Assessing botanical capacity to address grand challenges in the United States

Project Staff
Dr. Kayri Havens, *Chicago Botanic Garden*
Dr. Andrea Kramer, *Botanic Gardens Conservation International U.S.*
Dr. Barbara Zorn-Arnold, *Chicago Botanic Garden*

Advisory Board
Dr. Patricia DeAngelis, *U.S. Fish and Wildlife Service*; Dr. Kent Holsinger, *University of Connecticut*; Dr. Kathryn Kennedy, *Center for Plant Conservation*; Rachel Muir, *U.S. Geological Survey*; Peggy Olwell, *Bureau of Land Management*; Dr. Kristina Schierenbeck, *California State University, Chico*; Dr. Larry Stritch, *U.S. Forest Service*; Dr. Marsh Sundberg, *Emporia State University*

Workshop Participants
Dr. Jim Bennett, *U.S. Geological Survey*; Dr. David Burney, *National Tropical Botanical Garden*; Mary Byrne, *Seeds of Success, Bureau of Land Management*; Dr. Chris Dionigi, *National Invasive Species Council*; Dr. Christine Flanagan, *U.S. Botanic Garden*; Holly Forbes, *Univ. of California Botanical Garden at Berkeley*; Dr. Kakoli Ghosh, *Food and Agriculture Organization of the U.N.*; Dr. Robert Gropp, *American Institute of Biological Sciences*; Dr. Kayri Havens, *Chicago Botanic Garden*; Dr. Patrick Herendeen, *Chicago Botanic Garden*; Dr. Kent Holsinger, *University of Connecticut and Botanical Society of America*; Dr. Tom Kaye, *Institute for Applied Ecology*; Dr. Kathryn Kennedy, *Center for Plant Conservation*; Dr. Susan Kephart, *Willamette University*; Dr. Andrea Kramer, *Botanic Gardens Conservation International U.S.*; Dr. Gary Krupnick, *Smithsonian Institution*; Olivia Kwong, *Plant Conservation Alliance*; Dr. Nancy Morin, *Flora of North America*; Dr. Greg Mueller, *Chicago Botanic Garden*; Rachel Muir, *U.S. Geological Survey*; Christopher Mulvaney, *Chicago Wilderness*; Peggy Olwell, *Bureau of Land Management*; David Pivorunas, *U.S. Forest Service*; Dr. Eric Ribbens, *Western Illinois University*; Nicola Ripley, *Betty Ford Alpine Gardens and American Public Gardens Association*; Dr. Kristina Schierenbeck, *USDA - ARS & California State University, Chico*; Dr. Sedonia Sipes, *Southern Illinois University*; Dr. Larry Stritch, *U.S. Forest Service*; Dr. Marshall Sundberg, *Emporia State University*; Dr. Bruce Young, *NatureServe*; Dr. Barbara Zorn-Arnold, *Chicago Botanic Garden*

Preface

Plants are central to the future of scientific discovery, human well-being, and the sustainable use and preservation of the nation's resources. The botanical community in the United States plays a mission-critical role in researching, conserving, and sustainably managing our plant diversity and resources. Botanical expertise is required to address current and future grand challenges and issues, including climate change mitigation, land management and wildlife habitat restoration, understanding the provision of ecosystem services, management and control of invasive species, and the conservation and recovery of rare species. Despite the fundamental role botanical capacity plays in tackling each of these issues, this report outlines where botanical capacity, particularly human capacity, is lacking across all sectors (government, academic, and private). In the United States over the past two decades, the botanical community has experienced significant changes in the demands placed upon it and the resources available to it. Since the early 1990s a series of published and anecdotal reports have outlined declining botanical capacity in many facets of this sector. This includes declines in human resources like botanical training and expertise, financial and management-level support for research, education and application, and the loss of infrastructure such as herbaria. The nation's science and land management agenda is suffering as a result.

Government agencies are losing botanical capacity as staff botanists retire and positions are not refilled, either because positions are eliminated, replaced by individuals without equivalent botanical training, or because there is an inability to find appropriately qualified new candidates to fill them. Botanical education and training likewise appears to be on the decline, with many botany departments at universities being subsumed into more general or interdisciplinary departments, and subsequently losing resident expertise as professors retire and are replaced by individuals without botanical expertise. Organizations in the private sector (e.g. botanic gardens and other non-profit conservation organizations, as well as for-profit businesses and self-employed individuals) are filling these widening gaps in capacity, providing botanical training, expertise, application, and infrastructure where it otherwise would not exist. Though there are ongoing concerns about funding and program sustainability, organizations in the private sector are poised to do more with additional resources and the right partnerships.

Prior to this project, it was unclear exactly where the most critical gaps existed and which sector was most capable of filling them in both the short and long-term. Funding from the National Fish and Wildlife Foundation was awarded to the Chicago Botanic Garden to carry out a one-year project to assess the nation's current and future botanical capacity to conduct research in the plant sciences, to educate the public, train the next generation of plant scientists, and to conserve and manage the nation's native plant species and habitat. In conducting this assessment, we utilized all background information available relating to botanical capacity (education, training, research, application, and infrastructure) in the United States. We conducted literature searches and obtained documents on plant science education, research, and application.

With this information, and in consultation with members of an established Advisory Board and other individuals in the botanical community, we developed and conducted a series of seven on-line surveys. This included surveys for individuals involved in plant science research, education, or natural resource management at 1) federal government agencies; 2) state heritage programs; 3) other regional, state, county or city government agencies; 4) non-profit organizations; 5) self-employed and for-profit companies; 6) graduate school (master's and doctoral graduate students); and 7) academia (faculty and administrators). Surveys focused primarily but not exclusively on the human components of botanical capacity, and were open and publicly available for 8 weeks during the summer of 2009, with requests for participation sent via print and electronic means (e.g. the Botanical Society of America's Plant Science Bulletin, Facebook, websites, email, and through plant science, conservation, ecology and related listserves). We registered more than 1,500 survey respondents representing all 50 states, an indication that this topic is important and of interest throughout the United States. Survey results were an important source of information for this report, as the last time a survey was carried out that specifically targeted the botanical community in the United States was in 1989. Most surveys have been focused on a single sector (primarily the research/training components of the academic sector). **To our knowledge, this is the first time multiple sectors of the botanical community (e.g. the entire pipeline from education and training to research, application, and employment) in the United States have been surveyed simultaneously.**

Following closure of the surveys, a workshop for stakeholders from all sectors was organized at Chicago Botanic Garden from September 29-30, 2009. The purpose of this workshop was to bring the U.S. botanical community together to discuss the survey results and identify recommended actions needed to address and fill gaps it identified. Results of the literature search, surveys, workshop, and subsequent discussions are presented in here over the course of four chapters and appendices. Chapters 1 and 2 describe what was known about botanical capacity in the United States prior to this project, and attempt to explain the critical role it plays in addressing current and future grand challenges. Chapter 3 summarizes basic survey results, and Chapter 4 pulls all information together to illustrate gaps identified and to make recommendations for action.

Recommended citation:
Kramer, A.T., B. Zorn-Arnold, and K. Havens. 2010. Assessing botanical capacity to address grand challenges in the United States. 64 pp. plus appendices. Available at www.bgci.org/usa/bcap.

Acknowledgements

The Advisory Board wishes to thank the many individuals who provided input to this project, including over 1,500 survey respondents and individuals who provided input into the survey, workshop and report throughout the project. We extend special thanks to:

- Carolyn LeJuste (Institute for Conservation Leadership) for facilitating the project workshop
- Kelly Gravuer and Nancy Benton (NatureServe) for assistance in State Natural Heritage survey development and distribution
- Bill Dahl and Johanne Stogran (Botanical Society of America) for assistance in survey distribution
- Students in the Chicago Botanic Garden and Northwestern University Master's' Program in Plant Biology and Conservation for input on an early draft of the graduate student survey
- Members of the Plant Conservation Alliance for consideration and input into the project at numerous stages
- Botanists at the Bureau of Land Management for feedback on early drafts of the government agency survey
- Rick Luhman and Alison Arnold at the Center for Plant Conservation (CPC) for assistance distributing surveys to the CPC Plant Conservation Directory and the CPC network of institutions
- Members of the Botanical Society of America Board of Directors for input on the Report in Brief
- Particular thanks to all workshop participants and individuals who helped review earlier drafts of the report, including Kelly Gravuer, Chris Dionigi, Jim Bennett, Gary Krupnick and colleagues at the Smithsonian Institution, and Abby Hird

Contents

Contents (continued)

Tables

Figures

Chapter 1
Introduction

Plants are essential to life and central to the future of human well-being, the sustainable management and preservation of the nation's resources, and scientific discovery. In addition to delivering ecosystem services necessary to human health – such as water purification, food and climate modulation – our plant landscapes provide habitat for myriad fish and wildlife species across the United States. This rich legacy of biodiversity is an invaluable and irreplaceable component of American heritage.

Botany, or the scientific study of plants, provides basic understanding of fundamental processes that affect ecosystems, the natural environment, wildlife and humans. The study of plants, and the application of knowledge gained is one of the world's oldest and most important scientific endeavors, particularly when it comes to the environment and human health. Nineteenth century botanists, including Gregor Mendel and Charles Darwin, are credited with some of the world's most important scientific advances and up until the twentieth century most medical doctors were trained first in botany. We are now equipped with advanced technology that allows us to understand specialized aspects of plant science that were unimaginable during Mendel and Darwin's times; from plant genome sequencing to satellite imagery of the world's ecosystems. These advances, combined with growing global threats such as climate change, invasive species and habitat loss have made botany more relevant and critically important today than ever before. However, it is not clear that the nation has adequate botanical capacity in place to effectively capitalize on scientific advances and address growing environmental challenges.

1.1 Defining botanical capacity

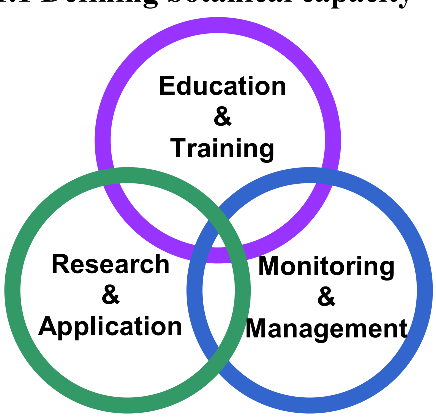


Figure 1.1: Components of botanical capacity

Key components of botanical capacity include: (1) education & training, (2) research & application, and (3) monitoring & management. Botanical capacity encompasses the resources (human, physical, financial, and technological) and management (leadership, networking and communication linkages) necessary for each of these components to fully support and complement one another (Horton et al., 2003). Together, these components of botanical capacity provide humans with a fundamental understanding of the processes that affect ecosystems, the natural and managed environment, wildlife, and human health and well-being. Without this basic understanding, progress in solving current and future grand challenges (Table 1.1) will be severely compromised.

1.2 The mission-critical role of botanical capacity

The nation's botanical sector plays a mission-critical role by studying, effectively managing, and guiding the sustainable use of critical life resources (PCAST, 1998). Botanical capacity is therefore a fundamental component of strategic planning and action to address today's grand challenges, particularly those related to climate change. Investments in this truly green sector will yield a high rate of return in environmental services and scientific advances while benefiting the health and well-being of the American people as well as the nation's wildlife.

Land managers, conservation agencies, and policy makers in public and private sectors face rapidly escalating needs for information in response to the many challenges emerging in the natural world. The urgency of climate change, expanding and changing energy needs, increased demand for water and other natural resources, biodiversity conservation, and landscape level restoration is forcing action. Public and private institutions will increasingly be called upon to help guide and implement these actions, which requires sound science and a strong infrastructure for effective and efficient implementation. Unfortunately, it is not clear that these institutions have the botanical capacity needed to meet this challenge.

Progress on the nation's science and land management agenda and, more broadly, the ability of the United States to address 21st century grand challenges (as recently outlined by President Obama and the National Research Council of the National Academy; see Appendix A) will be severely compromised if sufficient botanical capacity is not in place throughout all necessary sectors. Specifically, numerous components of botanical capacity in both research and management will be needed to address each challenge, as identified in Table 1.1.

Table 1.1: Grand challenges requiring botanical capacity as part of a multidisciplinary effort.

Grand challenge identified	Botanical capacity (research) required to address grand challenges	Botanical capacity (management) required to address grand challenges
Biological Diversity and Ecosystem Functioning in a Changing Climate [a, b] Challenge: To understand factors affecting biological diversity and ecosystem structure and function so habitat can be managed to sustain biological diversity, humans and wildlife in the face of rapid climate change.	• Improve tools for rapid assessment of plant diversity at all scales • Produce quantitative theory of spatial and temporal plant diversity • Elucidate relationship between plant diversity and ecosystem function • Understand how human activities and climate change affect plants and, as a result, ecosystem function, develop interventions to minimize harmful effects	• Work with researchers to develop, test and implement techniques to modify, create, and manage native plant habitats that support biological diversity and ecosystem functioning • Identify and monitor plants and ecosystems at risk due to climate change, invasive species or pathogens • Monitor ecosystem function and its relationship to plant species diversity and habitat composition
Sustainable Food Production [b] Challenge: to generate *food plants* to adapt and grow sustainably in changing environments. This is a critical contribution toward making it possible to feed people around the world with abundant, healthy food, adapted to grow efficiently in many different and ever-changing local environments.	• Advance knowledge of how genetic background of crop plants confers adaptation to local conditions • Use genetic and breeding tools and techniques to develop crop plant varieties adapted to different local conditions • Use horticultural and agronomic techniques to understand how to sustainably and efficiently grow plant varieties adapted to different local conditions	• Monitor and manage native habitat to ensure wild genetic diversity of current and future crop wild relatives is not lost • Bank seeds of current and future wild crop relatives to ensure the range of genetic diversity is accessible for research and future use

Table 1 continued

Grand challenge identified	Botanical capacity (research) required to address grand challenges	Botanical capacity (management) required to address grand challenges
Biogeochemical Cycles [a] Challenge: to further understand the Earth's major biogeochemical cycles, evaluate how they are being perturbed by human activities, and determine how they might better be stabilized.	• Quantify plant-based sources and sinks of key nutrients, including carbon and nitrogen, and understand factors regulating transformations among them • Understand how changes in plant habitat diversity and composition caused by human activities alters biogeochemical cycling and impacts on ecosystem function	• Work with researchers to develop, test and implement techniques to manage, modify, and re-create native plant habitats that can support ecosystem functioning and help stabilize biogeochemical cycle perturbations
Climate Variability [a] Challenge: to increase our ability to predict climate variations, to understand how this variability may change in the future, and to assess realistically the resulting impacts.	• Improve tools to observe and record impacts of climate variability on plant species, plant habitat, and the wildlife that depends on it • More effectively incorporate impacts of climate variability on plants into comprehensive climate change models assessing future effects	• Work with researchers to develop, test and implement techniques to observe and record impacts of climate variability on native plant habitats, including resulting impacts on biodiversity and ecosystem functioning • Take steps to mitigate impacts of climate variability on native plants and the wildlife and ecosystem functions that they support • Bank seeds of native plant populations to ensure genetic diversity is available for research and future use
Optimized, ultimately carbon-neutral fuel production [b, c] Challenge: to expand sustainable alternatives to fossil fuels and ultimately develop biological systems that can turn sunlight into carbon-neutral fuel	• Identify which plants produce the most useful form of cellulose • Determine how alternative biofuel crops can be developed and grown efficiently and sustainably • Identify how alternative biofuel crop species, selected and produced in different regions, can be utilized to ensure carbon-neutrality and maintain ecosystem function	• Monitor and manage native habitat to ensure wild genetic diversity of current and future biofuel crops is not lost • Bank seeds of current and future biofuel crops, to ensure the range of genetic diversity is accessible for research and future use

[a] Taken from (NRC, 2001) [b] Taken from (NRC, 2009) [c] Taken from (NEC, 2009)

While these grand challenges require interdisciplinary work to achieve success (NRC, 2009), disciplinary expertise is needed even in a multidisciplinary effort (Policansky, 1999). The knowledge and expertise that the discipline of botany in general, and botanists specifically, bring to bear on addressing the grand challenges of this century often goes unrecognized (perhaps a form of plant blindness[1]) and under-supported. Failure to include botanical expertise in these efforts will impede progress and lead to greater challenges in the future. Yet reports of declines in capacity throughout the botanical community have generated significant concern about the nation's

[1] Plant blindness has been defined as (a) the inability to see or notice the plants in one's environment; (b) the inability to recognize the importance of plants in the biosphere and in human affairs; (c) the inability to appreciate the aesthetic and unique biological features of the life forms that belong to the Plant Kingdom; and (d) the misguided anthropocentric ranking of plants as inferior to animals and thus, as unworthy of consideration. (Wandersee and Schussler 1999)

collective resources and expertise available to address the challenges confronting us, including climate change, renewable-energy issues, ecosystem restoration, as well as biodiversity conservation and sustainable use. Despite the immediacy of these problems and the overwhelming need for appropriate botanical capacity in governmental, academic and private sectors, the nation's current and future botanical capacity is largely unmeasured and unknown.

1.3 Botany is not optional

Botanical expertise is a fundamental component of efforts to address key issues relating to the environment and human health and well-being in the United States today (Figure 1.2).

Particularly given rapidly changing natural, urban and agricultural landscapes, capacity for botanical research, application, education, training and infrastructure is required to efficiently and economically address the following key issues:

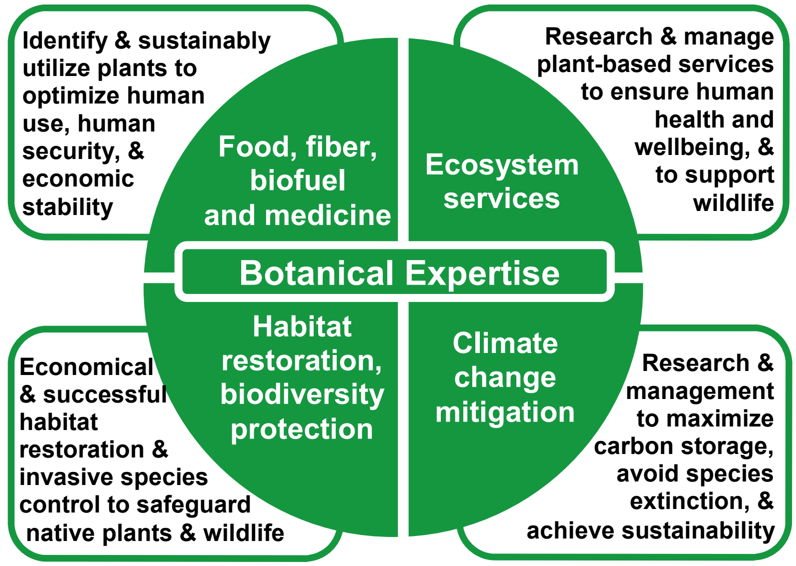


Figure 1.2: Four areas requiring botanical expertise (within circle) and the contributions botanists make to them (adjacent boxes).

