity to induce random mutations, creating the desired trait

Radiation was used to produce a deeper color in the red grapefruit.

Polyploidy

Multiplication of the number of chromosomes in a crop to impact its fertility

Seedless watermelons are created by crossing a plant with 2 sets of chromosomes with another that has 4 sets. The seedless fruit has 3 sets.

Transgenesis

Addition of genes from any species to create a new variety with desired traits
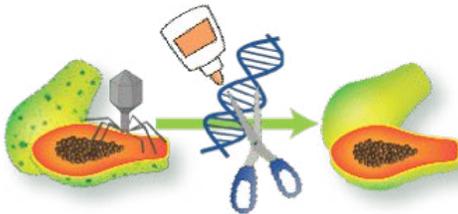
The Rainbow Papaya is modified with a gene that gives it resistance to the Papaya Ringspot Virus.

Cross Breeding

Combining two sexually compatible species to create a variety with the desired traits of the parents

The Honeycrisp Apple gets its famous texture and flavor by blending the traits of its parents.

Protoplast Fusion

Fusion of cells or cell components to transfer traits between species
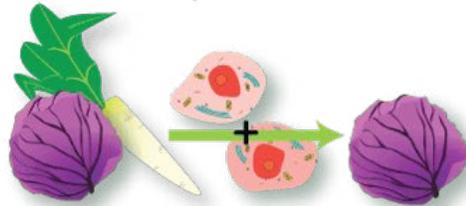
Male sterility is transferred from radishes to red cabbage by fusing their cells. Male sterility helps plant breeders make hybrid crops.

Genome Editing

Use of an enzyme system to modify DNA directly within the cell
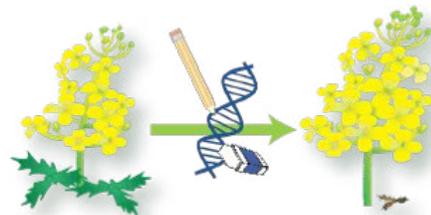
Genome editing was used to develop herbicide resistant canola to help farmers control weeds.

By Layla Katiraee (@BiochicaGMO) in collaboration with Karl Haro von Mogel (@kjhvm) for Biology Fortified, Inc (@franknfoode) Shared under a Creative Commons Attribution-NonCommercial-NoDerivatives License - 2015

biofortified.org

Figure 2. Examples of crop modification and development techniques. Image credit: Biology Fortified, Inc. (CC BY-NC-ND).

crops. Polyploidy[7] is a condition in which an organism has more than the typical two sets of chromosomes due to abnormal cell division. This is especially common in plants. Crossing plants with different numbers of chromosomes results in infertile offspring. For example, this is how seedless watermelons are produced. Protoplast fusion[8] is a hybridization technique that combines somatic cells and fuses nuclei of different plant species by removing their cell walls and exposing the cells to electric shock or chemicals. Recently, new advances in genome editing[9] also have great promise for crop production (Georges and Ray 2017). Genome editing involves the alteration of specific locations in the genome using DNA nucleases (i.e., "molecular scissors") in order to modify gene expression for desired traits, such as disease resistance. This approach is more precise and controlled than mutagenesis and has grown in prominence due to the development of the CRISPR/Cas9 system[10] and other gene editing tools.

Approaches such as selective breeding, mutagenesis, polyploidy, protoplast fusion, and genome editing are undoubtedly forms of genetic modification since they involve changes in gene expression and DNA manipulation driven by humans. However, the use of the term genetically modified organism[11], or GMO, more commonly refers to a transgenic, or genetically engineered, organism (i.e., transgenesis in Figure 2). Transgenic organisms have genes from a different species artificially incorporated into their genetic makeup using recombinant DNA[12] technology. In GM crops, these transgenes[13] confer traits that are deemed beneficial for agricultural production. Transgenic crops are tested for safety with regards to human health and the environment and are regulated by multiple governmental agencies.

Question 1
People often use the phrase "genetically modified organism", or GMO, when referring to a food crop that contains one or more genes that have been artificially introduced from another species. Based on the information given above, why might "genetically engineered" or "transgenic" be better terms than simply "genetically modified" to distinguish these crops from other crops?

WHAT GM CROPS EXIST AND TO WHAT EXTENT HAVE THEY BEEN ADOPTED?

Since the commercial introduction of GM crops in 1996, research on and development of GM crops has increased dramatically. Hundreds of different types of GM crops are tested annually. GM crop traits are related to pest resistance, herbicide tolerance, and improved agronomic traits and product quality (Sawaya 2014). Additionally, pollination control traits have been developed to reduce the risk of weed species acquiring GM traits via hybridization with GM crops (Daniell 2002, ISAAA 2017). At least 28 different crops now contain commercial GM traits (Table 1). Of these, the most widely adopted GM crops are insect-resistant or herbicide-tolerant corn, cotton, and soybean. These crops are staple commodities, and the GM traits have provided farmers with new options for management of pests.

Insect (pest)-resistant crops

Bacillus thuringiensis (Bt) is a common bacterium that is known to have insect-killing properties. This bacterium produces over 250 different kinds of insecticidal toxins, including crystalline (Cry) proteins that target the digestive tract of insects (Schnepf et al. 1998). Different Cry proteins are specific to different types of insects, many of which are crop pests during their larval stage. For example, some Cry toxins target certain species of moths, whereas others are specific to certain species of beetles. The larvae of these insects can be especially damaging to crops, as they feed on plants prior to pupation. Since *B. thuringiensis* is naturally occurring, effective, selective, and safe for humans, it is one of the most popular types of biopesticides[14] and frequently used in both organic and conventional agricultural systems (Hellmich and Hellmich 2012).

Through genetic engineering, some Bt cry genes have been incorporated into crops such as corn and cotton, and these plants are often referred to as Bt crops[15]. Since crops with these transgenes produce Cry proteins as part of their own genetic expression, the target insect pests are exposed to the toxins when feeding on the plant. Bt cotton targets bollworm, a moth pest, and Bt corn targets European corn borer (moth) or corn rootworm (beetle). These are some of the most notorious

Table 1. List of commercial genetically modified (genetically engineered) crops and traits (ISAAA 2017).