1.3.1 Provision and sustainable use of ecosystem services

Ecosystem services, as defined by the Millennium Ecosystem Assessment (MEA, 2005), are the benefits people obtain from ecosystems, including *provisioning* of food and water, *regulation* of atmosphere, floods, drought, land degradation, and disease, *support* for soil formation and nutrient cycling, pollution filtering, and *cultural services* like recreational, spiritual, religious and other nonmaterial benefits. Changes in any one of these services will affect human well-being via impacts on security as well as fundamental elements of life, health, and social and cultural interaction (NRC, 2008). Questions regarding the evaluation, conservation, restoration and sustainable use of these services, particularly in a context of rapid climate change, were among the top one hundred questions of importance to the conservation of global biological diversity (Sutherland et al., 2009). Although rarely explicitly acknowledged or perhaps even recognized, tackling these questions requires the contributions of individuals with fundamental botanical expertise that have access to botanical information in sufficient detail. For example, plants play a critical role in soil formation, yet if plant species in the ecosystem being studied cannot be identified, if their relationships to each other and other non-plant species in the ecosystem cannot be understood and accounted for, and if there is not historical data (e.g. herbarium and survey) to identify where species have been located, and when they tend to grow and senesce, it will be impossible to truly monitor, conserve, restore, or sustainably utilize this ecosystem service.

1.3.2 Climate change mitigation

Climate change already impacts the nation's plants in native as well as managed ecosystems in myriad ways. For example, flowering phenology among shrubs in the Sonoran desert advanced by as much as 21-40 days (Bowers, 2007), frost damage susceptibility in montane wildflowers is increasing (Inouye, 2008), plant distributions have rapidly changed in only 30 years (Kelly and

Goulden, 2008), and invasion potential for non-native species into new habitats is increasing (Dukes et al., 2009). Lack of botanical knowledge and resources drastically hinders efforts to predict, preempt, and mitigate future negative impacts of climate change on plants and the humans and wildlife that depend upon them. Unless botanical knowledge, expertise and resources are made more readily available and are more frequently employed to help address and mitigate these impacts, there will be significant consequences not only for plant diversity, but for the ecological services they provide, including but certainly not limited to carbon storage (Hawkins, Sharrock, and Havens, 2008; Marris, 2009). In addition, plants are a necessary component of climate change mitigation efforts currently being discussed within research institutions and federal agencies, including the use of biofuels and other alternative energy solutions. The establishment of alternative energy programs, such as the installation of massive solar and wind power plants throughout the nation, has the potential to negatively impact native plant communities and the wildlife that depend on them. It is critical that individuals with botanical training active participants in discussions on the range of climate change mitigation efforts.

1.3.3 Management and control of invasive species

The U.S. currently spends more than 25 billion dollars every year controlling invasive plant species (Pimentel, Zuniga, and Morrison, 2005; Pimentel, 2009), with costs likely rising over the next decade. There are over 3,300 nonnative plant species occurring in self-sustaining populations in natural areas in the U.S. today: sixteen invasive plant species alone infest an estimated 125 million acres (Duncan and Clark, 2005). Executive Order 13112 calls on all federal agencies to avoid the introduction and spread of invasive species, and created the National Invasive Species Council (Clinton, 1999; NISC, 2010). However, if there are not enough individuals with botanical training monitoring public lands, invasive plant species can easily become well-established before they are detected, at which point control may be either extremely expensive or impossible. Biological invasions can alter ecosystem services that are tied to climate change, such as carbon sequestration (Peltzer et al., 2009), and climate change can alter patterns and incidence of biological invasions (Bradley, 2009). Cohesive programs of habitat monitoring and species identification carried out by trained botanists as well as trained citizen scientists can offer early identification of aggressive exotics, directly saving taxpayers billions of dollars annually. Numerous botanic gardens around the country are partnering with other public and private agencies to establish and support early-detection invasive species programs, including the Invaders of Texas program (2010) and the Invasive Plants Atlas of New England (Simpson et al., 2009).

1.3.4 Human health and well-being

Through the provisioning of ecological services, plants directly affect every aspect of human life, from clean air and water to medicine, clothing and shelter. As the connection between climate change and human health is increasingly recognized and addressed, the critical link between climate change, plants and human health is largely forgotten, or ignored (Ziska, Epstein, and Schlesinger, 2009). The nation's ability to adapt to and mitigate negative impacts of climate change on human health will be increased if individuals with appropriate botanical expertise are included in discussions and decision-making between health care providers and policy makers on these issues. The cascading health issues surrounding climatic changes are only beginning to be understood and addressed from botanical and human health perspectives. Climate change is broadly expected to bring about significant impacts on human health through the loss of ecosystem services. Further, potentially important indirect effects of climate change on plants and human health (for example, increased toxicity in poisonous plants in response to elevated carbon dioxide levels, or the extinction of taxa with potential medicinal properties) must also be more fully understood and incorporated in decision-making at all levels.

1.3.5 Sustainable agriculture

Throughout human history, our destiny has been distinctly shaped by interactions with plants, from the development of agriculture to New World explorations driven by the quest for spices, up to the recent Green Revolution and continuing today (Pollan, 2002). Our fate is no more removed from plants than it once was, though the links are often hidden by packaging and global supply chains. In fact, in many ways we are now more dependent on plants than ever before, as the world's population of over 6.5 billion people relies upon only about 20 plant species to provide the majority of its food supply. At the same time, fewer and fewer people have any practical or intellectual knowledge of plants and plant culture. The global stock of some 300,000 plant species is declining both in numbers and variability, rapidly removing future options for use (Mlot, 1995). Agriculture, as we know it today, developed over the last 10,000 years when climates were relatively stable; rapid climate change and unpredictability stand to significantly shift needs, resources, and demands on the global food supply in unpredictable ways that will require significant botanical capacity in order to address. In 1983, the National Academy of Sciences' Briefing Panel on Agriculture Research Opportunities identified plant biology specifically as a research area that is "likely to return the highest scientific dividends as a result of incremental federal investments" (NSF, 1990). Given the growing challenges of biodiversity loss and climate change, this statement is even more true today (Breithaupt, 2008).

1.3.6 Land management and habitat restoration

Management and restoration efforts require the participation of a multidisciplinary group of trained individuals with access to as much scientifically-sound information as possible. Because plants form the backbone of every terrestrial habitat in the United States, it is particularly important that botanical expertise is specifically included as part of an interdisciplinary approach. Successful habitat restoration uses botanical expertise to predict a wide range of plant dynamics that promote healthy populations and habitats. For example, incorporating the right combination of plant species at appropriate densities and planting times can influence future plant community composition (Howe et al., 2006), moderate herbivore effects (Zorn-Arnold, Howe, and Brown, 2006), and help support valuable bumble-bee pollinators (Zorn-Arnold and Howe, 2007).

If land management or habitat restoration plans are developed with incomplete or incorrect botanical foundations, the outcomes will likely be far different than desired. For example, if botanical information and resources are not available for native and invasive plant species at a restoration site (including details like distribution and abundance information, as well as easy access to a botanist who can identify them), an inappropriate or incomplete mix of plant species may be used, resulting in a restored community that cannot effectively sustain wildlife in the region. Botanical expertise is also a critical component of research to develop seed transfer zones (to ensure success and economical restoration practices), and is also necessary to provide research and guide management that considers the use of assisted migration as a strategy to avoid plant extinction. Alternatively, new invasive species may escape early detection, delaying removal efforts until the problem is more pervasive and costlier to remediate. Lack of botanical input into the management and restoration process can lead to decreased restoration or management success (Zeiter and Stampfli, 2008), or even complete failure. Long term support of botanical survey and research efforts, and preservation of accessible botanical data sets (such as scientific collections maintained in herbaria or seed banks), along with appropriately trained botanists, will ensure successful land management and restoration processes.

1.3.7 Using plants to clean polluted soil, water, and air

Phytoremediation, using plants to decontaminate soil or water *in situ*, provides a significantly more efficient, economical, and aesthetically pleasing solution to pollution than engineering a physical solution (Salt et al., 1995). Certain plant species preferentially accumulate contaminants, such as arsenic, mercury, and lead sequestering them from contaminated soil or water. While relatively few species have been screened for their ability to accumulate specific contaminants under different conditions, ongoing research on previously untested native species is promising (Liu et al., 2008). Growth of botanical capacity in this arena could pay huge dividends.

1.3.8 Conserving and recovering rare or sensitive species

There are nearly 18,000 plant species native to the United States, which are essential components of the nation's ecosystems, and are inextricably linked to human health and well-being. Despite this, 30% of the nation's plant species, our natural wealth, are known to be imperiled[2] (NatureServe, 2010). Further, wildlife conservation often takes precedence over plant conservation (Stein and Gravuer, 2008), despite the fact that the two are inextricably linked. Over half of imperiled plant species in the United States are found on publicly-managed lands, and as a result conservation and recovery of rare and threatened plants is one of the primary activities of many state and federal agency botanists and wildlife biologists. The development and implementation of management and recovery plans for these species is rarely straightforward, and often must be done on a case-by-case basis, requiring a long-term commitment to resource-intensive monitoring. In many cases, little is known about life history and growth requirements for individual species, taxonomy can be confusing and difficult, and inter-species interactions is unknown. As a result, decline of any one species may be due to a cascade of multiple species interactions. For example, rare butterfly species are often limited not only by the distribution and abundance of one or a few host plant species for their larval stage, but also by the timing and quantity of plants that provide flower nectar during their adult stage. This is the case with the Fender's blue butterfly (Schultz and Dlugosch, 1999), and an example of restoration failure due to lack of botanical information and expertise during restoration and recovery work comes from the threatened El Segundo Blue Butterfly (Longcore et al., 1997). The host plant species (*Eriogonum fasciculatum*) for larvae of this rare butterfly was successfully restored to a site, but the seed source used was not from the correct local ecotype, and larvae ultimately died due to an apparent toxic response to what should have been an appropriate host plant. For these reasons and more, all conservation and recovery work, whether for plants or animals, requires significant botanical capacity and input to ensure time and resources are most effectively and successfully used.

1.3.9 Urban planning

Urban planning that incorporates botanical information and resources can create spaces that are sustainable, more affordable, healthier, safer, and more efficient than those that disregard plants. For example, Washington DC's urban forest is comprised of nearly 2 million trees that sequester carbon, reduce the urban heat island effect, and lower environmental pollution, which are ecosystem services valued at over $3.6 billion dollars annually (Nowak et al., 2006). If properly planned,

[2] Here 'imperiled species' are defined as those with a global conservation status rank of G1 (critically imperiled), G2 (imperiled), or G3 (vulnerable). Imperiled species may or may not be listed as threatened or endangered under the federal Endangered Species Act. See NatureServe 2010.

botanical information and expertise effectively integrated with urban planning can provide key habitat for threatened species (Smallidge and Leopold, 1997), corridors that allow both plants and animals to migrate with and adapt to changing climates, and green space that provides outdoor recreational opportunities which ultimately both conserve biodiversity and enhance human well-being (Miller, 2008). Botanical planning on even small scales can make significant contributions toward sustaining plant and animal biodiversity (Tallamy, 2007). Efforts are underway to address this, including the cross-sector partnership that created the Sustainable Sites Initiative (SITES, 2009).

1.3.10 Carbon-neutral (biofuel) research and production

Solar energy captured and stored by plants during photosynthesis can be made available as biofuel. With increasingly sophisticated technology, biofuel has the potential to supplement or replace fossil fuels in the transportation sector. Current 'energy crops' include corn and sugar beets, where sugar and starch are converted to ethanol, but these crop plants have been bred for food production, not biofuel production, and there are many other potential energy crops that could produce energy much more economically and efficiently. Grasses such as *Miscanthus* spp. (native to Asia) are being tested as more efficient biofuel crops, yet there are significant concerns about the invasive potential of these non-native taxa (Barney and DiTomasso, 2008) and input from botanists specializing in invasive species biology is needed. Individuals that understand plant biology and plant communities are essential to implementing risk mitigation steps needed to avoid the introduction and spread of invasive plants in biofuels production programs, and to meeting the mandates of the 2007 Energy Independence and Security Act, 2008 Farm Bill and Executive Order 13112 on invasive species (DiTomasso et al., 2010). Native plants also present great potential for use as biofuel crops, as they maintain a wealth of genetic diversity and adaptations that could make them among the most efficient biofuel crops in the regions where they grow. However, very few plants not already bred and produced as food crops have been tested as potential energy crops, despite the significant potential they present (Rubin, 2008).

1.4 Botanical expertise: an urgent need for assessment

Despite the economic and environmental importance of botanical capacity in the United States, the nation's full botanical capacity in education, research, and management is unknown. While information on individual components of the botanical community is often available, it is out-of-date and narrowly focused. For example, the last nation-wide survey focused specifically on botanical capacity was carried out in 1989 (NRC, 1992): this survey assessed the academic sector. *To our knowledge, a comprehensive assessment of national botanical capacity capturing all sectors has never been carried out.* Without the broad base of information such an assessment provides, it is difficult to fully identify strengths or weaknesses in the botanical community, and nearly impossible to take actions that will efficiently and effectively fill critical gaps.

1.5 Project scope and methodology

To begin addressing the need for a comprehensive and up-to-date analysis of the nation's current botanical capacity, this project was initiated to evaluate the state of botanical capacity in the United States as it broadly applies to plant science research, education, and application. As such, identified stakeholders included: (1) GOVERNMENT (staff and management personnel in federal, state and local government agencies), (2) ACADEMIA (college or university faculty and graduate students), and (3) PRIVATE ORGANIZATIONS (staff and management personnel at private organizations, including non-profit and for-profit organizations).

An initial search of published and grey literature was carried out to gather and synthesize all available background information available regarding past and current botanical capacity (education, training, research, application, and infrastructure) in the United States. Project staff worked in consultation with members of the advisory board and other individuals in the botanical community to develop, test, and ultimately carry out seven on-line surveys. This included surveys for 1) federal government agency staff, 2) state heritage program staff, 3) other regional, state, county or city government staff, 4) non-profit organization staff, 5) self-employed and for-profit staff, 6) graduate students (masters- and doctorate-level), and 7) academic faculty.

Surveys included approximately 30 questions, and covered the following topics:

1. Educational background
2. Current employment and general roles/responsibilities
3. Use of botanical knowledge in daily activities and use of continuing education
4. Perception of key ecosystem and management needs
5. Barriers to progress
6. Key roles that botanists play
7. Current levels of resourcing and limitations
8. How partnerships are utilized and their effectiveness
9. Retirement and future staffing
10. Skill sets of new employees

Online surveys were open and publicly available for 8 weeks during the summer of 2009, with requests for participation sent via print and electronic means (e.g. Plant Science Bulletin, Facebook, websites, email, and through listserves), targeting scientists, graduate students, administrators, and land managers involved in natural resource management, education and research throughout the United States.

Following survey closure, a facilitated workshop involving 30 stakeholders from government, academic, and private institutions was held at Chicago Botanic Garden from September 29-30, 2009 (see page 2 for workshop participants). The purpose of the workshop was to bring professionals from the U.S. botanical community together to discuss the survey results and make recommendations to fill critical gaps in botanical capacity which it identified.

This report is based on the results of the literature search summarized in Chapters 1 and 2, survey results presented in Chapter 3, and presents gaps and recommendations from the survey and workshop outlined in Chapter 4.

Chapter 2
The current state of botanical capacity in the United States

This chapter is based on literature searches and data available prior to the completion of this project, in order to describe the current state of botanical capacity in the United States. It summarizes information available on the national employment outlook in the botanical sector, and describes current understanding of botanical capacity in human resources and infrastructure in academic, government, and private sectors.

2.1 National employment outlook – all sectors

The U.S. Bureau of Labor Statistics produces the National Industry-Occupation Employment Matrix as part of its Occupational Employment Projections Program (BLS, 2010). This contains detailed data for approximately 300 industries and 700 occupations, and is available online as part of the U.S. Bureau of Labor Statistics' 2008-2018 Employment Matrix. Only one occupational category presented in this Matrix (Soil and Plant Scientist), provides an appropriate indication of nationwide employment relating to the botanical sector. Information retrieved from the online matrix for the "Soil and Plant Scientist" occupational category is presented in Table 2.1. Information from this matrix on the "Zoologist and Wildlife Biologist" occupational category is included in the table as a point of comparison.

Data from the U.S. Bureau of Labor's 2008 National Industry-Occupation Employment Matrix is the foundation for the 2010-11 edition of the *Occupational Outlook Handbook* (BLS, 2010). This 2010 Handbook provides a summary of employment in different sectors, including the Biological Sciences sector, of which botanists are a part. The Handbook provides detailed information on employment in the sector, including a) nature of the work, b) training, other qualifications and advancement, c) employment, job outlook and projections, d) earnings and wages, and e) related occupations. The Handbook section on Biological Sciences includes comprehensive employment, wage, and job outlook projections for the subdiscipline of Wildlife Biology, but unfortunately does not include similar information on Botany/Plant Science.

Table 2.1: U.S. Bureau of Labor Statistics Occupation Employment Matrix (National Employment Matrix, 2008-2018) for two occupational categories: A) "Soil and Plant Scientists" and B) "Zoologists and Wildlife Biologists".

Employment Industry by Occupational Category	Employed 2008	Projected Employed 2018	% change 2008 - 2018
A. Soil and Plant Scientists			
Federal government	2,000	2,100	7%
Educational services, public and private	2,000	2,300	12%
Self-employed workers; all jobs	1,700	1,900	13%
Research & development in physical, engineering & life sciences	1,700	2,200	25%
Miscellaneous nondurable goods merchant wholesalers	1,500	1,400	-7%
Management, scientific, and technical consulting services	1,000	1,900	85%
Local government, excluding education and hospitals	600	600	9%
Support activities for agriculture and forestry; all jobs	500	600	14%
State government (excluding education and hospitals)	400	500	9%
Testing laboratories	400	400	11%
Museums, historical sites, and similar institutions	300	400	23%
Animal production; all jobs	300	300	0%
Farm product raw material merchant wholesalers	300	200	-6%
Landscaping services	200	200	28%
Crop production; all jobs	200	200	-6%
Management of companies and enterprises	200	200	5%
Total employment, all soil and plant scientist workers	*13,900*	*16,100*	*16%*
B. Zoologists and Wildlife Biologists			
State government (excluding education and hospitals)	6,900	7,500	8%
Federal government	4,900	5,300	7%
Management, scientific, and technical consulting services	2,100	3,400	65%
Research & development in physical, engineering & life sciences	1,100	1,300	13%
Educational services, public and private	900	900	1%
Local government, excluding education and hospitals	800	800	-3%
Self-employed workers; all jobs	500	500	-5%
Social advocacy organizations	500	500	-1%
Total employment, all zoologists and wildlife biologist workers	*19,500*	*22,000*	*13%*

2.2 Current botanical capacity in education and training

Botanical education and training is the foundation upon which all other botanical capacity in the United States rests. It is critical that adequate human resources, networks and infrastructure are in place in all sectors to ensure future botanical capacity needs are met in order to address the nation's grand challenges, as outlined in Table 1.