CROP	Insect resistance	Herbicide tolerance	Disease resistance	Abiotic stress tolerance	Altered growth/yield	Modified product quality	Pollination control
Alfalfa		X				X	
Apple						X	
Bean			X				
Bentgrass		X					
Canola		X				X	X
Carnation		X				X	
Chicory		X					X
Cotton	X	X					
Eggplant	X						
Eucalyptus					X		
Flax		X					
Maize	X	X		X	X		
Melon						X	X
Papaya			X			X	
Petunia							
Plum			X			X	
Poplar	X						
Potato	X	X	X				
Rice	X	X				X	
Rose						X	
Soybean	X	X		X	X	X	
Squash			X			X	
Sugar beet		X					
Sugarcane				X			
Tobacco		X					
Tomato	X		X			X	
Wheat		X				X	

pests of these crops, annually causing billions of dollars of yield loss. With Bt crops, a farmer only has to plant the crop in order to control these pests, as opposed to having to scout for them and apply insecticides. As a result, the increased use of Bt crops has been linked to decreases in insecticide use (Brookes and Barfoot 2012). In addition, due to the narrow target range of Cry toxins, Bt crops have minimal effect on non-target organisms as compared to crops in which insecticides are used to control the same target pest (Naranjo 2009).

One concern related to Bt crops—as with all pest management techniques—is the development of resistance within pest populations. Since Bt crops are so effective at controlling their target pests, farmers are required by the US Environmental Protection Agency to devote 5%–50% of farm acreage to non-Bt versions of the crop (Fleischer et al. 2014). These non-Bt areas, or refugia, are used to proactively prevent or slow the development of resistance, by preserving susceptible alleles within the pest population (Gould 1998, Bates et

al. 2005). This approach is analogous to the judicious use of antibiotics by health care professionals to slow the development of drug-resistant bacterial pathogens. After more than two decades of Bt crop use, incidences of resistance have emerged in some areas and resistance management remains an important focus of study (Tabashnik and Carrière 2017).

Herbicide-tolerant (HT) crops

Herbicides are chemicals applied to a field to kill weeds, with the main aim to limit crop competition by weeds, which have been shown to cause up to 34% crop loss if unmanaged (Oerke 2006). Broad-spectrum herbicides kill a wide variety of weeds and can also cause damage to crops, so growers are limited to using them at times when they do not have a crop in the field. Narrow-spectrum herbicides, in contrast, kill some plants but not others, requiring more in-depth understanding by applicators regarding which herbicides target which plants. Herbicide-tolerant crops (HT crops) have been developed through genetic engineering (and also conventional breeding methods) to create crops that can survive being sprayed with broad-spectrum herbicides. Thus, growers are able to spray a crop field after the crop begins growing, killing the weeds that are in the field without damaging their crops. This provides growers with an effective, efficient way to manage weeds during the season. The most popular herbicide-tolerant crops are genetically engineered varieties that are resistant to glyphosate, a common, broad-spectrum herbicide. Glyphosate kills plants by inhibiting synthesis of some essential amino acids in plants. All herbicides carry risks, whether to the people applying the herbicides, non-target organisms such as wildlife or bees, or consumers (see Henderson et al. 2010 for information on glyphosate specifically). These risks vary widely depending on the toxicity and amount of the active ingredient, formulation, and other factors. Compared to other herbicides commonly used in agriculture, glyphosate has low mammalian toxicity and binds tightly to the soil, limiting leaching into groundwater (Henderson et al. 2010, Duke and Powles 2008). While glyphosate use has increased dramatically since the release of glyphosate-tolerant crops, there is also evidence of a decrease in toxicity associated with herbicide use on some of the major crops in the United States (Kniss 2017).

Adoption of herbicide-tolerant crop varieties occurred more quickly in crop types that had limited cost-effective weed management options prior to this technology, like soybeans and sugarbeets. The herbicide options available for soybeans were more costly or more complicated, for instance relying on narrow-spectrum products, than the simplicity presented by herbicide-tolerant crops. Corn, in contrast, had several effective approved herbicides for use in that system, thus growers were slower to adopt this technology in corn (Figure 3). For example, narrow-spectrum herbicides that only target broadleaf plants can be used on corn, which is a grass, but not on broadleaf crops such as soybeans and sugarbeets. Herbicide-tolerant crops can also be referred to as herbicide-resistant crops, or by the common phrase used in the press—"Roundup Ready"—which refers to crops that are resistant to applications of the herbicide "Roundup" the original trade name for glyphosate.

Adoption of genetically modified crops

Bt and HT crops provide growers with new options for managing pests. However, this technology can be expensive as GM seeds cost more than their conventional counterparts. Because of regulations, growing GM crops may also prevent growers from selling to certain foreign markets. These expenses may be counteracted by greater yields, reductions in pesticide applications, and lower fuel and labor costs, however this may depend on the severity of the pest/weed problem and other local factors. To illustrate the response of farmers to this technology, Figure 3 shows the trends in adoption rates of the main types of GM crops in the United States.

Question 2
What can you conclude from Figure 3? Summarize in three points the main information being presented.

AGRICULTURE AND GM CROPS: CONSERVATION SCENARIOS

Clearly, GM crops have been widely and rapidly adopted in the United States. At a global scale, they are now planted in 28 countries and on over 170 million hectares each year (ISAAA 2017). Over the first two decades since their commercial release, this represents billions of acre-
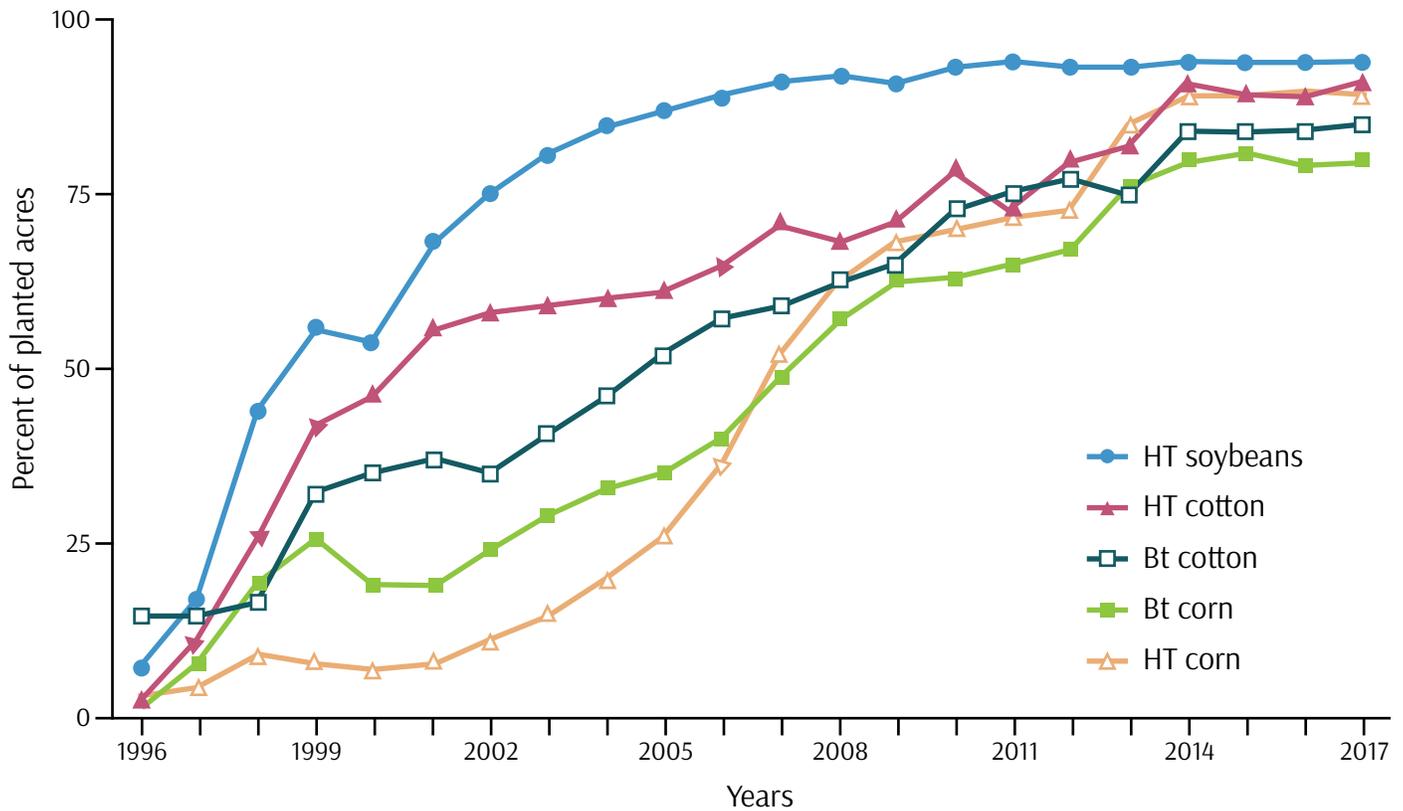
Figure 3. Adoption of genetically engineered crops in the United States, 1996–2017. Image credit: USDA Economic Research Service (US government work); adapted by Nadav Gazit.

years of GM crop production. In this case study, you will be asked to consider how the adoption of GM crops may affect farm management inputs and biological conservation on farmlands. Use the following scenario of Greta Greenthumb, a (fictional) farmer in Iowa, to explore these effects and to draw conclusions about this important topic in agriculture and conservation.

Greta Greenthumb grew up on a corn farm in Iowa that was about 300 acres—a little smaller than the average farm size in the state. Iowa is in the heart of the Midwestern United States, and agriculture plays an important role in these communities of people and in the ecosystems present there. Greta's parents grew field corn and soybeans to be used as feed for livestock and Greta was happy to chip in with farm chores when she wasn't in school. After graduation, Greta moved to Des Moines for a job, but often missed her life back on the farm. She decided she wanted to return home to run the farm when her parents got older. That time had finally come and she was back at the old farmhouse. It was winter and she was planning for the upcoming field season. She was excited but also a little bit nervous about all the decisions she would need to make.

Conservation Scenario #1: From Prairie to Agriculture

The north central part of the US is one of the most agriculturally productive regions in the world. Greta was always proud of her family's history of farming in this region. Her family valued hard work, common sense, and a connection to the land. Greta had always been interested in the history of the area and enjoyed looking at old maps and books in the local library. She had learned that this part of the country was historically prairie land (Figure 4), containing numerous species of grasses and wildflowers that, in turn, supported diverse communities of arthropods, birds, and mammals. These prairie plants and their complex root systems, in combination with the climate and geology in this region, resulted in deep, fertile soils, rich in organic matter— perfect for growing food. As such, many of the native prairies were eventually converted into agricultural lands and a family farm culture emerged as more settlers moved into the area in the late 19th and early 20th century. Over time, and with economic diversification, many of these smaller mixed-use family farms have given way to larger specialized grain production farms.
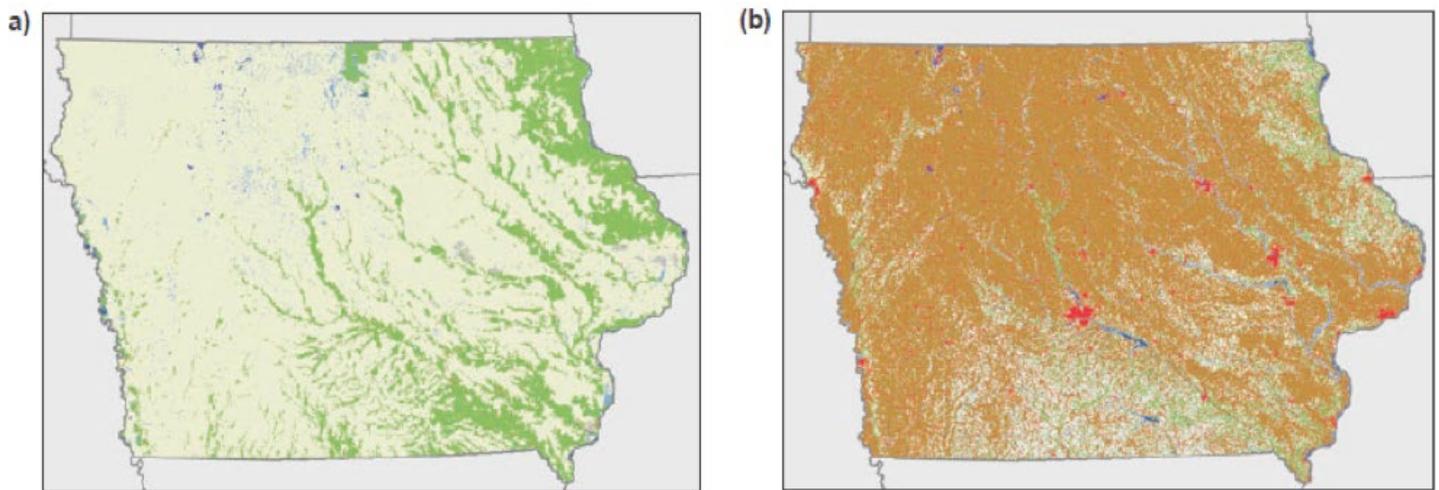
Legend