2.2.1 Current botanical education and training capacity - academic institutions

Academic institutions provide botanical capacity in human resources and infrastructure in the form of botanical education and training, as well as a botanical research and application. For this project, information on education and training at public or private universities or colleges with botany, plant science, or plant biology departments or personnel was sought through literature searches in peer reviewed as well as online and grey literature. Some of the most comprehensive data identified comes from the early 1980s when plant biology was recognized as a critical component of the nation's science programs, and a research area "likely to return the highest scientific dividends as a result of incremental federal investment" (Andersen, 1984). However, at the time it was noted that necessary information specifically on plant biology research and training was limited (particularly for subfields within plant biology) due to the tendency of researchers to group data by much larger categories (e.g. biological sciences).

In response to this need, the National Science Foundation's (NSF) Division of Physiology, Cellular and Molecular Biology initiated a survey in 1983 that identified plant biology personnel and training capacity at doctorate-granting institutions (Andersen, 1984). A slightly modified version of this survey was carried out again in 1989, and a 1990 report identified trends and outcomes of these two surveys (Chaney, Farris, and White, 1990):

- In the 1982-1983 academic school year, a survey of 165 institutions identified 4,759 full time faculty dedicated to plant biology. Departments in which plant biology faculty were most commonly located were, in order of frequency: agronomy/soil science (806 faculty), botany (600), horticulture (506), plant pathology (434), and biology (428).
- In the 1988-1989 academic school year, a survey of 154 institutions identified 4,517 full time faculty dedicated to plant biology. Departments in which plant biology faculty were most commonly located were (in order of frequency) agronomy/soil science (724 faculty), botany (589), biology (584), plant pathology (562), and horticulture (531).
- In 1983, the top three areas of concentration for faculty research and graduate student training were, in order of frequency: ecology, plant physiology, and systematics. In 1989, this had shifted slightly to ecology, molecular biology, and plant physiology (graduate student training) and plant physiology, ecology, and molecular biology (faculty research).
- In 1983 and 1989, the most often identified shortage of positions was in ecology, systematics, anatomy/morphology and evolution.
- In 1983 and 1989, a surplus of positions was identified in molecular biology, biochemistry and genetics (1983 only).
- In 1989, factors identified as most limiting progress included, in order of the frequency of mention: insufficient financial support for research (86%), insufficient support for graduate students (83%), and inadequate equipment (65%). (Note: surveys did not include questions about what was limiting progress in plant biology.)

Almost immediately following the last comprehensive NSF survey in 1989, reports began to appear suggesting that plant biology research and training were insufficiently emphasized and in a downward spiral relative to other biological disciplines, despite their vital importance to scientific progress in the United States. The most thorough analysis of the situation is found in a 1992 report entitled *Plant Biology Research and Training for the 21st Century,* published by the National Research Council (NRC, 1992). In this report, major impediments to the success of plant biology research in the United States were clearly laid out, including (1) failure to recognize plant science as a basic discipline of biology, (2) isolation of plant sciences from other biological disciplines, (3) insufficient and fragmented funding and support for basic plant biology research, and (4) inadequate training and facilities. The report's key recommendation to reverse the downward trends in plant biology research and training focused on the establishment of a National Institute of Plant Biology (NIPB) in the U.S. Department of Agriculture (USDA) dedicated to leading a coordinated federal plant biology program involving all federal agencies charged with supporting research and training in plant biology. However, key recommendations of the 1992 NRC report were never implemented, and the plant biology community has not been specifically and systematically surveyed since the 1990 NSF report.

The only comprehensive and up-to-date source of information currently available to indicate national capacity in botanical education and training at academic institutions is found in general annual reports released by the U.S. Department of Education's National Center for Education Statistics on undergraduate and graduate degrees (NCES, 2009). Figure 2.1 depicts the trends in undergraduate degree awards from 1991 through 2008. While general biology awards have increased 70% over this timeframe, botany/plant biology awards have failed to keep pace over the long-term, and in fact have declined since 1991.

Figure 2.1: Comparison of the number of undergraduate students graduating with a degree in botany/plant biology versus a degree in general biology, 1991 - 2008 (as reported by the National Center for Education Statistics). (Note: numbers for general biology graduates are divided by 100 to facilitate viewing on a single graph, e.g. 196 graduates in botany and 54,000 graduates in general biology in 2008.)

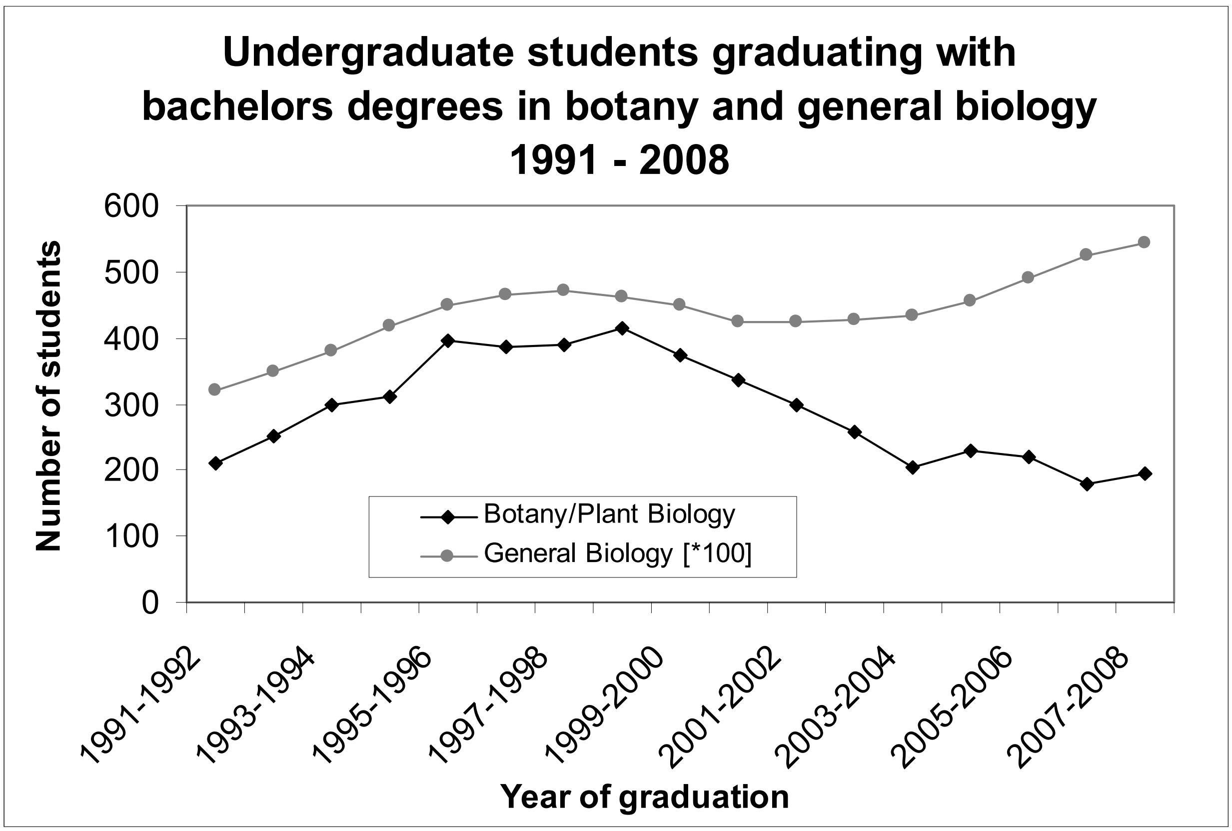
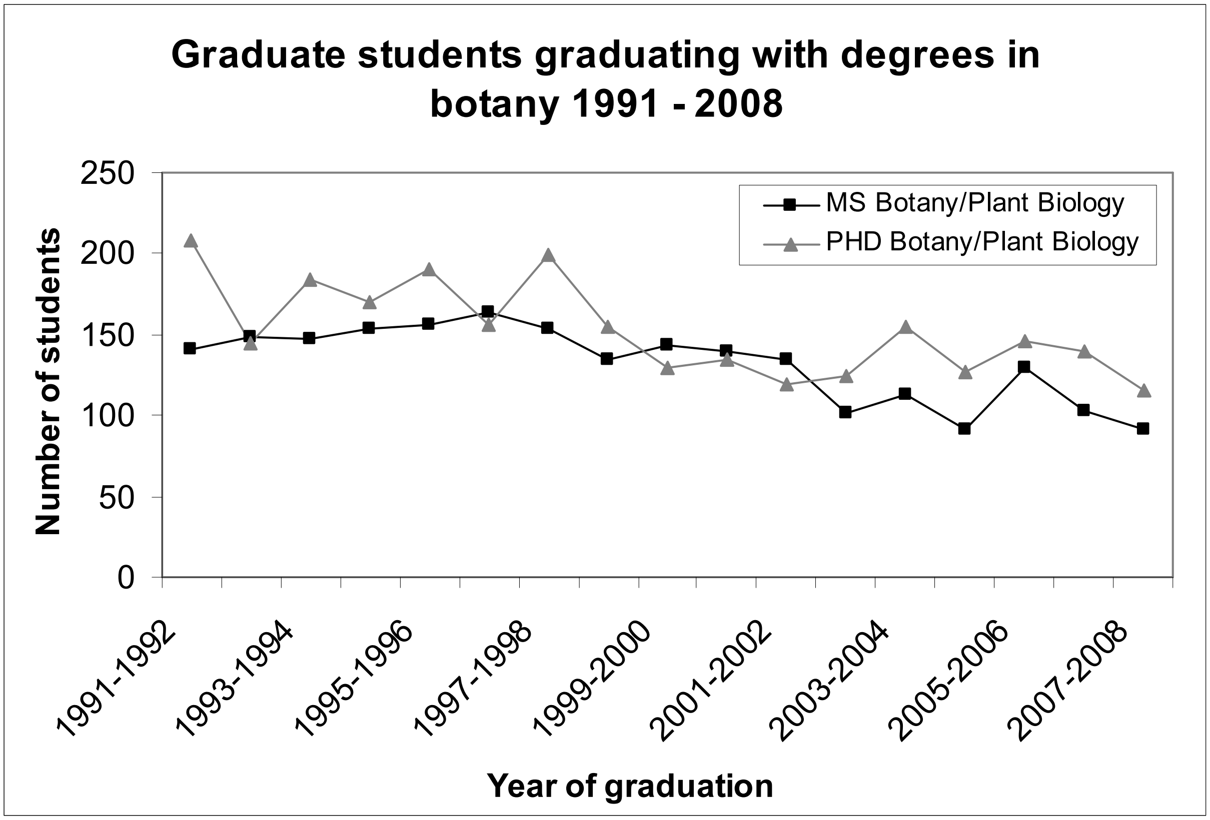


Figure 2.2: Summary of the number of graduate students earning a Master of Science or Ph.D. degree in botany/plant biology, 1991 - 2008 (as reported by the National Center for Education Statistics).



Awards of Master and Doctorate degrees in botany/plant biology have declined since 1991 (Figure 2.2), mirroring the trend of declining undergraduate awards in botany seen in Figure 2.1. This may be a result of the marked decline in botany/plant biology programs at universities around the United States during this time (Sundberg, 2004), despite a community-wide recognition that demand for botanists exceeds supply (Dalton, 1999). Plant science programs that focus on agronomy and horticulture have reported similar declines in graduate student enrollment and retention (Darnell and Cheek, 2005).

A comparison of statistics on research funding collected and published by NSF (NSF, 1990, 1999, 2009) helps shed light on this trend. In 1988, 36 of the top 50 universities with the largest federally-financed research and development programs in biology offered doctorate degrees in plant biology or botany. By 2006, 19 of those 36 universities cut their doctorate program in plant biology/botany. Seven out of the 19 universities that cut their PhD program in botany/plant biology retained a concentration in the field under a biology degree. These schools include Harvard, Yale, and University of North Carolina-Chapel Hill. The rigor of these remaining plant biology programs varies greatly as indicated by course offerings, ranging from 4 to 14 courses (based on May 2009 online course catalog searches). It is interesting to note that 15 out of the 19 universities that eliminated their PhD program in botany/plant biology also experienced reduced federal funding during this 18 year (1988-2006) period. These schools include University of Chicago, John Hopkins University, Stanford, University of Colorado, SUNY at Buffalo, Boston University,

University of Utah, University of Miami, Rockefeller University, and Virginia Commonwealth University.

Evidence of future shortfalls in botanical capacity: education

Loss of botanical degree programs: In 1988, 72% of the nation's top 50 most funded universities offered advanced degree programs in botany. Today, more than half of these universities have eliminated their botany programs and many, if not all, related courses. Statistics from the U.S. Department of Education reveal that undergraduate degrees earned in botany are down 50% and advanced degrees earned in botany are down 41%. During the same time, undergraduate degrees awarded in general biology have increased 17% and advanced degrees earned in general biology have grown by 11%.

As early as 1952, a general decline in botany/plant-based curriculum relative to general biology curriculum at America's universities and colleges was noted (Greenfield, 1955), and by all indications this trend continues today. This may be due in part to the widely-recognized decline in organismal biology and taxonomy, including a decline in the support of natural history collections for both plants and animals (Gropp, 2003; Schwenk et al., 2009; Yoon, 2009), and is likely amplified by the phenomenon of plant blindness (Wandersee and Schussler, 1999; Hershey, 2002). Research has shown that students have better recall for animals than plants (Schussler and Olzak, 2008) and science textbooks do nothing to help change this, as they describe and detail animals much more than plants in general (Link-Pérez et al., 2009). Much has been written about the need to update botanical curriculum and education programs from pre-college (Daisey, 1996; Hershey, 1996; Goins, 2004; Enger, 2006; Hoot, 2009) to post-secondary education (Greenfield, 1955; Uno, 1988, 1994; Ewers, 2000; Uno, 2002; Cantino, 2004; Carter, 2004; Curtis and Bell, 2004; Sundberg, 2004; Uno, 2007; Senchina, 2008; Uno, 2009). Yet declines are ongoing and much remains to be done to ensure plant science is more broadly and effectively incorporated into the nation's science and management curriculum.

While the number of undergraduate botany degrees awarded has dramatically declined across the United States, steady growth in the undergraduate botany program at Humboldt State University is a notable success story (Lawlor, 2008). Other undergraduate programs are formulating new ideas for curriculum development and working to include botany and the study of species into liberal arts curriculum (Nesom and Weakley, 2009). The evolution of undergraduate as well as graduate botany programs to make education and training opportunities more directly related to the needs of potential employers in the private and government sectors (including decision making ad implementation of policy) may create new avenues for growth (Muir and Schwartz, 2009).

2.2.2 *Current botanical education and training - government agencies*

The federal government provides information on training and career opportunities for all disciplines, including botany, at www.usajobs.gov/studentjobs/. Various programs provide ways for agencies to attract, train, and ultimately employ recent post-secondary graduates at all levels:

- Student Career Experience Program (SCEP) allows appointment of students to positions that are related to their academic field of study. Participants who meet program requirements may be noncompetitively converted to term, career, or career-conditional appointments. SCEP is intended to help grow the federal workforce by hiring students into developmental positions to address future agency needs.

- Federal Career Intern Program (FCIP) helps agencies recruit exceptional students into a variety of occupations at higher levels, and allows individuals to be appointed to a 2-year internship that provides formal training and developmental assignments as established by the agency. Upon successful completion of the program, the interns may be eligible for non-competitive permanent placement within the agency.
- Presidential Management Fellows Program (PMF) helps agencies meet workforce and succession planning needs by connecting agencies with outstanding graduate students. The Office of Personnel Management (OPM) oversees the program, recruiting annually by reaching out to accredited graduate schools around the world and hosting a searchable online resume bank and job posting system. Successful fellows are matched with agency needs to complete a two-year fellowship that provides formal training and development assignments. Upon successful completion of the Program, Fellows convert to a non-competitive permanent position within the agency.

2.2.3 *Current botanical education and training - private organizations and businesses*

The private sector includes for-profit businesses, self-employed and contracted individuals, as well as non-profit organizations such as botanic gardens and arboreta. These different stakeholders make important contributions to botanical education and training, both individually and in partnership with government and academic sector organizations. While little quantitative information describing the full contributions of the private sector to botanical capacity has been published, particularly with respect to for-profit businesses and self-employed and contracted individuals, information detailing some of the contributions made by non-profit organizations (particularly botanic gardens) was identified, and is described in the following paragraphs.

Botanic gardens and arboreta have a long history of work in plant exploration, taxonomy and systematics, developing regional floras, building and maintaining herbaria, and carrying out plant education and outreach programs for students of all ages. In the past century, the number of botanic gardens in the United States has grown from fewer than 40 institutions to more than 450 (BGCI, 2010b). According to the American Public Gardens Association (APGA, 2010) about 70 million people now visit the nation's public gardens every year. Botanic gardens in the United States are often managed as non-profit organizations, although a number are managed by or affiliated with universities or non-federal government agencies. These institutions provide a diverse and ever-growing array of botanical education, training, research, application, management and monitoring services at local, national, and global scales (Affolter, 2003; Miller et al., 2004; Havens et al., 2006; Kuzevanov and Sizykh, 2006; Donaldson, 2009).

An online database of resources at the world's botanic garden maintained by Botanic Gardens Conservation International (BGCI, 2010b) identifies education programs at 121 U.S. gardens, with more than 380 staff helping to carry out these programs (at 50 botanic gardens that provided detailed employment statistics; see Table 2.2 for additional information on education work at botanic gardens). BGCI is an international non-profit organization working with over 700 of the world's botanic gardens and conservation partners to conserve the world's plants for people and the planet, works to connect and build education programs at botanic gardens. This includes publishing a biannual botanic garden education review (Roots), producing and connecting online education resources (BGCI, 2010a), and hosting training programs for botanic staff around the world while providing networking opportunities through global education congresses.

Table 2.2: Education, training and outreach summary statistics for U.S. botanic gardens and arboreta, as detailed in BGCI's database.

GardenSearch field	Summary data as of April 2010
Have an education program	121 gardens
Number of education staff	383 staff (N = 50 gardens)
Education programs for K-12 students	52 gardens
Education programs at university-level	35 gardens
Education programs for visitors	89 gardens
Number of volunteers engaged in activities	20,000 volunteers (N = 69 gardens)

The Center for Plant Conservation (CPC, 2010a) is a non-profit conservation organization coordinating a network of 36 botanical institutions in the United States to secure and restore the nation's imperiled plants through establishing ex-situ conservation resources and conservation action in the wild. The Center develops and supports best scientific practices in plant conservation work, and has published 3 technical volumes on plant conservation for vulnerable species and populations. The CPC's Applied Plant Conservation Training Program, developed and carried out in collaboration with leading plant conservation scientists from around the country, has been presented for federal and state government agencies since 2005 and trained more than 125 current and future practitioners. The weeklong course of work presents an intensive overview of the multidisciplinary nature of plant conservation and the many plant science specialties involved in conservation and management of plant biodiversity. The Center also maintains a website that provides resources including an international reintroduction project registry, ecotype bibliography, conservation directory, and invasive species link portal. The Center supports one of the only full time communications positions in the nation dedicated to increasing public awareness of our vulnerable native plants. The position promotes improved understanding of the value, beauty and usefulness of our at-risk plants, and the work of our scientists and communities to secure and restore them.

Botanic gardens around the country maintain formal botanical education programs for undergraduate and graduate students. For example, New York Botanical Garden has maintained a graduate studies program for over a century which provides degrees in systematic and economic botany in association with six universities in New York (NYBG, 2010a), and the Missouri Botanical Garden likewise has a long history of graduate programs in plant systematics, evolution and ecology offered in cooperation with four universities in Missouri and Illinois (MOBOT, 2010). In California, Rancho Santa Ana Botanic Garden is home to the botany department of Claremont Graduate University, offering graduate degrees in plant systematics and evolution (RSABG, 2010), in Illinois the Chicago Botanic Garden and Northwestern University recently began a program to offer graduate degrees in plant biology and conservation (CBG, 2010a), and in Florida the Fairchild Tropical Botanic Garden partners with two universities in Florida to offer graduate degrees in tropical plant biology and conservation (FTBG, 2010).

Many botanic gardens and arboreta offer college credit for courses carried out at their institution, for example The Morton Arboretum via the Chicago Region Cooperative College Botany Program (MORTON, 2010). Other botanic gardens are directly affiliated with universities, and therefore provide both formal and informal botanical education and training opportunities to students – examples include the North Carolina Botanical Garden (NCBG, 2010), Sarah P. Duke Gardens (DUKE, 2010), the Lady Bird Johnson Wildflower Center, and the University of Washington

Botanic Gardens (UWBG, 2010). Finally, botanic gardens of different shapes and sizes offer training opportunities to students and recent graduates, including the New England Wildflower Society's long history of offering internship and fellowship programs (NEWFS, 2010), the Chicago Botanic Garden's Conservation and Land Management Intern Program, offered in partnership with federal land management agencies as a way to fill gaps in botanical capacity at federal field offices and to recruit and train a new generation of federal botanists (CBG, 2010b), as well as Denver Botanic Garden's internship programs in horticulture and plant research and conservation (DBG, 2010).

Many other non-profit organizations have environmental education programs that focus on or incorporate classes on plants, local flora and native ecosystems. For example, the Institute for Applied Ecology (IAE, 2010) carries out a series of programs and curriculum development to engage K-12 students, teachers, and adult community members in the study of native plants and restoration through school programs, summer teacher workshops, community learning courses, and volunteer work. Other examples comes from the North Cascades Institute's Celebrating Wildflowers workshop and educator's guide to help teachers teach students about native plants in Washington State (Scherrer and Johannessen, 1996) and intended for use as a model nationwide (Scherrer, 1999), as well as native plant societies such as the California Native Plant Society (CNPS, 2010) and the Florida Native Plant Society (FNPS, 2010). Important training opportunities are also widely found with non-profit organizations, such as the internship opportunities in native plant production and seed banking offered to New York City college students by Greenbelt Native Plant Center (GNPC, 2010).

2.3 Current botanical capacity – research and management

As detailed in Table 1, botanical research and management are critical components of work to address key issues like climate change and the preservation, restoration, and sustainable use of ecological services and native plant diversity. Academic institutions, government agencies and organizations in the private sector are playing an important role in advancing these issues, but much more remains to be done, as detailed below.

2.3.1 Current botanical research and management capacity - Academic institutions

Academic institutions provide botanical capacity in human resources and infrastructure at the education and training level, as well as at a research and management level. Academia provides classroom-based botanical education and training for students, and many academic institutions maintain a number of other botanical resources and infrastructure, including field stations and/or natural areas as well as herbaria of varying size and scope where students gain field experience and training. This infrastructure is also vital for basic and applied research around the country. Most basic botanical research is produced by faculty, staff and students at academic institutions, At some institutions, particularly land-grant universities, more applied research is also carried out.

A 2007 paper ranking academic institutions in the United States and Canada according to research productivity in conservation biology over four years (Grant et al., 2007) identified a threefold increase in the number of institutions offering instruction in conservation biology (from 75 in 2003 to over 300 in early 2007). The article identified many of the top performing universities in the United States (based on the number of publications and citations in leading conservation biology journals) as federal land grant universities with close ties to federal and state natural resource-based agencies (such as the U.S. Geological Survey, U.S. Forest Service, and U.S. Environmental Protection Agency), and in many cases top-performers were located in close proximity to federal laboratories. While this paper did not differentiate between conservation biology research on different organisms, it is likely that a majority of the research this study identified was carried out on animals. For example, results of a search on ‘‘population genetics’’ for all articles published in the journals Conservation Genetics, Conservation Biology, and Biological Conservation in 2008 showed that 72% of 99 identified studies were on animals, while only 26% were on plants (2% were reviews that incorporated both plant and animal studies) (Kramer and Havens, 2009).

An indication of how well conservation science research carried out over the past 20 years matches up with known priorities and threats is summarized in a 2006 review paper (Lawler et al., 2006). This review showed that research on over-exploitation and disease appeared to be keeping up with known threats, while a considerable gap in the study of invasive species was identified, despite the significant threat they pose to plant diversity and the functioning of ecosystems.

2.3.2 Current botanical research and management capacity - Government agencies

Nearly one-third of all land in the United States is managed by the federal government. Specifically, it is managed almost exclusively by five federal land management agencies, including the Bureau of Land Management (BLM), Department of Defense (DOD), National Park Service (NPS) US Forest Service (USFS), and US Fish and Wildlife Service (USFWS). In 2008, there were 1,520 species (831 vascular plants, 374 vertebrates, 313 invertebrates, and 2 lichens) protected by the Endangered Species Act known to be located on federal lands in the United States. At the same time, 3,069 additional species on federal lands were considered imperiled (2,686 plants, 383 vertebrates) (Stein, Scott, and Benton, 2008).

Botany staff at the nation’s five federal land management agencies, together with staff at state land management agencies, is responsible for managing a large share of the nation’s natural heritage, including threatened plant species that occur on public lands. Given this, government botanists perform a number of mission-critical roles in managing the nation’s living resources which require specific botanical training and expertise. In many cases, the workload and responsibilities of a federal botanist are much greater than that for federal wildlife biologists. For example, on California’s National Forests each plant specialist is responsible for an average of 14 sensitive plant species, while animal specialists are each responsible for an average of only *one* sensitive animal species (Roberson, 2002). However, botanists are not equally compensated for this greater workload. In fact, they are paid much less than their counterparts: in March 2009, the U.S. Bureau of Labor Statistics reported that Federal Government microbiologists earned an average annual salary of $97,264; ecologists, $84,283; physiologists, $109,323; geneticists, $99,752; zoologists, $116,908; and **botanists, $72,792** (BLS, 2010).

Federal land management and research agency botanists

Botanists at federal agencies fall under the U.S. Office of Personnel Management's 0430 Job Series Code, defined as *covering positions that manage, supervise, lead, or perform professional research or scientific work that involves the study of plant life - work involves studying plant taxonomy, morphology, ecology, and ethnobotany*. (OPM, 2005)

Actual tasks carried out by federal botanists are much more diverse and critically important to the management and sustainable use of the nation's natural resources than its description implies. Typical tasks performed by botanists include: (adapted from Roberson 2002)

- Perform biological evaluations to assess risk of projects (renewable and non-renewable energy development, logging, grazing, road construction, recreation, fire) on sensitive plant species, and participate in interdisciplinary teams to protect botanical resources during these projects
- Develop and implement habitat restoration and plant species recovery plans
- Survey and monitor populations of rare plants
- Implement recovery plans for listed plant species, in consultation with state and other federal agencies
- Survey and monitor populations of invasive species, develop and/or implement activities to manage invasive species
- Carry out public education and outreach programs
- Regulate sustainable harvest of non-timber forest products, including mushrooms and medicinal plants
- Manage botanical resources, including during wildfires through post-fire restoration efforts

Individuals hired under the **0430 job code** must have at least 24 credit hours of coursework in botany, which is becoming increasingly difficult to attain for recent college graduates given the noted decline in botany programs at universities nationwide.

Federal botany staffing does not meet the nation's public land management needs, as many regional and local offices of federal land management agencies do not have a single botanist on staff (Roberson, 2002). Likewise, federal botany staffing is not meeting the nation's research needs, particularly in the US Geological Survey (USGS), which is the research arm of the BLM, NPS, and USFWS National Wildlife Refuge system and is therefore charged with research to support management of the native plant communities comprising almost 400 million acres of public lands. To support the nation's research needs, USGS maintains 18 science, research, and technology centers throughout the United States whose activities are intended to align with the diversity of biological resources in the area. Researchers at these science centers represent an array of scientific disciplines, from ecologists to geneticists, fishery and wildlife biologists, as well as plant ecologists and botanists. However, plant ecologists and botanists are severely underrepresented on science staff at these centers, particularly in the western United States. An online search of 6 science centers in the western U.S. in April 2010 revealed that wildlife staff outnumber by botanical staff by a margin of over 20 to 1.

Evidence of current gaps in botanical capacity: research and management

Bureau of Land Management (BLM) — charged with managing biological resources on 40% of all public lands, but on average only employ approximately one botanist for every 4 million acres of land (an area equivalent to the size of the state of Connecticut)

US Geological Survey (USGS) — provides the science to guide management of nearly 400 million acres of public lands. All USGS survey respondents said their agency did not have enough botanically trained staff to meet current needs. A preliminary assessment of USGS scientists at science centers in the western U.S., where most public lands are located, shows that wildlife scientists outnumber botanical scientists by over 20 to 1.

Literature searches and information requests were unable to identify exactly how many botanists are currently employed by different federal land management and research agencies. This is a key component of assessing the nation's botanical capacity and should be made more easily accessible. However, there appears to be a trend away from hiring under more specific job codes (such as the 0430 botany code) in favor of hiring individuals under a general code (0401, general natural resources management and biological sciences). If this trend continues it will make it even more difficult to identify and manage critical components of the nation's botanical capacity.

Recent reports identifying current employment and future growth of mission-critical jobs in the federal government for the next decade (PPS, 2009; BLS, 2010) do not provide sufficient resolution to understand current or future botanical capacity in research or management, particularly at the Department of the Interior, where only general biological science and wildlife biology are reported. The work of the nation's botanists is as mission-critical to the U.S. as the work of wildlife biologists. This is particularly true in a rapidly changing climate, because health and well-being of humans and wildlife alike will be directly impacted by how plants and the native habitat and ecosystem services they provide respond to climate change.

Table 2.3: Mission-critical jobs identified by the Partnership for Public Service in 2009. This publication was notable because it included wildlife biologists but did not mention or include an indication of the nation's botanical capacity.

Professional Field By Agency	Number of Employees Sept. 2008	Total Hires FY 2007-08	Projected Hires FY 2010-12
Department of Agriculture			
Biological Science Technician	2,336	195	192
Biological Specialist	4,778	321	667
Forestry Specialist	1,979	54	258
Forestry Technician	8,376	925	501
Soil Conservation Specialist	4,082	105	454
Soil Conservation Technician	1,329	90	155
Soil Science	1,144	45	140
Department of Commerce			
Fishery Biology	897	130	102
Department of Health and Human Services			
General Biological Science	1,806	380	546
Microbiology	937	147	234
Department of Homeland Security			
General Biological Sciences (Ag. Sciences)	2297	628	970
Department of the Interior			
General Biological Science	3374	221	330
Wildlife Biology	997	55	90
Environmental Protection Agency			
General Biological Science	839	199	157
Toxicology	191	38	48
National Science Foundation			
Program Director	66	28	42
TOTAL	***35,428***	***3561***	***4886***

MISSION CRITICAL BIOLOGICAL SCIENCES POSITIONS IN THE US FEDERAL GOVERNMENT
SOURCE: Biological Sciences > Where The Jobs Are - Partnership for Public Service
data.wherethejobsare.org/wtja/field/1484 (PPS, 2009)

At a more local level, many regional, state, and local government agencies are responsible for managing and preserving plant and habitat diversity on non-federal public lands. The primary source of information on the precise location and condition of at-risk plant species and threatened ecosystems across the United States comes from State Natural Heritage Programs. Most natural heritage programs are state government agencies, although some are housed at universities. Botanists employed by natural heritage programs conduct extensive field inventories to locate and verify species locations and to assess the conservation status of at-risk plant populations, and utilize consistent standards across the nation to allow information to be compiled and shared consistently and accurately. The data collected and maintained as a part of this network of natural heritage programs (see section 2.3.3) represents more than three decades of continuous inventory and database management, making it the most complete and current dataset available to determine the conservation status of the nation's plants.

At the state-level, botanists charged with preserving plant diversity have fewer resources available than for wildlife. This is exemplified by state wildlife action plans completed by all U.S. states and territories in 2005. These action plans are considered the nationwide strategy to prevent wildlife from becoming endangered (Stein and Gravuer, 2008), and they have become the primary resource, or 'strategic blueprint' that guides conservation planning and funding efforts to safeguard the nation's biological diversity and living natural resources around the country. Yet most state wildlife action plans don't mention or address plant diversity or the fact that wildlife can't be conserved without conserving the native plant communities that they depend upon. In addition, the federal guidelines that governed the development of these action plans explicitly excluded plants from the definition of "wildlife", and provided no similar avenue of developing strategies and support for safeguarding the nation's plant diversity. These factors present significant challenges to maintaining adequate botanical capacity across the United States.

2.3.3 Current botanical research and management capacity – private sector

The private sector contributes significantly to botanical research and management capacity in the United States. This includes for-profit businesses and self-employed or contract botanists that perform consultative services such as plant and habitat monitoring, habitat restoration, seed and plant production for restoration purposes, among other roles. Non-profit organizations including native plant societies as well as botanic gardens and other conservation organizations likewise provide a range of botanical research and management services that contribute to local, state, national and global botanical capacity.

The Native Seed Network maintains a database of vendors in the United States who provide 1) native plant seeds, seedlings, and equipment for restoration use, 2) seed cleaning, storing, and testing services and facilities, and 3) restoration research, consulting and installation (NSN, 2010). A search of this database in July 2010 identified 260 registered businesses and 44 self-employed individuals who indicated providing one or more of the above services. And a database of native plant seed suppliers maintained by the Lady Bird Johnson Wildflower Center (LBJWF, 2010) contained more than 150 businesses as of July 2010. This is a significant botanical resource for ecological restoration and land management in the United States.

The non-profit organization NatureServe coordinates a network of 82 member organizations that span the non-profit, academic and governmental sectors (state natural heritage programs or conservation data centers) to collect, analyze, and make available critical data about plants (as well as animals and ecological communities) in the United States, Canada, Latin America and the Caribbean. The NatureServe network provides the single source for information on conservation status of the nation's plants (NatureServe, 2010) and represents more than 800 dedicated scientists with a collective annual budget of almost $50 million (it is not known what portion of these resources is dedicated to animals and what portion is dedicated to plants). NatureServe is also actively involved in understanding and predicting the impacts of climate change on the nation's biological diversity through their Climate Change Vulnerability Index (NatureServe, 2009) and in developing applications to help integrate conservation with land use and resource planning through a computer program called NatureServe Vista.

The California Native Plant Society works to protect California's native plant heritage and preserve it for future generations (CNPS, 2010). More than just a member-based organization, CNPS draws strength and support from nearly 10,000 members to carry out native plant appreciation, education, and outreach programs along with conservation and rare plant and ecosystem research programs that connect CNPS staff with citizen scientists to collect scientifically rigorous data. The rare plant program, begun in 1968, tracks the conservation status of hundreds of plant species, maintained in the CNPS Inventory of Rare and Endangered Plants of California.

The Center for Plant Conservation (CPC) is a coordinated network of 36 botanical organizations dedicated to conserving and restoring our most imperiled native plants. The network collectively works with nearly 750 vulnerable species including seed banking and restoration in the wild. In 2008 the cumulative value of the work underway for imperiled plant conservation exceeded $10 million. Over the last 25 years, this network has banked nearly 22 million seed destined for future restoration efforts. CPC participating institutions monitor about 2100 vulnerable plant sites, are involved in over 202 reintroduction projects, are working to control invasive species at 94 wild sites, conducting 47 other kinds of habitat restoration projects, and engaging nearly 4500 community volunteers. The network workforce includes 190 full time equivalents with 28 Ph.D. positions, and in 2008 the conservation programs produced 29 peer reviewed journal articles and 86 gray literature articles (Kennedy, 2008; CPC, 2010b). As part of its support for national plant conservation progress, the CPC facilitates communication and networking among partners by maintaining the National Plant Conservation Directory (CPC, 2010c). This searchable directory lists contacts in federal and state agencies, conservation organizations, native plant societies, and academic experts experienced in plant conservation work, and includes links to legislation and regulations.

As a nationwide network, botanic gardens and arboreta in the United States collectively contribute expertise, facilities, and outreach in their neighborhood, state, and across the nation. The GardenSearch database, maintained by Botanic Gardens Conservation International summarizes the minimum level of contributions by botanic gardens in a variety of areas related to research and management, summarized in Table 2.4.