▮ Forest / woodland	▮ Grassland	▮ Cropland	▮ Wetland	▮ Urban / settled
▮ Brush / scrub	▮ Barren	▮ Pasture / hay	▮ Water	

Figure 4. Iowa land cover in the mid-1800s (a) and in 2001 (b). Image credit: Gallant, A.L., W. Sadinski, M.F. Roth, and C.A. Rewa. 2011. Changes in historical Iowa land cover as context for assessing the environmental benefits of current and future conservation efforts on agricultural lands. Journal of Soil and Water Conservation 66(3):67A-77A, doi:10.2489/jswc.66.3.67A.

One of the primary crops being grown is maize, or field corn, used for livestock feed and biofuel production. Thus, this region is often called the "Corn Belt" due to this crop's predominance in the landscape along with other cash-grain crops. Such farms are often described as relying on monocultures[16] of corn, since at times it is the only thing being grown over a very large area. Corn is typically rotated annually with soybean, another very common crop in Iowa.

Question 3

1. Compare the land use maps of Iowa from the mid-1800s and 2001 (Figure 4).
2. In 2–3 sentences, describe the major changes in Iowa land cover between the two maps.
3. Take a moment to identify and write down how an agricultural field differs from natural habitat it replaces (in this case, a corn monoculture versus a prairie). For example, in terms of disturbance, habitat heterogeneity, and anything else that jumps to mind. Then briefly explain below in the table what effects these differences may have on the biodiversity of three different groups of organisms: 1) plants, 2) soil arthropods and microorganisms, and 3) above-ground animals (arthropods, birds, mammals).

ORGANISMS	AGRICULTURAL FIELD VS. NATURAL HABITAT: EFFECT ON BIODIVERSITY
1. Plants	
2. Soil arthropods/ microorganisms	
3. Above-ground animals	

Conservation Scenario #2: Adopting Bt Corn

Despite the changes to the natural environment that agriculture may present, food production is necessary and more agricultural production will likely be needed for the growing human population. Knowing this, Greta was committed to managing her farm in a sustainable fashion, from both from an economic and environmental standpoint. Therefore, she was open to considering multiple tactics for controlling crop pests, as long as they assured the economic viability of the farm. For example, she was keen on using biological and cultural control tactics that could reduce pest populations; this may include supporting or introducing organisms that naturally kill pests, or using tillage and crop rotation[17] patterns to reduce pest pressure and maintain healthy soils. Ideally, pesticides would be used as a last resort,

however she understood that pesticides often need to be used, especially when pest densities are high.

Like Greta's family farm, most of the neighboring farms were also over 100 acres in size and many of these farms were devoted to corn production. Corn was typically planted in late April/early May and harvested in October. Although various insect pests present a challenge for growing corn, one of the major pests in the region was the European corn borer, a moth whose larvae feed on corn and other crops. In the Corn Belt, European corn borers go through at least two generations a year (Figure 5). The larvae of the first generation will feed on the leaves of the young corn plants. The second-generation larvae can damage the leaves, stalk and ears of corn, before overwintering in the corn stalks and residue. Both generations only feed on the surface of the plant for a
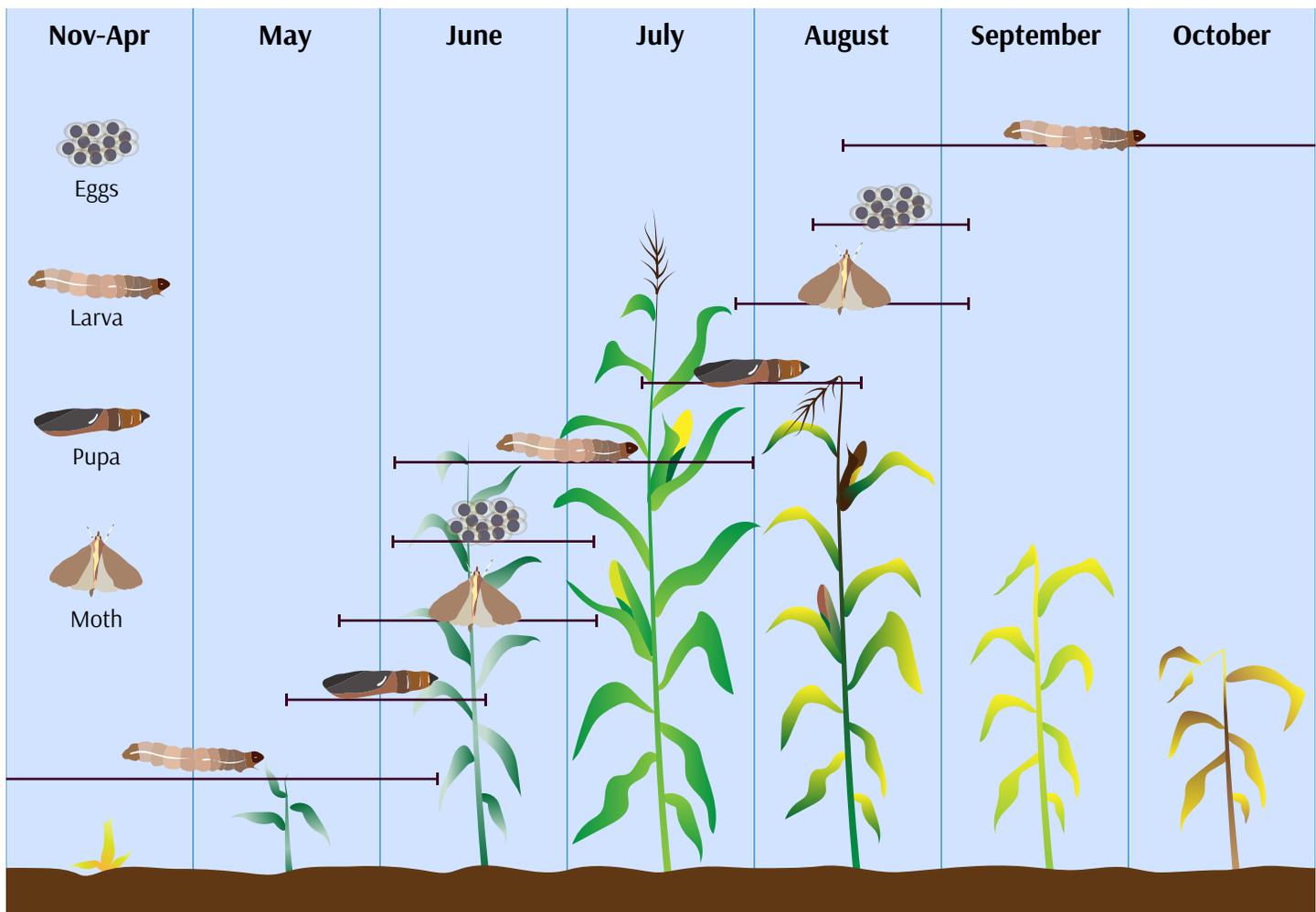