Table 2.4: Plant research and management summary statistics for U.S. botanic gardens and arboreta (Botanic Gardens Conservation International GardenSearch database)

GardenSearch field	Summary data as of April 2010
Number of plant conservation and research staff	359 staff (N = 28 gardens)
Have an herbarium	32 gardens
Number of accessions in herbaria	over 15 million (N = 32 gardens)
Have a micropropagation/tissue culture facility	15 gardens
Have a seed bank	27 gardens
Maintain a plant conservation program	63 gardens
Maintain a plant ecology research program	31 gardens
Have an invasive species biology research program	28 gardens
Have a restoration ecology research program	21 gardens
Have a plant systematics/taxonomy research program	19 gardens
Have a floristics research program	17 gardens
Have an urban environment research program	15 gardens

2.4 Botanical capacity - Infrastructure

Specialized infrastructure needed to meet botanical needs includes buildings such as greenhouses and laboratories, as well as equipment and technology necessary to conduct scientific research and widely share results and data. Herbaria are a critical component of the nation's botanical infrastructure that encompasses building, human resource, and technological needs. For over three centuries, the earth's plant and fungal diversity has been documented by scientists via dried reference specimens maintained in herbaria collections. The New York Botanical Garden maintains a global directory of public herbaria and associated staff called the Index Herbariorum (NYBG, 2010b). This Index contains information on approximately 3,990 herbaria around the world (713 located in the United States), and approximately 10,000 associated curators and biodiversity specialists. This network of the world's herbaria collectively contains some 350 million specimens documenting the earth's vegetation. Unfortunately, this network of herbaria, collections and expertise it is not receiving the support needed to maintain let alone expand its critical role in addressing grand challenges of this century.

Herbaria have significant research, education and training value, yet support for herbaria and natural science collections throughout the United States has eroded to a critically low level (Dalton, 2003; Gropp, 2003; Elisens, 2004; Gropp, 2004; Suarez and Tsutsui, 2004; Gropp and Mares, 2009). The curators of herbaria of all sizes are struggling to maintain basic functions over the long-term (Snow, 2005). There is also an ongoing decline in plant collecting and documenting just when the demands of climate change, invasive species, and alternative energy exploration require that they be on the rise (Prather et al., 2004b, a). Herbaria staff and the natural history collections they curate are vital for both basic and applied research around the country. For example, herbarium collections are increasingly used for climate change research, as they provide a historical record of the distribution and flowering of species as well as invaluable DNA samples that can help understand and predict how plants will respond to changing climates (Primack et al., 2004; Loarie et al., 2008). More broadly, the nation's herbaria play an often unrecognized role in science and society by contributing to homeland security, public health and safety, as well as monitoring and predicting environmental change while safeguarding the nation's natural and agricultural resources (Suarez and Tsutsui, 2004). Herbaria and the natural science collections they curate are therefore necessary and irreplaceable components of the nation's botanical infrastructure (National Science and Technology Council, 2009).

2.5 Botanical capacity – networks and partnerships

Resources in the botanical sector are severely limiting, but a number of within and cross-sector partnerships and networks have developed that are helping to pool resources nationally while building capacity locally, eliminating duplication of effort and increasing program effectiveness. Examples of partnerships and networks combining resources to maximize efficiency, at local, regional, and national levels are highlighted below.

The National Ecological Observatory Network (NEON) is a project of the U.S. National Science Foundation which, along with many other U.S. agencies and cooperating non-governmental organizations, will soon begin uniformly collecting data across the United States on the impacts of climate change, land use change and invasive species on natural resources and biodiversity on a continental scale over multiple decades (Keller et al., 2008). The NEON network, scheduled to begin construction in late 2010 and to be fully operational in 2016, will allow data to be strategically collected from sites within each of 20 ecoclimatic domains in the United States. Data collected will include information on how land use, climate change and invasive species affect biodiversity, disease ecology, and ecosystem services – this data will be freely available to users. The design, implementation, and management of this network will rely heavily on current botanical expertise and infrastructure in the United States while at the same time providing important and needed input, growth and support for botanical capacity in the future.

The Plant Conservation Alliance (PCA, 2010) is a multi-sector consortium of ten federal government Member agencies and over 275 non-federal Cooperators (including non-profit organizations, foundations, and for-profit companies). The PCA adopted a National Framework for progress in 1995 that helps guide the work of its members. This successful alliance provides funding for on-the-ground plant and habitat conservation and restoration projects via a matching funds grant program administered by the National Fish and Wildlife Foundation, and acts as a forum for the exchange of ideas and sharing of best practices. While important work has been carried out through this Alliance, additional resources are needed to ensure it is supported over the long term and to provide resources for broader incorporation of academic partners.

Another nationwide, multi-sector partnership example comes from the Seeds of Success program (SOS, 2010), led by the Bureau of Land Management. This national native seed collection and banking program is the result of a public-private collaboration involving numerous federal agencies and private institutions (particularly botanic gardens) across the country. Since it began in 2001, this partnership has banked over 9,000 collections of native seeds, safeguarding native species against genetic erosion or even extinction, and providing opportunities for efficient and effective research and production of the nation's native plants, some of which may be the next vital biofuel or food crop. While great progress has been made over the previous decade, much more remains to be done to safeguard the wide range of genetic diversity resident in the nation's native plant populations, and additional resources are needed for an expanded work program in the next decade.

Ongoing partnerships between different Federal agencies are effectively pooling resources to increase botanical capacity, including the Interagency Rare Plant Inventory Project in Utah (Clark, 2003) and the Interagency Special Status/Sensitive Species Program (ISSSSP, 2010). The ISSSSP is a partnership between the Pacific Northwest Regional Office of the U.S. Forest Service and Oregon/Washington State Office of the Bureau of Land Management, established as an interagency program for the conservation and management of rare species. This coordinated program is working to identify high priority species and habitats as well as data gaps and information needs, and is developing conservation assessments and strategies, conducting range-wide inventories, and managing data. Agencies around the country could benefit from increasing this kind of collaborative effort, yet many agencies don't have even minimal botanical capacity to initiate, let alone carry out, this type of positive partnership.

At a regional level, successful cross-sector partnerships focused on plant conservation include the New England Wildflower Society's New England Plant Conservation Program (NEPCOP, 2010), begun in 1991 and now engaging 68 different public agencies, nonprofit organizations, universities, land trusts, state parks, and environmental consulting companies to prevent the extirpation and promote the recovery of the region's endangered native flora. Since its establishment in 1995, the Georgia Plant Conservation Alliance (GPCA, 2010) has grown to a productive cross-sector partnership between 15 public gardens, government agencies and other environmental organizations focused on coordinating research, education and conservation programs to conserve endangered plants. Other examples of regional partnerships come from the Colorado Rare Plant Conservation Initiative (RPCI, 2010), comprised of 22 academic, non-profit, and government agency partners who formed to develop and publish a statewide plant conservation strategy in 2009.

Other key components of the nation's botanical infrastructure include professional societies such as the Botanical Society of America (BSA, 2010). The BSA works to "promote botany, the field of basic science dealing with the study and inquiry into the form, function, development, diversity, reproduction, evolution, and uses of plants and their interactions within the biosphere". To accomplish this, the BSA works to 1) support formal and informal education about plants, 2) encourages basic plant research, 3) provides expertise, direction, and position statements concerning plants and ecosystems, and 4) fosters communication within the professional botanical community and between botanists and the rest of humankind through publications, meetings, and committees. The BSA has worked with botanical scientists and educators for over 100 years (Mlot, 1995; Smocovitis, 2006), and plays a significant role in supporting the nation's botanical capacity in education, training, and research. The BSA maintains valuable resources on these topics, including a career center and teacher training resources, on its website and through its publications and meetings, and should play an increasingly important role in current and future efforts to strengthen the nation's botanical capacity.

2.6 Botanical capacity - Global trends

The global loss of biodiversity will undermine economic performance and threatens the global economy because the natural systems that support it are at risk of collapse (CBD, 2010). In particular, the continuing global decline of plant diversity will impact human society more significantly than any other type of biodiversity loss (Schatz, 2009), yet basic efforts to assess the conservation status of plants lags far behind similar efforts for amphibians, mammals and birds (Callmander, Schatz, and Lowry, 2005; Lawler et al., 2006). Resolving this imbalance will require significantly more botanical capacity, resource sharing and coordination than is currently in place at local, national, and global levels.

Declines noted in key areas of botanical expertise and infrastructure suggests that lack of botanical capacity is hindering environmental efforts around the globe. Plant taxonomy is on the decline in China just as it is in the U.S. (Jiao, 2009), and similar declines in plant and animal taxonomy have been well-documented in Australia (ABRS, 2006; FASTS, 2007). In Europe, a lack of awareness about the threats faced by plants as well as dearth of scientific and monitoring information on plants are presenting considerable challenges to developing management plans for the continent's most-threatened plants (Natura, 2007). In France, declines in traditional academic botany programs and infrastructure are noted the book In Praise of Plants (Hallé, 2002). And in the United Kingdom, similar concerns regarding declines in national botanical capacity led to the production of The Ghost Orchid Declaration in 2009 (PlantLife, 2009), a call to arms for governments, conservation organizations and the general public to ensure that botanical capacity is in place so no additional plant species are lost to extinction. On the topics of systematics and taxonomy, the House of Lords recently published a review of taxonomic resources in the country (HL, 2008). This review found the state of systematics and taxonomy in the UK to be unsatisfactory, and in some areas to the point of crisis, and broad recommendations were made to halt the identified declines.

In southern Africa, concern about a lack of botanical capacity to conserve the region's fascinating and unique flora led to the formation of the South African Botanical Diversity Network (SABONET), which was a global donor-funded project carried out from 1996 until 2005, and considered a significant success (Siebert and Smith, 2004). This Network carried out needs assessments of the botanical community (particularly herbaria and botanic gardens) held workshops and training courses, and produced numerous newsletters and publications that helped connect the botanical community and build their botanical resources from a human resource and infrastructure perspective (Smith, Willis, and Mossmer, 1999; Willis and Huntley, 2001; Steenkamp and Smith, 2003; Bredenkamp and Smith, 2008b, a).

In 2002, the United Nations Convention on Biological Diversity adopted a Global Strategy for Plant Conservation (GSPC), which aims to halt the loss of global plant diversity (Wyse Jackson and

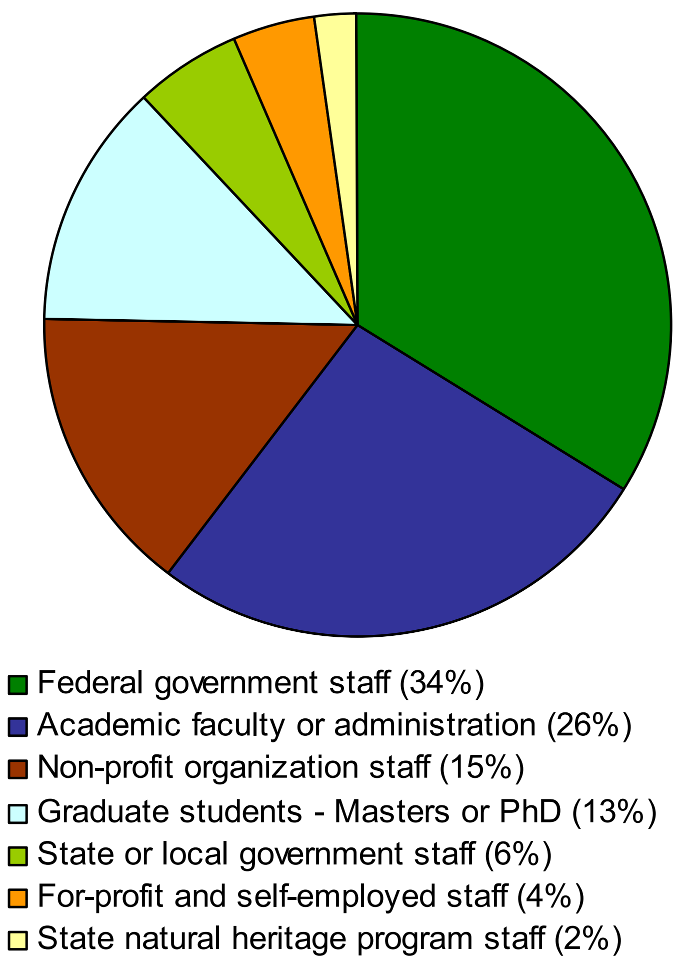
Kennedy, 2009). One key target of this strategy is the building of botanical capacity (Target 15), particularly in developing nations where there is a significant gap between plant diversity and botanical expertise and infrastructure. The capacity building target of the GSPC suggests that the number of trained people working in plant conservation world-wide would likely need to double between 2002 and 2010. This target remains a key component of the GSPC as it looks to be renewed and updated for the period 2010 through 2020, as much remains to be done, particularly given the current global trend of decreasing botanical capacity in developed countries where it had previously been much stronger.

Chapter 3
Survey respondent summary

This chapter summarizes basic background information gathered from each sector surveyed for this project. This includes the Government sector (federal government, non-federal government, and state natural heritage programs), Academic sector (faculty and administration, as well as graduate students), and Private sector (non-profit organizations as well as for-profit businesses and self-employed individuals). Detailed information is available in appendices as described, and the results of specific questions designed to identify gaps in botanical capacity are presented and discussed in Chapter 4, along with recommendations for action to fill identified gaps.

All surveys were open and publicly available for over 8 weeks, after which time 1,569 individuals from all sectors combined had completed a survey (Figure 3.1). Respondents hailed from all 50 states (Appendix 1), included slightly more women than men (Appendix 2) and represented a wide range of ages, expertise, and job type.

Figure 3.1: Survey respondents by group type (n = 1,569)



3.1 Government agencies

3.1.1 Federal government staff

Federal government staff represented the largest group of survey respondents, with 532 individuals taking the survey from over 13 different agencies (Table 3.1).

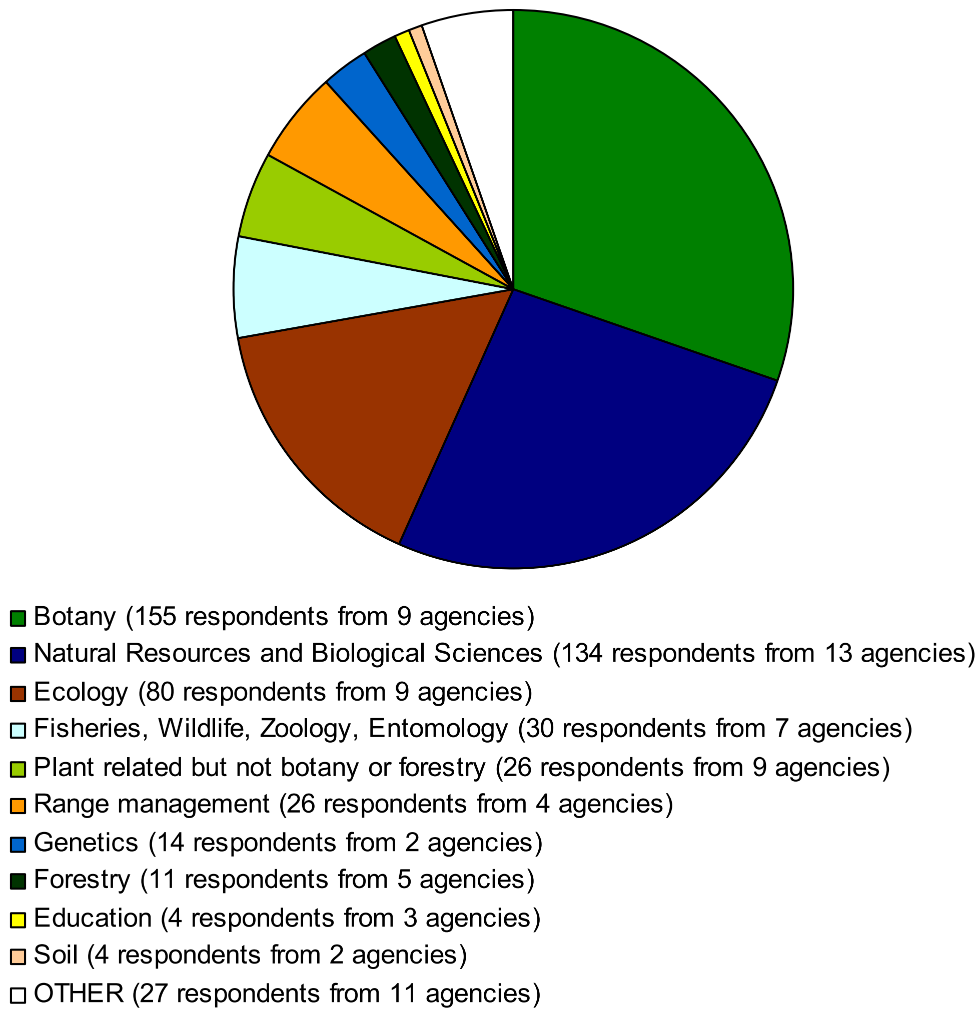
Table 3.1. Federal government respondents, shown as percent responding by agency.

Federal Government	Response (%) N=517
Agricultural Research Service (ARS)	4.4
Army Corps of Engineers	1.4
Bureau of Land Management (BLM)	21.1
Department of Defense (DOD)	2.9
Environmental Protection Agency (EPA)	0.6
National Park Service (NPS)	19.0
Natural Resource Conservation Service	2.3
Smithsonian Institution	3.7
US Fish and Wildlife Service	7.7
US Forest Service	29.0
US Geological Survey	4.6
USDA, including Animal and Plant Health Inspection Services (APHIS)	0.6
Other	2.7

Respondents from federal agencies represented a range of job descriptions, geographic locations, and botanical expertise, ranging from wildlife biologists who utilize botanical knowledge on a daily basis to administrators, scientists, and botanists working in field offices with direct responsibility for managing and conserving imperiled plants while at the same time monitoring and eradicating invasive species and working to restore native plant habitat after wildfires (Figure 3.2). The highest earned degree for most federal government staff responding to the survey was a Masters degree (43% reported a M.S. or M.A. degree), while 34% reported a bachelors degree as their highest earned degree and 23% a Ph.D (Appendix 3).

Almost 85% of all Federal survey takers indicated that they use botanical knowledge either on most days or every day. Eighty three percent of Bureau of Land Management respondents indicated that they used botanical knowledge at least on most days: 45% said of the same group said they used botanical knowledge daily, while 53% of U.S. Forest Service respondents, 28% of National Park Service respondents, and 50% of U.S. Fish and Wildlife respondents said that they use botanical knowledge daily (Appendix 4). The top five daily activities indicated by federal government staff included: 1) Habitat and species monitoring, 2) Invasive species management, 3) Rare species conservation, 4) Habitat restoration, and 5) Land management (Appendix 5).

Figure 3.2: Federal government respondents by work area/job code.