Figure 5. European corn borers typically go through two full life cycles during the growing season of corn in Iowa. Larval corn borers will spend the winter in the senescent corn stalks before emerging as flying adults the following year. Image credit: reprinted with permission from Iowa State University Extension and Outreach; Edwards, E., editor, European Corn Borer Ecology and Management, NCR 327, 1996; adapted by Nadav Gazit.

short period of time before tunneling into the stalks or ears of the corn.

Although a farmer will use a variety of tactics to best avoid or minimize corn borer infestations (e.g., alter planting dates), controlling this pest may require insecticide applications. Insecticides are usually applied in mid-summer and late summer when larvae are present (Figure 5). Since the larvae are able to quickly tunnel into the plant, there is only a brief window of time in which insecticide applications are effective. Therefore, growers must devote time and resources to scouting for the pest to identify the best times for insecticide applications. European corn borer adults lay eggs over several weeks, so sometimes a single insecticide application is not sufficient to control emerging larvae, and a second application may be needed. Insecticides may be applied in granular or liquid form using tractors with spray tanks or overhead sprinkler systems. These insecticides often have long residual times to control emerging larvae over longer periods of time, and most are nerve poisons that are toxic to many organisms other than the pests.

Due to the tunneling activities of corn borer larvae, managing this pest with conventional foliar applications of insecticides, as described above, can be difficult and expensive. An alternative pest control option for the farm would be to plant Bt corn that specifically targets European corn borer. When speaking with her neighbors, Greta learned that since the commercial introduction of Bt corn in 1996, more than half of her neighbors had chosen to adopt Bt corn for corn borer control. Greta wondered how this may have influenced corn borer populations in the Corn Belt and came across a long-term study led by Dr. Bill Hutchison at the University of Minnesota that examined how the introduction of Bt maize (corn) in the Midwestern United States has influenced European corn borer densities (summarized in Figure 6).

Question 4

Carefully inspect Figure 6 (including the caption, the legend, and the axis titles) and answer the following questions.

1. What do the vertical gray bars represent?
2. What general trend do you see over time for this variable?

3. Why are there no values for this variable prior to 1996?
4. What do the white dots represent?
5. What pattern(s) do you see for this variable prior to 1996?
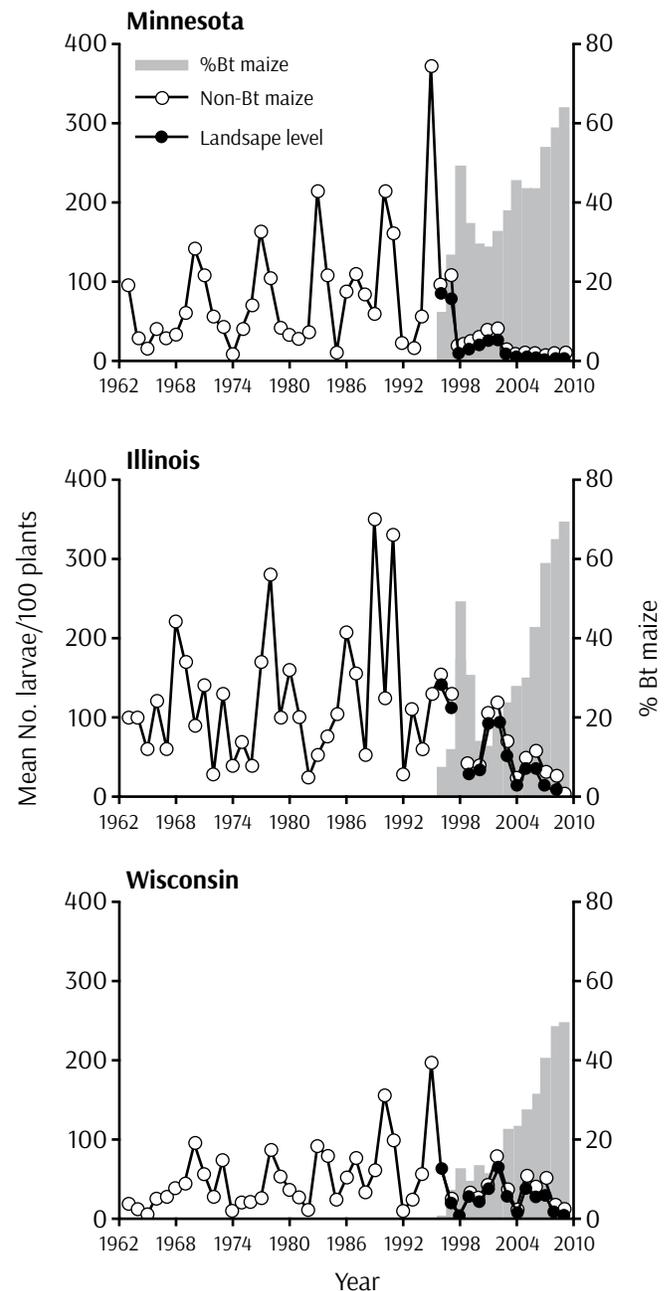
Figure 6. European corn borer densities (mean number of larvae per 100 plants, in both Bt maize field and the whole landscape, which comprises Bt and non-Bt combined) and Bt maize adoption over time in three states of the US Corn Belt. European corn borer larvae overwintering in corn stalks were counted annually from 1962–2010. Image credit: Hutchison et al. 2010 (Science/US government work); adapted by Nadav Gazit.