Of all survey respondents, those most directly charged with managing the nation's plant heritage are those hired under the job code 0430 (Botany). While it is not clear exactly how many staff working under the 0430 code are found at different federal agencies, a range of agencies were represented by survey respondents (0430 respondents represented nine federal agencies). Nearly half of all respondents from federal agencies who reported their position was under the 0430 (Botany) job code as listed by the U.S. Office and Personnel Management came from the U.S. Forest Service (47.1%), followed by the Bureau of Land Management (23.9%); see Table 3.2 for additional information.

Table 3.2: Federal agencies where botanists (job code 0430) responding to the survey are employed, shown by percent responding from each federal agency.

Agency	Response (%) N=155
U.S. Forest Service (USFS)	47.1
Bureau of Land Management (BLM)	23.9
National Park Service (NPS)	9.0
U.S. Fish and Wildlife Service (USFWS)	9.0
Agricultural Research Service (ARS)	2.6
Smithsonian Institution	2.6
U.S. Geological Survey (USGS)	2.6
Army Corps of Engineers	1.3
I prefer not to answer	1.3
USDA	0.6

3.1.2 Non-federal government staff

There were 120 respondents to the surveys designed for regional, state and local government agency staff. Of these, the largest group of respondents was state government staff (44%) and state natural heritage programs (29%). See Table 3.3.

Table 3.3: Non-federal government respondents (including state natural heritage program staff), shown as percent responding by agency type.

Government agency type	Response (%) N=120
Regional government	2.5
State government	44.2
State natural heritage programs	29.2
County government	10.8
City government	10.8
Other	2.5

A majority reported that their job role was either a botanist or an ecologist (Table 3.4), and they were responsible for a range of botanical field work, administration, and data management duties.

Table 3.4: Job roles of non-federal government agency respondents. Percentages do not add up to 100 because respondents were allowed to select more than one job role.

Job Role	State, Regional, and Local Government (%) n = 83	State Natural Heritage (%) n = 35
Administration	10.8	8.6
Botanist	**38.6**	**60.0**
Data Manager	6.0	11.4
Ecologist	**37.3**	**40.0**
Environmental Reviewer	14.5	14.3
Executive Management	1.2	5.7
GIS Specialist	6.0	2.9
Interpreter/Educator	7.2	-

A majority (62%) of survey respondents from this group reported a Masters degree as their highest earned degree (Appendix 3). Forty eight percent of respondents use botanical knowledge every day, except state natural heritage program respondents, where 68% reported using botanical knowledge every day (Appendix 4). For survey respondents in these two categories, the top daily activities indicated included: 1) Understanding native habitats and populations 2) Habitat and species monitoring, 3) Invasive species management, 4) Rare species conservation, 5) Habitat restoration, and 6) Threatened/endangered plant recovery (Appendix 5).

3.2 Academic Institutions

3.2.1 Faculty and administration

A majority of 407 academic faculty responding to the survey were employed by public universities (251 individuals), followed by four year colleges (82 individuals). Of these, 20% reported that their job description did not include teaching, while 7.5% reported that their position did not include research. Over half of all respondents reported their current position as either professor (33%) or associate professor (21%). See Table 3.5 and 3.6 for additional details.

Table 3.5: Academic faculty and administration survey respondents, shown as percent responding by institution type.

Institution Type	Faculty Response (%) N=407
Two-year College	3.4
Four-year College	20.1
Public University	61.7
Private University	10.1
Other	5.7

Table 3.6: Position held by respondents from academic institutions, shown as percent responding by position type. Percentages do not add up to 100% because respondents were able to select more than one position type.

Current Position	Faculty Response (%) n=407
Lecturer	3.2
Adjunct/Part-time Faculty	4.7
Assistant Professor	12.0
Associate Professor	21.4
Professor	33.0
Administrator	7.6
Post-Doctoral Researcher	4.7
Permanent Full-time Researcher	5.7
Laboratory Staff	0.2
Other	18.7

A majority of responding faculty identify themselves as botanists, ecologists, or evolutionary biologists (Appendix 6) and most respondents are from departments with nine or fewer full-time faculty members, 80 or fewer undergraduate students, six or fewer Master's Degree students, nine or fewer PhDs, and three or fewer post-doctoral associates (Appendix 7). About half of faculty respondents do not advise PhD or Master's (MA/MS) students, while 30% advise 1-3 undergraduate students (BA/BS) and 27% advise over twelve undergraduate students (Appendix 8). When asked about the number of introductory and advanced plant science courses offered annually by their institution, faculty responses revealed that the majority of all academic institutions offer between 1 and 3 introductory and advanced plant science courses (Figures 3.3 and 3.4).

Figure 3.3: Introductory plant science courses offered annually, as indicated by faculty survey responses, shown by academic institution type.

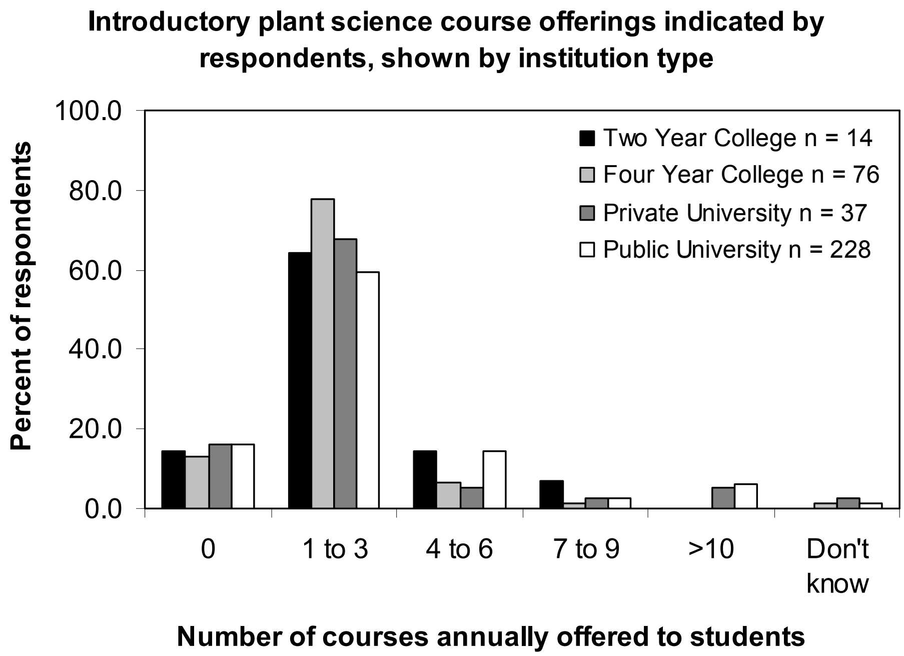
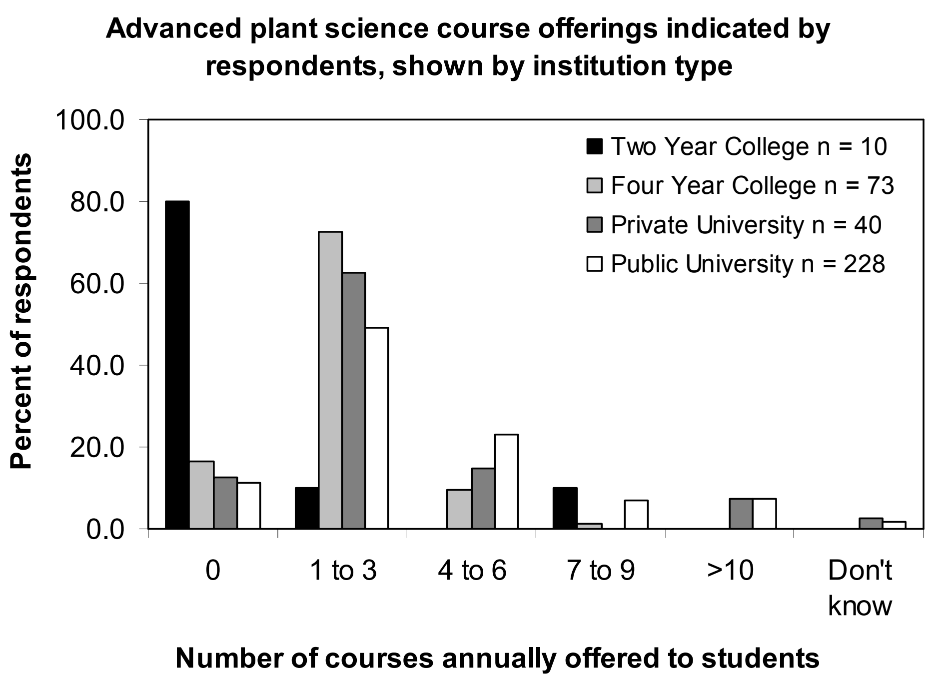


Figure 3.4: Advanced plant science courses offered annually, as indicated by faculty survey responses, shown by academic institution type.



The top five research areas identified by faculty respondents included: 1) botany 2) ecology, 3) evolutionary biology, 4) plant systematics, and 5) plant taxonomy (Appendix 9). Given these research areas, the top five activities faculty indicated their research is applicable to included: 1) Understanding fundamental plant biology, 2) Understanding native habitats and populations 3) Habitat and species monitoring, 4) Rare species conservation, and 5) Diversity maintenance and management (Appendix 5).

3.2.2 Graduate Students

Thirteen percent (13%) of all respondents were graduate students, the majority of which were Ph.D. students at public universities (95 individuals). See Table 3.7.

Table 3.7: Graduate student survey respondents shown as percent responding by degree and institution type.

Degree and Institution Type	Graduate Student Response (%) N=180
Masters Degree, Public University	35.6
Masters Degree, Private University	5.0
PhD, Public University	52.8
PhD, Private University	6.7

Responding students reported that they primarily rely on university teaching assistantships and tuition waivers for financial support during their graduate school career (Appendix 10). The top five research areas respondents identified included: 1) ecology 2) botany, 3) evolutionary biology, 4) restoration ecology, and 5) plant conservation (Appendix 9). Given these research areas, the top five activities graduate students indicated their research is applicable to included: 1) Understanding native habitats and populations, 2) Habitat and species monitoring, 3) Habitat restoration, 4) Understanding fundamental plant biology, and 5) Diversity maintenance and management (Appendix 5).

3.3 Private organizations and businesses

3.3.1 Non-profit organizations

Staff employed by non-profit organizations represented 15% of all survey respondents, with the majority (102 individuals) employed by a botanic garden or arboretum, followed by conservation or research organizations (86 individuals). See Table 3.8.

Table 3.8: Summary organization type for non-profit organization respondents.

A. Non-profit organizations	Response (N)	Response (%)
Conservation/Research Organization	86	43.8
Botanic Garden/Arboretum	102	36.9
Museum	11	4.7
Zoo	10	4.3
Other	24	10.3
NUMBER RESPONSES	233	

Forty percent of respondents indicated their highest earned degree as a master's degree, while 26% had earned a Ph.D. and 30% a bachelor's degree (Appendix 3). A majority of respondents identified themselves as botanists, administrators, or educators (Appendix 6) with daily activities related to 1) Understanding native habitats and populations, 2) Habitat / species monitoring, 3) Rare species conservation, 4) Habitat restoration, and 5) Invasive species management (Appendix 5).

Most non-profit organizations reported more staff in administrative and/or education positions than in plant science research positions, and the sector engages a high number of volunteers (Appendix 11). Key activities incorporated in the organizational mission statements of respondents varied by type of institution: conservation or research organizations most often incorporate plant/habitat conservation (89%) in their mission, while a majority of botanic gardens and arboreta as well as museums and zoos have education in their mission statements (94%, 82%, and 90% respectively). Botanic gardens and arboreta more often incorporate plant/habitat conservation (80%) while museums incorporate research (73%) and zoos incorporate native habitat management (80%). See Appendix 12.

3.3.2 For-profit business staff, self-employed and contract individuals

Respondents from for-profit businesses represented a small but important component of survey responses (4%), including 34 individuals that either owned or were employed by a for-profit business. Most respondents were from small businesses with between 30 and 90 employees. (see Table 3.9 and Appendix 13).

Table 3.9: Response summary from the for-profit business sector by business type.

Type of employment	Response (%) N=59
For-profit business employee	33.9
For-profit business owner	23.7
Self-employed	18.6
Contracted by for-profit business	20.3
Other	3.4

Respondents indicated that a majority of their businesses provide native plant and habitat surveys (59%), monitoring (47%) and restoration (42%). See Appendix 14 for additional details. Half of all respondents in this category identified themselves as botanists, followed by ecologists and plant conservation biologists (Appendix 6), with their primary daily activities most directly related to 1) Habitat and species monitoring, 2) Habitat restoration, 3) Understanding native habitats and populations, 4) Rare species conservation, and 5) Invasive species management (Appendix 5).

3.4 Summary

A very strong response from federal government agencies, academic institutions and non-profit organizations provides a broad picture of basic botanical capacity in the United States that was previously not available. Responses in other sectors were less complete, particularly in the private/for-profit sector. Future surveys would do well to include this group, as well as to expand the scope to include education, training, and research beyond universities and colleges.

Chapter 4
Recommendations to fill critical gaps in botanical capacity

Results, discussion and recommendations presented in this chapter are drawn from survey results as well as discussions that took place during the project's cross-sector workshop and follow-up discussions. Gaps in botanical capacity and recommendations identified to resolve them are presented for education and training, communications and outreach, and finally for research and management.

4.1 Botanical capacity in education and training

The first five recommendations coming from this project involve education and training actions needed to remedy identified gaps in university and college coursework, cross-sector communication, and pre-college and continuing education work. Gaps identified and recommendations that follow are highlighted below, along with supporting evidence from survey results or workshop discussions.

4.1.1 University and college coursework

RECOMMENDATION 1

Faculty and administration involved in college and university biology education should ensure plant science is appropriately incorporated in annual course offerings for undergraduate and graduate students to ensure they are employable both within and outside the academic sector. This includes offering courses that meet requirements for employment as a federal botanist (such as botany, plant anatomy, morphology, taxonomy and systematics, mycology, ethnobotany, and other plant-specific courses), and encouraging interdisciplinary research programs to train students in both basic research and applied science.

RECOMMENDATION 2

Faculty and administration at the nation's academic institutions should ensure plant science, including basic organismal expertise, is strongly represented within interdisciplinary departments, particularly as staff with botanical expertise retires in the coming decade. Accreditation bodies should develop recommendations and criteria for monitoring and evaluation to support adequate representation of botanical disciplines in biology departments and interdisciplinary study programs nationally.

RECOMMENDATION 3

Non-profit organizations play an increasingly critical role in filling gaps in botanical education and training. They contribute to course development and classroom education while providing amplification and practical experience, particularly for subjects that are most in demand for the nation's botanical workforce outside of academia. Because demand will likely only increase in this area, non-profit organizations should take strategic steps to increase their ability to fill this gap in capacity in this area. Leadership to recognize, support and sustain the ability of non-profit organizations to fill this role is needed from private foundations as well as academic and government sectors.

Education at the university level is a critical component of the nation's current and future botanical capacity. Nearly 99% of all survey respondents (1,527 individuals) have at least a bachelor's degree (72% of these have a master's or doctoral degree, see Appendix 3), and more than 35% of all survey respondents plan to retire within the next decade, leaving a significant need for workforce education and training (Figure 4.1).

This need is particularly great within the federal government, where more than 40% of all respondents indicated they would retire within the next decade. And as indicated in Figure 4.2, trained botanists represent one of the most extreme needs within the federal workforce, as nearly 50% of federal botanist respondents (employed under the 0430 job code) will be retiring in the next decade. The 0430 (botanist) job code requires a combination of education and experience equivalent to a major in botany or basic plant science that included at least 24 semester hours in botany. Courses that count towards this requirement include basic botany, plant anatomy or morphology, cytology, histology, genetics, taxonomy or systematics, algology, mycology, ethnobotany, and those dealing with specific problems of a botanical nature or with specific groups of plants.

Figure 4.1: Retirement timeline of survey respondents from academic and government sectors illustrates the need for education and training.

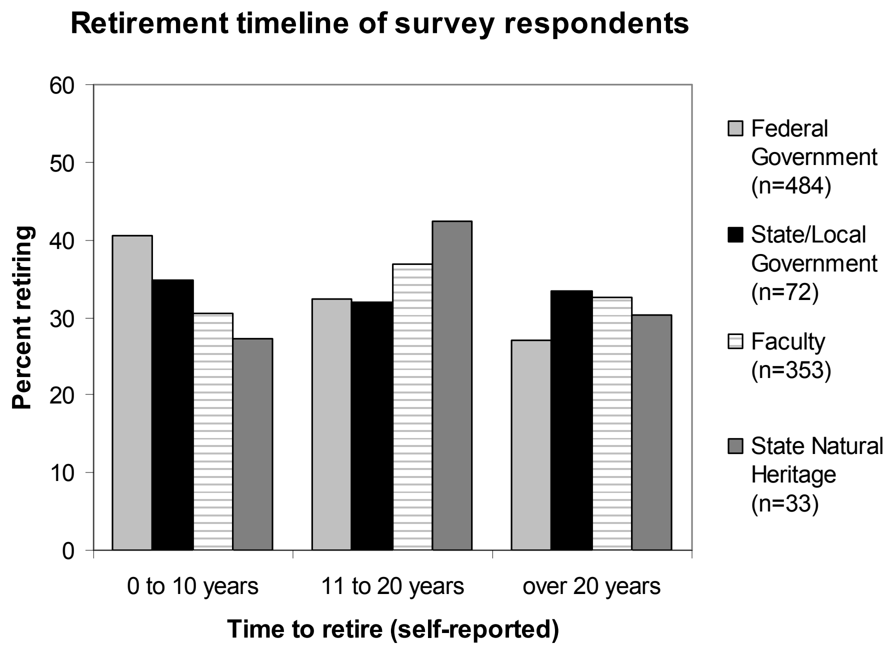
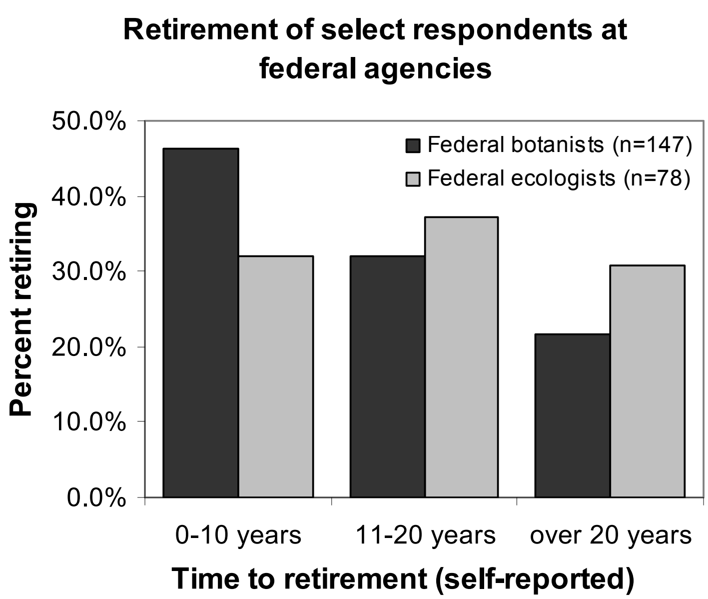


Figure 4.2: Retirement of survey respondents who are employed as federal botanists (0430 job code) versus federal ecologists (0408 job code). There will be a significant need for a botanically trained workforce to fill the vacancies created by retiring botanists.



Without an equivalently trained workforce ready to fill the vacancies left by these retirements, the nation will miss opportunities to efficiently and economically address grand challenges. Yet the results of several questions asked by this survey reveal a continued trend of declining university course offerings as well as dissatisfaction in course offerings among students and faculty alike

(Table 4.1), and a mismatch between what coursework much of the botanical workforce has taken and what is now being offered to students (Appendix 15). This situation appears likely to worsen over the coming decade as faculty teaching botanical courses most in-demand will be retiring and are unsure whether their positions will be filled by someone with equivalent botanical expertise.

Identified gap in botanical capacity: university education

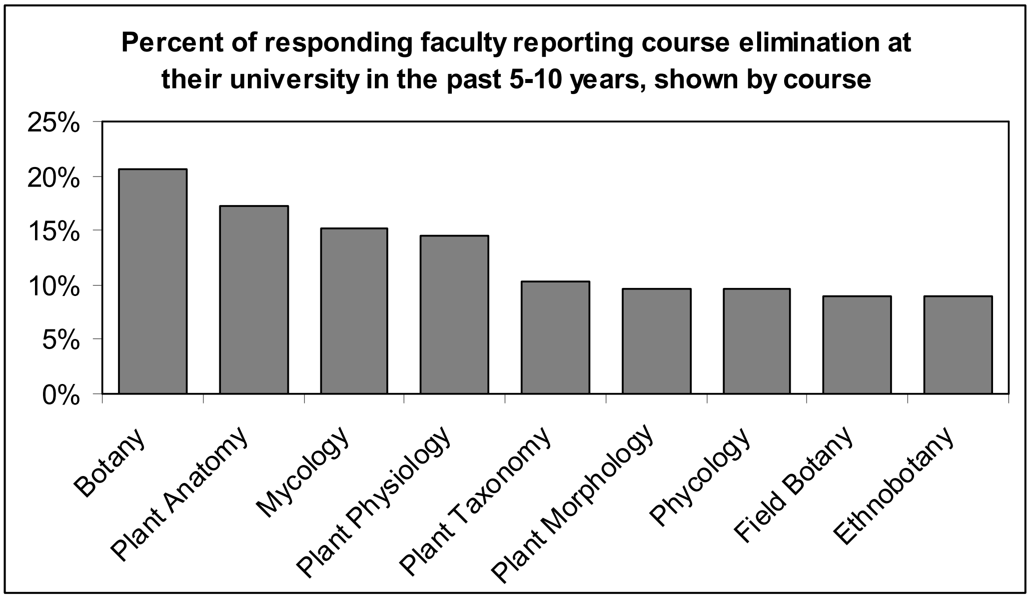
Decline in botanical course offerings: Nearly forty percent of the over 400 university faculty who completed the survey said botany courses in their department had been cut in the past 5-10 years. The courses eliminated tend to be from among those required for the 0430 (botanist) federal job code. A majority of faculty and graduate student respondents were dissatisfied with botany courses offered by their college or university.

Table 4.1: Course elimination and course availability satisfaction, as indicated by faculty and graduate students. Summary of responses to the questions ***Have any plant science courses been eliminated at your institution within the last 5 to 10 years?*** (Faculty only) AND ***Do you feel satisfied with the number of plant science courses offered at your university?*** (Faculty and graduate students) Response with the most selections is indicated in bold.

Response	*Courses eliminated?* **Faculty (%) N = 392**	*Satisfied with courses offered?* **Faculty (%) N = 379**	**Student (%) N = 180**
Yes	**39.3**	30.6	34.4
No	32.7	**51.2**	**52.2**
I don't know/unsure	28.1	18.2	13.3

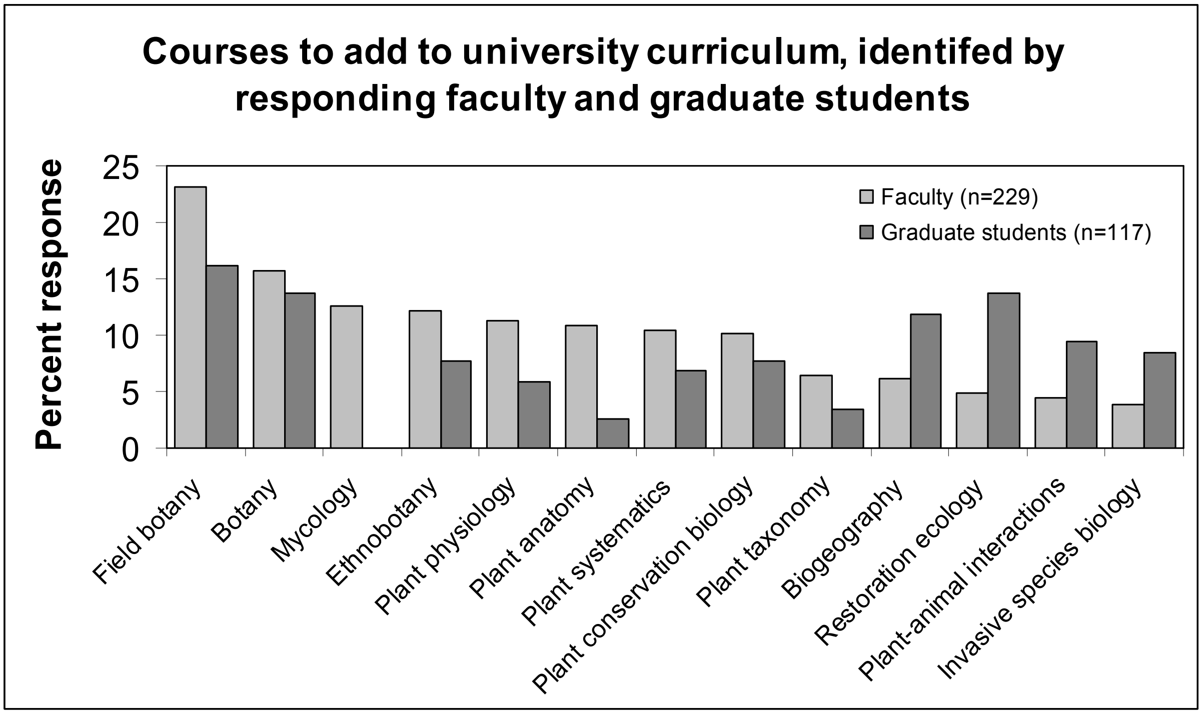
Almost 40% of faculty indicated that plant science courses have been eliminated at their institution in the past 5-10 years. A range of courses were listed as being eliminated, but the two courses most often identified by faculty were botany and plant anatomy (see Figure 4.3). The majority of graduate students as well as faculty expressed dissatisfaction with the selection of plant science courses offered at their institutions.

Figure 4.3: Courses eliminated at universities in the past decade, as reported by faculty.



Faculty and graduate students were also asked to identify courses they felt should be added to the curriculum (*Question asked: If you think that your college/university should add plant science classes to its program, then please select the top three (3) courses that you think should be added.*) Faculty recommendations largely focused on fundamental courses, whereas many of the top selections for graduate students focused on applied plant science courses: faculty most often selected Botany, Mycology and Field Botany as courses that should be added to the curriculum, while graduate students selected Field Botany, Restoration Ecology, and Biogeography as their top three course additions (Figure 4.4).

Figure 4.4: Plant science courses faculty and graduate students felt should be added to their university's curriculum.



All survey respondents were asked to report university-level botanical courses they had taken or, if applicable, those they taught at least every two years. Comparing all surveyed sectors identified current botanical capacity at academic institutions in terms of college-level courses (taught by faculty and non-profit staff), and provided a point of comparison between courses taken by graduate students and survey respondents working at government agencies. This comparison also revealed current trends in coursework, gaps in education and training, and locations where gaps are being filled (Appendix 15).

Identified gap in botanical capacity: university education

Non-profit organizations teaching critical courses: For 9 of the 13 courses identified by faculty and graduate students as most in need of being added to their institution's plant science curriculum, a greater proportion of survey takers from non-profit organizations are teaching needed courses than are faculty (field botany, botany, mycology, plant physiology, plant systematics, plant taxonomy, restoration ecology, and invasive species biology; see Figure 4.4).

A comparison of courses taken and taught in all sectors (Appendix 15) shows that staff at non-profit organizations are teaching university-level classes and beginning to fill a significant gap in botanical capacity. They are teaching classes in nearly every subject identified as eliminated in the last 5-10 years and in need of being added to curriculum (including courses required for the federal botanists job classification (0430) like botany, mycology, plant systematics and taxonomy, and field botany, as well as courses students are demanding like restoration ecology and plant conservation). Unfortunately, while these organizations house an important and increasingly unique component of the nation's botanical capacity, they are also extremely resource-limited and their ability to provide services over the long-term is uncertain without appropriate funding and support from outside sectors.

The proportion of graduate students taking plant science courses has not kept pace with the training of existing plants scientists at government agencies. The percent of respondents taking courses was always greater for federal government staff than for graduate students with the exception of 4 courses (evolutionary ecology, invasive species biology/ecology, pollination ecology, and restoration ecology). The widest discrepancies in completed courses between graduate students and government agency staff were in Botany, Plant Taxonomy, Plant Biology, Plant Anatomy, Plant Community Ecology, Fire Ecology, Forest Ecology, and Rangeland Ecology/Management.

A majority (86%) of faculty respondents reported that openings in the plant sciences have remained steady or decreased (Appendix 16) while college enrollment has increased and bachelor degrees awarded in biology have increased by 60% (Figure 2.1). Openings for full-time positions in the last 5-10 years at respondents' academic institutions were most often in the subject areas of ecology, molecular biology, and evolutionary biology, while the greatest need was in ecology, botany, and plant systematics (Appendix 17). Reasons most often cited for this need included faculty retirements or departures (48%), intellectual development (40%), and research need (39%). Some of the most saturated areas where openings exceed perceived need include molecular biology, ecology, and cell biology. Research areas where reported need greatly exceeded openings included climate change, plant conservation biology, plant taxonomy, and mycology.

Faculty retirements in the next decade will only widen the gap in botanical capacity at university level. While less than 1/3 of all faculty respondents indicated they would retire in the next 10 years, they were among the least confident that their positions would be replaced by someone with similar botanical expertise. For example, 27% of faculty respondents who reported teaching botany will retire within the decade. Of them, 75% indicated that they either a) did not know whether their position would be replaced or by what expertise (57%), b) believed their position would be eliminated (30%), or c) believed their position would be replaced by someone in a different area of expertise (13%).

4.1.2 Cross-sector communication and student preparation

RECOMMENDATION 4

A full-time liaison position should be established between the Botanical Society of America and federal land management and research agencies to ensure botanical education and practical training needs for expert resource management are met. Similar to the current liaison position between the Bureau of Land Management and the Society for Range Management, this position would strengthen collaboration and workforce building through avenues such as quick-hire programs as well as the Office of Personnel Management's Student Educational Employment Program and Presidential Management Fellows Program.

A question often raised over the course of this project was whether graduate students are aware of and being appropriately trained for available jobs, and whether faculty are aware of the employment options available to their students and the education and training experience they will need to excel in those roles.

Identified gap in botanical capacity: university education

Preparation for employment at federal agencies: Neither students or faculty were aware of the coursework requirements for employment as a federal botanist (24 credit hours in botany). Given course offerings at many academic institutions, it is likely that many students considering careers as federal botanists will graduate without meeting coursework requirements for federal hiring.

Students appeared realistic about job opportunities in different sectors, indicating that they believed few jobs were available in academe but opportunities were available in government (Table 4.2). They were quite pessimistic about job opportunities at nonprofit organizations.

Table 4.2: Summary of graduate student responses to the question "***How would you classify the current job market in the plant sciences for the following positions***?"

	Graduate Student Response (%) n = 161		
Positions	**Plentiful Jobs**	**Some Jobs**	**Few Jobs**
Postdoctoral training	17.8	**63.1**	19.1
Permanent research	1.3	34.4	**64.4**
Tenure-track faculty	0.0	33.5	**66.5**
Part-time faculty	10.1	**63.5**	26.4
Federal government	7.6	**69.0**	23.4
State government	1.9	**53.8**	44.4
For-profit businesses	8.3	**56.4**	35.3
Nonprofit organization	3.1	39.6	**57.2**

Despite being pessimistic regarding open faculty positions at universities, a majority of students chose a university as their preferred future employer, followed by conservation organizations. Federal government positions was the fourth most selected option for a preferred future employer (selected by 41% of graduate student respondents - see Appendix 18). However, over the course of discussions at the project workshop as well as during follow-up conversations with graduate students and faculty, it became clear that neither faculty nor students were aware of the course requirements for federal employment of botanists (24 credit hours in botany). As the majority of survey respondents indicated that their academic institution offers only 1-3 introductory and 1-3 plant science courses on an annual basis (see Figure 3.3 and 3.4), it is likely that many students are graduating without the minimum required credit hours for federal employment. There is clearly a need for improved communication and collaboration between the academic and government sector to rapidly remedy this gap.

To identify whether skills incorporated in education and training match up with employment demand, graduate students were asked to identify their top five greatest strengths and those needing the most improvement, while all other sectors were asked to identify strengths and areas for improvement of recent hires. Response options included 24 general content areas (e.g., Botany and

Ecology) or specific skill sets (e.g., plant identification ability). Results revealed discordance between how graduate students perceive their strengths and where employers are finding deficiencies in numerous skill sets (Table 4.3). Survey data suggests students are not receiving a clear and accurate assessment of their skill sets, and faculty could be better informed about the job requirements for employment in the public and private botanical sectors.

Table 4.3: Responses to two survey questions asked among four different sectors reveal disconnects between students' perception of their top five greatest strengths and employers' perception of the top five areas for improvement amongst new hires (shown as % response by skill set). Bolded responses indicate inclusion among the top five identified skill sets (strengths or need for improvement) selected by each sector.

	Strengths	*Areas in Need of Improvement*					
Skill set	**Graduate Students (%, n=171)**	**Faculty (%, n=324)**	**Federal Gov. (%) n=326**	**State/ local gov. (%) n=50**	**State nat'l heritage (%) n=25**	**Non-profit org. (%) n=135**	**For-profit company (%) n=23**
Written Communication	**49.7**	**53.4**	**41.7**	**40.0**	**44.0**	**44.3**	**47.8**
Ecology	**48.5**	7.4	32.5	**32.0**	**36.0**	**29.5**	**43.5**
Field Skills	**47.4**	**29.3**	**36.8**	**26.0**	**52.0**	27.0	**34.8**
Plant Identification	**40.4**	**38.6**	**42.9**	4.0	**48.0**	**48.4**	**60.9**
Botany	**37.4**	19.8	**35.0**	**34.0**	**52.0**	**38.5**	**47.8**
Problem Solving Skills	35.7	**37.7**	**36.8**	10.0	16.0	24.6	30.4
Verbal Communication	31.0	**29.9**	24.5	**26.0**	12.0	**33.6**	26.1

Colleges and universities would do well to place special priority on enhancing the content of training in areas where new hire weaknesses are most pronounced. For example, written communication skills, plant identification ability, botany and ecology are four of the five areas where the all government and private sectors agree there is the greatest need for improvement. In particular, both faculty and students recognized plant identification ability as a weakness. Clearly, additional training is needed for this skill. Likewise, faculty concur with all employment sectors that written communication skills are a weakness; students and employers alike would benefit if more college training were more effective at teaching strong writing skills.

Examples of organizations or programs specifically focused on elevating curriculum, training, and education in plant science at the graduate level exist, but there is a need for greater focus and cross-sector inclusion in these efforts. Federal initiatives such as the National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) program for graduate students provide a platform for stronger development of core botanical skills while integrating and communicating between disciplines on college campuses (Moslemi et al, 2009). However, it is not clear how often plant science is incorporated as an involved discipline in programs currently underway. Inclusion of government and private sectors throughout the process is a critical component of making the IGERT and similar programs successful, and should be more strongly emphasized.

4.1.3 Pre-college education and continuing education needs

RECOMMENDATION 5

Academic, government and private sectors should work collaboratively to strategically strengthen botanical education and training at all age levels. This includes curriculum development that recognizes the central role plants play in biological systems and human life, and better integration of plant science into biology standards and textbooks. Work through the STEM Education Coalition as well as organizations like the Botanical Society of America, the American Institute of Biological Sciences and the National Association of Biology Teachers is needed to build support for and better integration of plant science education and training in biology coursework.

While this project focused on botanical capacity in education at the college and university level, discussions carried out over the course of the project and comments recorded by survey respondents made it quite clear that botanical capacity needs in education and training extend well beyond this narrow focus, from pre-college education to continuing education for adults. This includes partnering across sectors and working more closely with groups such as the STEM Education Coalition (focused on advocacy), as well as the American Institute of Biological Sciences, National Association of Biology Teachers and National Science Teachers Association to ensure that 1) plant science is incorporated into biological science curriculum, teacher training, and textbooks, and 2) students are engaged on the topic of botany in creative and memorable new ways as a component of battling nature deficit disorder (Louv, 2008).

Non-profit organizations have a key role to play in filling this gap, particularly site-based organizations such as botanic gardens which have the opportunity to engage millions of visitors, including students, parents, and teachers. This survey asked non-profit organizations what types of pre-college and continuing education programs they regularly provide: over half of the 178 individuals responding reported providing adult courses in local flora, natural areas, and plant identification, and nearly as many reported providing plant science programs for students and teachers from kindergarten through high school (Appendix 19). Work to support the nation's botanical education and training needs in the pre-college and continuing education realm should more strongly involve collaboration between non-profit organizations as well as academic, government, and for-profit sectors.

4.2 Botanical capacity in communication and outreach

RECOMMENDATION 6

All sectors should work both individually and collaboratively to strategically increase outreach efforts to different audiences, and to monitor the effectiveness of this work. Action is needed to create appropriate materials and deliver information that increases the level of botanical literacy and appreciation among policy makers, other scientific disciplines, and the general public. The private sector should build on current outreach efforts to the government and general public, the government sector should ensure outreach efforts to the public effectively include plants as well as the wildlife that depends upon them, and the academic sector should make a commitment to increase outreach efforts beyond the academic sector.