6. What may have caused such patterns?
7. What happens to these values after 1996?
8. If you were to plot only two variables—% Bt maize against European corn borer densities (using data from 1996-present)—what might the graph look like? Label the axes, write a caption and draw a hypothetical trend line.

Greta realized that transitioning from a conventional insecticide-based pest management program to Bt corn-based system may not only influence pest densities, but may also influence insecticide use patterns and ultimately the diversity of organisms in and around the farm. Greta started doing some research and soon realized that numerous studies (e.g., O'Callaghan et al. 2005, Romeis et al. 2008, Naranjo 2009) had examined the effects of Bt crops on non-target organisms[18], or those organisms not being targeted by a pesticide. In general, due to the target specificity of Cry toxins, Bt crops do not seem to have substantial effects on non-target organisms, especially as compared to the effects of using insecticide applications to control the same pest on non-Bt crops (Naranjo 2009). On a farm, non-target organisms may include birds and mammals that feed, nest, or simply pass through these farm fields. However, since Bt corn specifically targets insect pests, non-target effects are more often assessed for arthropods. Non-target arthropods may include other pests of the crop, however most non-target studies have looked at effects on crop-beneficial arthropods. These organisms include arthropods that are predators and parasitoids[19] of pests. Predators and parasitoids of pests may also be referred to as natural enemies[20], or biological control[21] agents. These arthropods are considered integral parts of the agro-ecosystem and how they are affected by changes in farm management practices is an important component of ecologically-based farming. Some of these beneficial arthropods, such as ladybugs/ladybird beetles (Figure 7A), feed on a wide range of pests and are known as generalist predators. Others, such as some parasitoid wasps (Figure 7B), will exclusively target a single species; these natural enemies are known as specialists.

Question 5
Consider two farming scenarios: one with Bt corn and one using conventional pest management options to control European corn borer. In the table below, choose answers to indicate how you think insecticide applications, the abundance of pests, and the abundance of non-target organisms would compare between Bt corn (targeting European corn borer) and conventionally-managed corn. Below the table, provide a brief justification for your answers.
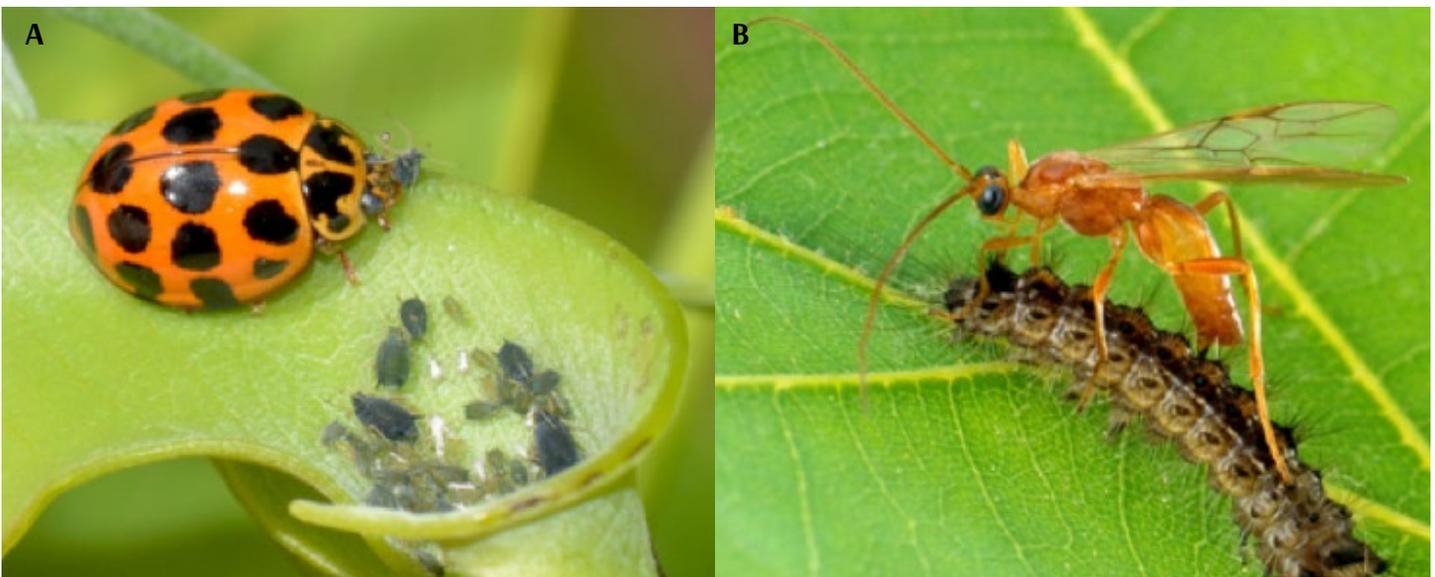
Figure 7. Natural enemies are organisms that kill crop pests. These include predators such as ladybird beetles (A) and parasitoid wasps (B). Image credit: 7A: Jean and Fred/Flickr (CC BY 2.0); 7B: Scott Bauer, Image Number K7659-1 (USDA/US government work).

COMPARED TO A CONVENTIONALLY-MANAGED CORN FIELD, A BT CORN FIELD WILL HAVE:			
☐ fewer	☐ the same number of	☐ more	insecticide applications
☐ fewer	☐ the same number of	☐ more	European corn borers
☐ fewer	☐ the same number of	☐ more	specialist parasitoids of European corn borers
☐ fewer	☐ the same number of	☐ more	generalist predators

Conservation Scenario #3: Adopting Herbicide-Tolerant Crops

Iowa farmers most often employ a corn-soybean rotation, planting corn and soybean in the same fields in alternate years. Crop rotation helps reduce pest populations in both crops since many insect pests and pathogens are specific to one crop or the other (Robertson et al. 2014). Greta, however, is still struggling with large populations of weedy plants that compete with both the corn and soy crops. Her current management strategies include narrow-spectrum herbicides that are approved for use on these crops, if the timing is right to use them, as well as tillage, which she completes prior to and after planting of her crops, between the crop rows.

Tillage, a term referring to some sort of soil disturbance (Figure 8A), is one way farmers kill weeds and other plant residues either after crop harvest or prior to planting. However, this practice is disruptive to the soil, alters the community of soil animals and microbes that live there (Stinner and House 1990, Lundgren et al. 2006), and destroys soil structure, making it much easier for soil to blow away or float away in wind or water erosion (Karlen et al. 1994). Soil is highly valuable as habitat for biodiversity and for ecosystem services such as carbon sequestration[22] and water filtration (Lavelle et al. 2006). Conservation tillage[23], also referred to as reduced or no-till practices, can improve soil quality through reduced disturbances and maintenance of crop residue on the soil surface (Figure 8B). Greta recently went to a farming conference where she heard other Iowa farmers talking about how much they support no-till farming and keeping their ground covered. She loves the idea of protecting her soil for generations to come. She couldn't believe it when she heard at the conference that in some parts of Iowa, topsoil is being lost at rates of 10–50 times faster than soil is being formed at those sites (Neuman 2011).

However, if Greta switches to no-tillage farming, she will have to change the way she manages weeds, because she won't be tilling the ground to kill the plants. Her neighbor tells her that's why he uses herbicide-tolerant crops. He can plant his soybeans and then go right over the whole field with a broad-spectrum herbicide that kills all the weeds but does not kill his crops.

A group of scientists led by Wade Givens were curious to find out if farmers who adopted herbicide-tolerant crops changed their tillage practices at all (Givens et al. 2009). Could switching over to herbicide-tolerant crops affect what type of tillage farmers use? If so, this could have implications for soil conservation.

Dr. Givens and his collaborators surveyed 1,195 growers from six states in the Midwestern United States. The results are presented in Table 2.

Question 6
Examine the data table below (Table 2) from their study. Did farmers change their tillage practices after adopting herbicide-tolerant (HT) crops? Explain how you came to your conclusion below.

Question 7
Do you think these changes have any impacts on biodiversity or ecosystem services provided by soil? Explain.

Figure 8. Conventional tillage of farm field (A). Under conservation tillage (B), crop residue is left on the soil surface. Image credits: 8A: Joevilliers, via Wikimedia Commons (Public Domain); 8B: USDA NRCS South Dakota/Flickr (CC BY-SA 2.0).

Table 2. Percent farmers using each type of tillage before and after adopting herbicide-tolerant (HT) crops.

TYPE OF TILLAGE	BEFORE HT CROPS ADOPTED	AFTER HT CROPS ADOPTED
Conventional till	37%	18%
Reduce till	38%	41%
No till	25%	41%

Adapted from Givens et al. 2009. Weed Science 23(1):150–155.

Question 8

Greta is wondering if switching to herbicide-tolerant crops means that she will change the amount of herbicide used on her farm. Based on what you have learned so far about herbicide-tolerant crops, predict whether herbicide use would increase, decrease, or neither following adoption of herbicide-tolerant crops. Justify your answer.

To compare the ecological effects of different agricultural management practices, including tillage, researchers at the Kellogg Biological Station in southwest Michigan started an experiment in 1989 called their "Main Cropping System Experiment" (Kellogg Biological Station 2017). This experiment is particularly valuable given its long-term nature (Robertson et al. 2008). The impacts of different crop management strategies can be very different over a long time-frame rather than in a single season.

For this experiment, scientists compared ecosystems along a management intensity gradient, including four annual cropping systems: 1) a "conventional" system (conventional tillage and use of GM crops since 2009), 2) "no-till" system (same as conventional except no tillage is used), 3) a "reduced-input" system (fewer synthetic fertilizers applied, cover crops included as nitrogen source), and 4) a "biologically based" system (certified organic, no GM crops, no synthetic fertilizers applied, includes tillage) (Robertson et al. 2014). For this exercise, we will focus on the comparison between conventional and no-till systems, given that GM crops have better enabled farmers to use no-till strategies if they wish. Scientists have studied various dimensions of the ecosystem in this experiment, including soil health, nutrient loss, and water storage capacity. Water is a conservation issue of concern to growers, as extreme conditions such as droughts considerably reduce food production (Lesk et al. 2016). The data shown below are from 24 years after the initiation of the experiment and focus on soil moisture, a rough indicator of how much water is available in the soil for plants to access.
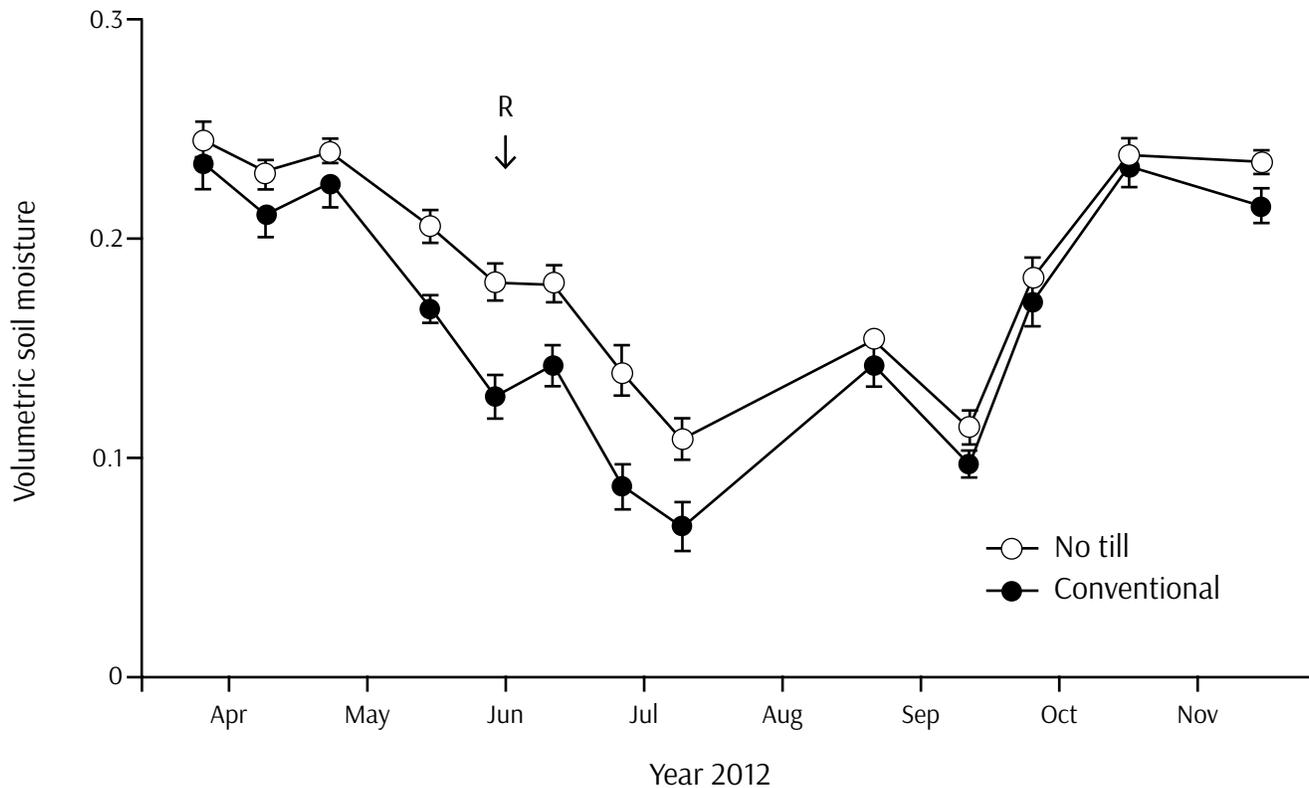
Figure 9. Mean soil moisture (in cubic cm per cubic cm) in no-till and conventional soybean systems during the 2012 soybean growing season. A 6-week drought began after the June rainfall event indicated with the R on the figure. Error bars represent the standard error (n = 6 soil moisture samples). Image credit: Robertson et al. 2014. Bioscience 64(2):404–415 (CC BY); adapted by Nadav Gazit.

Question 9

Examine data from the Kellogg Biological Station cropping systems experiment in Figure 9. What can you conclude from this graph? Please support your claims.

REFLECTION AND SYNTHESIS

This case study has highlighted several different management choices that Greta can make (using a GM crop that is insect resistant and/or herbicide tolerant, adopting no-till strategies, using crop rotation). If you were Greta, and were concerned about biodiversity and soil health, how would you manage your farm? Would you plant GM crops? Justify your answer. Include advantages and disadvantages to your decision.

GLOSSARY

1. **Biodiversity**: The variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it. It usually is measured as the number and types of living organisms that reside in a particular area.

2. **Ecosystem services**: the direct and indirect contributions of ecosystems to human well-being.

3. **Agro-ecosystem**: an agricultural area considered as an ecosystem, which includes living and non-living components and their interactions.

4. **Tillage**: mechanical agitation of soil to aid crop production, can be used prior to and during crop production.

5. **Selective breeding**: choosing and mating parents with certain traits to produce offspring with more desired characteristics.

6. **Mutagenesis**: the process by which an organism's genetic makeup is changed due to natural mutations or by exposure to certain physical or chemical mutagens.

7. **Polyploidy**: a condition in which a normally diploid cell or organism has more than two sets of chromosomes.

8. **Protoplast fusion**: a type of genetic modification in which cells of two species are fused together to produce a somatic hybrid.

9. **Genome editing**: the modification of DNA at precise locations in the genome of an organism or cell, often using DNA nucleases.

10. **CRISPR/Cas 9 system**: Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) are a group of prokaryotic DNA sequences that contain viral DNA from previous infections. These embedded sequences, along with CRISPR-associated (Cas) enzymes that splice DNA, are used to recognize and destroy viruses in subsequent attacks. Using a synthetic RNA guide, the Cas9 nuclease can be used in laboratory settings to splice and edit genomes at specific locations complementary to the RNA guide.

11. **Genetically modified organisms**: organisms that contain genes from other organisms using inserted recombinant DNA methods.

12. **Recombinant DNA**: DNA combined from two or more sources.

13. **Transgene**: a gene that has been transferred from one organism to another.

14. **Biopesticide**: pesticide derived from natural materials.

15. **Bt crops**: genetically engineered crops that contain genes from the bacterium, *Bacillus thuringiensis* (Bt). Bt genes are expressed throughout the plant and encode for crystalline proteins that are toxic to certain insects.

16. **Monoculture**: the cultivation of single crop over a large area.

17. **Crop rotation**: the practice of growing different crops in succession on the same land, most commonly to increase crop yields, reduce pest pressure, and for soil nutrient management.

18. **Non-target organism**: species not specifically targeted by a pesticide.

19. **Parasitoid**: organisms that parasitize and kill their hosts; some are "specialists", in that they only target one host species.

20. **Natural enemies**: organisms such as predators, parasites and pathogens that contribute to control of pests.

21. **Biological control**: control of a pest by the introduction of predators, parasitoids, or pathogens.

22. **Carbon sequestration**: process by which carbon is removed from the atmosphere and held in solid or liquid form.

23. **Conservation tillage**: low intensity preparation of soil for growing crops that seeks to conserve soil, water, and energy and features retention of plant residues.

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