Another key outcome of the workshop which was supported by comments from survey respondents was that botanists on the whole should strive to be more effective at communicating and collaborating within and between sectors (academic, government, private) as well as to policy makers, scientists in other disciplines, and the general public.

While outreach needs are great at all levels, survey responses provide an indication of important areas where outreach is already occurring today, as measured by a) presentations and interviews to different audiences (Table 4.4) and b) consultations with different audiences (Table 4.5). In general, faculty are very strong in outreach within the sciences, but staff at non-profit organizations play a larger role in outreach to local interest groups, government, and the general public (see Appendices 20-24 for more detailed information).

Identified gap in botanical capacity: outreach

Private sector: Respondents in this sector provide the greatest outreach to government agencies and private citizens, but more is needed. While 50% of respondents from this sector consulted with government agencies on botanical matters from 2007 - 2009, over 70% consulted with private citizens, and non-profit respondents gave on average 2.3 media interviews during the same timeframe.

Academic sector: While outreach within the academic sector is strong, there is a need for greater outreach to government agencies and private citizens: fewer than 37% of respondents reported consulting with government agencies on botanical matters, only 2.2% consulted with private citizens, and each respondent gave an average of 1.3 interviews to the media from 2007 - 2009.

Table 4.4: Outreach through seminar talks (in 2008) or media interviews (between 2007 and 2009), presented as average number of talks or interviews reported per respondent, and total counts (in parenthesis) for faculty at academic institutions and staff at non-profit organizations and for-profit companies.

Audience for seminar (in 2008) or interview (2007-2009)	Faculty talks/respondent (and total) N = 370	Non-profit organizations talks/respondent (and total) N = 212	For-profit companies talks/respondent (and total) N = 53
University	1.1 (420)	0.7 (143)	0.5 (27)
Annual society meeting	1.2 (430)	0.9 (197)	0.8 (41)
Non-profit organization	0.7 (275)	1.7 (368)	1.0 (52)
Special interest group	0.7 (256)	1.6 (341)	1.1 (58)
Local interest group	0.3 (109)	0.8 (172)	0.4 (22)
Local government	0.2 (60)	0.7 (139)	0.4 (19)
State or federal government	0.3 (106)	0.8 (164)	0.5 (25)
Public media interview	1.3 (493)	2.3 (484)	1.0 (55)

Table 4.5: Botanical consulting to different audiences from 2007 to 2009, reported by faculty, non-profit organization staff, and for-profit or self-employed staff.

Groups Receiving Consultations	Faculty (%) n = 357	Non-profit Organization (%) n = 205	For-profit / Self-Employed (%) n = 52
Federal Government	37.0	51.2	51.0
State Government	36.7	54.6	41.5
Local Government	25.2	52.2	49.1
International groups	14.3	23.9	11.3
Non-profit Organizations	42.0	70.2	58.5
Citizens	2.2	72.2	83.1
Green Architecture/Urban Planning	-------	9.3	90.6

4.3 Botanical capacity in research and management

The final eight recommendations focus on applications requiring botanical expertise, botanical research to support management, botanical capacity to manage the nation's biological resources, workforce planning, and partnering to fill identified gaps in capacity.

4.3.1 Applications requiring botanical expertise

RECOMMENDATION 7

The significant impacts of climate change on plants, as well as the people, wildlife, and ecosystem services that are dependent upon plants for survival and well-being, should be recognized. Appropriate botanical expertise should be incorporated into climate change planning and policy efforts in all sectors to ensure appropriate proactive research efforts are initiated, and collaborative partnerships are encouraged to support effective, efficient, and economically defensible solutions. This includes ongoing work by the Department of Interior in developing and managing Climate Science Centers and Landscape Conservation Cooperatives, where botanical capacity is currently greatly underrepresented.

As outlined in Chapter 1, botanical capacity in research and management is necessary to address ongoing and emerging grand challenges in the United States, including invasive species control and climate change mitigation and adaptation. Survey respondents were asked to assess which areas of work they believe most require botanical expertise: areas most often selected by all sectors included rare plant conservation, invasive species management, habitat restoration and habitat monitoring (Table 4.6).

Table 4.6. Top five activities requiring botanical expertise, as indicated by each respondent group. Response totals tally beyond 100% because the question allowed for several responses. Each response indicates the percent of participants that selected a choice as one of their answers.

	Academic		*Government*			*Private*	
Most selected areas of work	**Faculty (%) n = 327**	**Graduate Student (%) n = 159**	**Federal Gov. (%) n = 461**	**State/ Local Gov. (%) n = 75**	**State Nat'l Heritage (%) n = 33**	**Non-Profit Org. (%) n = 203**	**For-profit (%) n = 50**
Rare/sensitive plant species conservation	**55.0**	**50.9**	**58.6**	**69.3**	**66.7**	**59.6**	**56.0**
Climate change effects on plants/ecosystems	**47.4**	36.5	32.1	26.7	**45.5**	30.5	14.0
Invasive species detection & management	**46.5**	**39.6**	**34.3**	33.3	33.3	**41.9**	36.0
Threatened & endangered plant species recovery	**46.2**	**40.9**	**47.9**	**60.0**	**66.7**	**50.7**	**40.0**
Native plant selection for ecological restoration	**38.2**	**38.4**	29.1	**44.0**	36.4	**41.4**	**48.0**
Native habitat restoration	34.9	**37.1**	**37.7**	**46.7**	**51.5**	**40.9**	**42.0**
Habitat and species monitoring	36.7	36.5	**37.5**	**56.0**	**54.5**	**40.9**	**46.0**

One area of botanical expertise that was surprisingly lower than expected was on the topic of climate change effects on plants and ecosystems. While faculty and state natural heritage program staff ranked this as among the top five areas of work requiring botanical capacity, no other sector did. These results likely explain the general tendency to exclude or ignore plants in most planning and policy decisions around climate change. *Workshop participants noted that the perception that plants do not need consideration in climate change discussions is categorically false.* Indeed, plants are already being impacted by climate change, often more so than wildlife because they are not able to as easily migrate to new suitable conditions (Hawkins, Sharrock, and Havens, 2008; Marris, 2009). And because plants form the backbone of the ecosystem services humans depend upon, including provisioning of resources for wildlife, it is in the nation's best interest to ensure plants are brought more completely into climate change planning and research.

Gap in botanical capacity: underappreciated climate change connection

Plants are being left out of climate change planning and action: Planning and policy actions within federal and state government agencies focused on climate change adaptation and mitigation are not incorporating botanical expertise. This is likely due at least in part to a false perception that plants are not being impacted by climate change, when in reality they will often be more impacted than the wildlife and people who depend upon them.

Comments on the survey as well as discussions during and after the workshop provide a clear example of how a failure to recognize the importance of incorporating plants in climate change planning is leading to a significant gap in botanical capacity at the federal Department of the Interior (DOI; responsible for managing a majority of the nation's public lands). Within the DOI, a key response to climate change has been the development of a series of Climate Science Centers (CSCs) and Landscape Conservation Cooperatives (LCCs). Survey respondents and workshop participants noted that botanists and plant ecologists should be actively engaged in the creation and operation of these centers, yet documents describing core staff at these centers includes no mention of incorporating plant science or botanical expertise (although it explicitly identifies a need for quantitative fish and wildlife biologists) (DOI, 2009). This is a significant gap that, if allowed to remain or widen, could lead to a cascade of negative impacts on the nation's natural resources.

4.3.2 Botanical research to support management of the nation's biological resources

RECOMMENDATION 8

Public and private funding should be directed to help all sectors close key gaps identified in plant science research that are directly linked to top needs and applications identified by this survey. This includes identified research needs in invasive species control, climate change mitigation and adaptation, habitat restoration, and the preservation of ecosystem services.

A follow-up question regarding which land management issues respondents believed required additional research revealed a slightly stronger emphasis on climate change needs (Table 4.7). However, climate change was selected much less often than invasive species control, which was unanimously identified as the top management issue requiring research by all sectors. This does not match with faculty or graduate students reporting of areas applicable to their research (Appendix 5).

Identified gap in botanical capacity: invasive species research

Demand for research not being met: Survey respondents were unanimous in selecting invasive species control as the top management issue requiring additional research, yet very few faculty or graduate students reported undertaking research that was applicable to invasive species control.

Table 4.7: Top five management issues requiring additional research. Response totals tally beyond 100% because the question allowed for several responses. Each response indicates the percent of participants that selected a choice as one of their answers. More than half of the participants selected invasive plant species control as one of their five top issues requiring additional research.

	Academic		*Government*			*Private*	
Management issue requiring research	**Faculty (%) n = 358**	**Graduate Student (%) n = 175**	**Federal Gov. (%) n = 494**	**Regional/ Local Gov (%) n=78**	**State Nat'l Heritage (%) n=35**	**Non-Profit Org. (%) n=204**	**For-Profit/ Self-Empl. (%) n=53**
Invasive species control	**68.7**	**57.7**	**72.3**	**69.2**	**62.9**	**60.7**	**61.5**
Climate change	**47.8**	**46.9**	**50.2**	**44.9**	**40.0**	**45.1**	26.9
Habitat & species monitoring	26.8	25.7	**30.8**	32.1	34.3	27.7	**40.4**
Habitat management	17.3	24.0	24.3	32.1	**51.4**	31.6	30.8
Habitat restoration	**41.9**	**47.4**	**43.9**	**53.8**	**40.0**	**34.0**	**48.1**
Plant selection for restoration	22.3	29.7	27.3	30.8	11.4	27.7	28.8
Ecosystem function & services	32.1	**43.4**	29.8	**41.0**	31.4	**34.5**	**34.6**
Diversity maintenance	**35.8**	**41.7**	28.7	20.5	34.3	25.2	25.0
Rare plant conservation	**34.6**	22.9	**32.8**	**33.3**	**48.6**	**35.0**	28.8
Threatened/endangered plant recovery	29.9	23.4	29.1	30.8	**45.7**	31.1	**36.5**

For academic faculty respondents and non-profit organization respondents, insufficient financial support was the most often selected reason limiting progress in plant science research at the respondent's institution. However, when asked to select the single reason most limiting research, faculty most often selected *Heavy teaching load.* Non-profit organizations were more unanimous in identifying limited financial support as the most limiting resource, with 76.8% of all respondents selecting it.

For-profit respondents noted that changes in demand from clients was the largest factor limiting progress in plant science research (36%), but a shortage of science staff was also noted (24%; see Table 4.8). The responses here are directly related to government attitude towards the plant sciences, as the federal government is the largest customer for businesses related to plant science. Some businesses indicated that they are limited by policy changes in science emphasis and by foreign outsourcing of jobs by federal and state agencies.

Table 4.8: Limits to progress in plant science research identified by sector (Responses to "p*lease select the top three reasons, if any that limit progress in plant science research at your institution*").

Limits to progress in plant science research	Faculty (%) n = 348	Non-Profit Org. (%) n = 155	For-profit (%) n = 48
Insufficient financial support	**46.6**	**76.8***	--
Shortage of science staff	--	**50.3**	**24.0**
Heavy teaching load	**42.5***	--	--
Lack of student interest	**34.8**	--	--
Loss of positions	27.3	19.4	--
Lack of greenhouse facilities/equipment	21.8	21.3	20.0
Change in institutional direction	20.7	7.7	--
Lack of laboratory facilities/equipment	14.9	**29.0**	--
Outdated research facilities/equipment	13.8	11.0	10.0
Not part of the institution's mission	12.9	16.8	**20.8**
Change in demand from customers/clients	--	--	**36.0***
Change in government contract availability	--	--	20.0

* Identified most often as single reason most limiting plant science research at respondent's institution.

4.3.3 Botanical capacity to effectively manage the nation's biological resources

RECOMMENDATION 9

The nation's five federal land management agencies* should increase the number of trained, full-time botanists on staff. Each agency should have *at minimum:* (a) one full-time botanist working collaboratively at the national level to address critical climate change issues facing plants on public lands, and (b) one full-time botanist with appropriate training on staff at all regional, state, and field offices.

*Bureau of Land Management (BLM), Department of Defense (DOD), National Park Service (NPS) US Forest Service (USFS), and US Fish and Wildlife Service (USFWS), which are collectively responsible for managing nearly 1/3 of the nation's landmass.

RECOMMENDATION 10

The US Geological Survey, responsible for carrying out research to guide management of Department of Interior lands** should have *at least* five full-time, diversely trained botanists on staff at each of its regional science centers.

**US Geological Survey (USGS) is the research arm of the BLM, NPS, and USFWS National Wildlife Refuge system, therefore charged with research on the native plant communities comprising almost 400 million acres of public lands.

RECOMMENDATION 11

Administrators and decision-makers at federal and state land management and research agencies should engage full-time staff botanists and work collaboratively with academic and private sector expert advisors in developing land-use plans, and in planning and implementing responses to key challenges (including climate change mitigation planning, habitat restoration and invasive species control strategies). This will lead to more successful, efficient, and economical outcomes.

Recommendation 12

Federal and state land management and research agencies should provide support for full-time staff botanists to identify and prioritize plant-related issues, and ensure these priorities are clearly and consistently communicated to the academic and private sector to allow for effective and efficient action. Once identified and communicated, management and funding decisions in the private and public sectors should ensure that capacity and resources are focused on the highest priority issues (such as invasive species) and/or taxa (such as those most critically threatened).

Respondents from all sectors were asked to identify how much of an impediment different gaps in national botanical capacity were to effectively managing native habitats in the United States. Results for all sectors consistently identified the most serious issues as 1) lack of funding for research and management, and 2) poor enforcement of environmental laws (see Appendix 25a, b, and c for additional details).

When government respondents were asked whether their agencies had enough botanical resources to meet habitat management needs, a majority of all respondents said no (75% of federal government respondents, 64% of non-federal government respondents, and 88% of state natural heritage program staff). Some federal agencies have greater apparent gaps in capacity than others; for example, 100% of all respondents from the U.S. Fish and Wildlife Service and the Environmental Protection Agency said their agency did not have sufficient botanical capacity to meet needs (Table 4.9). When respondents were asked to identify the top limiting resources at their agencies, two consistent gaps were identified: 1) lack of staff with botanical training and 2) lack of financial support.

An even greater proportion of respondents from the federal government (94%) indicated that their agencies did not have enough botanically trained staff to meet current management or research needs, and consistently identified botany as the area with the greatest shortage of jobs. Every respondent from the Army Corps of Engineers, Environmental Protection Agency, and U.S. Geological Survey and 97% of all respondents from the Bureau of Land Management and the U.S. Fish and Wildlife Service indicated that their agency did not have enough botanically trained staff. The reasons most often cited for this shortage included lack of funding and lack of perceived need (Table 4.9). When taken together, these results paint a clear picture that a lack of botanical capacity is limiting the efficiency and effectiveness of the nation's federal agencies.

Identified gaps in botanical capacity: natural resource management

Bureau of Land Management (BLM)—charged with managing biological resources on 40% of all public land, but employ just over one botanist per 4 million acres (equivalent to having one person responsible for all of Connecticut). Of the 95 BLM survey respondents, 97% said their agency did not have enough botanically trained staff to meet current needs.

Table 4.9: Primary botanical capacity needs identified by agency.

Responses by Agency	*Enough botanical resources to meet habitat management needs?*		*Enough botanically trained staff to meet management/research needs?*		
Agency respondents (N=432)	**Selected "No" (%)**	**Top 3 limiting resources** [a, b]	**Selected "No" (%)**	**Top 3 jobs with shortage** [b]	**Top 2 reasons for shortage** [b]
Agricultural Research Service (n=15)	60%	Financial support Available staff time Staff with botanical training	78%	Plant Conservation Botany Genetics	Lack of funding Lack of perceived need
Army Corps of Engineers (n=4)	50%	Staff with botanical training Available staff time	100%	Botany Ecology	Lack of perceived need Lack of funding
Bureau of Land Mgmt (n=95)	80%	Staff with botanical training Financial support Available staff time	97%	Botany Ecology Plant Conservation	Lack of perceived need Lack of funding
Department of Defense (n=14)	71%	Financial support Staff with botanical training Available staff time	90%	Ecology Botany Plant Conservation	Lack of perceived need Lack of funding
Environmental Protection Agency (n=3)	100%	Staff with botanical training Available staff time Financial support	100%	Botany Ecology Plant Conservation	Retirements/departures Lack of qualified Candidates
National Park Service (n=87)	80%	Financial support Available staff time Staff with botanical training	93%	Botany Climate Change Ecology	Lack of perceived need Lack of funding
Nat'l Resource Conservation Service (n=9)	89%	Available staff time Staff with botanical training Financial support	71%	Botany Ecology Plant Conservation	Lack of perceived need Uncertain
Smithsonian (n=11)	27%	Financial support Available staff time Staff with botanical training	67%	Botany Ecology Plant Conservation	Lack of funding Retirements/departures
U.S. Fish and Wildlife Service (n=37)	100%	Staff with botanical training Financial support Available staff time	97%	Botany Plant Conservation Ecology	Lack of perceived need Lack of funding
U.S. Forest Service (n=135)	85%	Financial support Available staff time Staff with botanical training	94%	Botany Ecology Plant Conservation	Lack of perceived need Lack of funding
U.S. Geological Survey (n=20)	90%	Staff with botanical training Financial support Available staff time	100%	Botany Plant Conservation Plant Physiology	Lack of perceived need Lack of funding
State/Local Gov't (n=74)	64%	Available staff time Institutional support Staff with botanical training	53%	Botany Data Management Ecology	Lack of funding Lack of perceived need
State Natural Heritage Prog. (n=33)	88%	Institutional support Available staff time Staff with botanical training	84%	Botany Ecology Data Management	Lack of funding Lack of perceived need

[a] Other limitations included but less commonly selected were work space, laboratory/greenhouse facilities/equipment, research materials, appropriate technology, vehicles/tools/field supplies, and scientific guidance.
[b] Non-numerical responses by selection percentages (highest to lowest)

The current lack of funding and staff time at state and federal agencies appears to be limiting the ability of government agencies to identify and prioritize plant-related work and to communicate important priorities to the academic and private sector in order to pool resources to help address them. Worse, it appears that even if priorities are identified and communicated, limited funding and staff time is forcing respondents to prioritize the work they do based on what is fundable rather than what is most urgent. For example, botanists at State Natural Heritage programs reported that they often are not able to visit their highest priority rare taxa unless they are able to opportunistically fit the work in with a funded project for a lower-priority taxa or habitat. Comments from survey respondents and workshop participants suggest the challenges in identifying, communicating, and addressing the highest priority issues and taxa are prevalent throughout all botanical sectors, which promises to increasingly limit the ability of the nation to address grand challenges such as climate change.

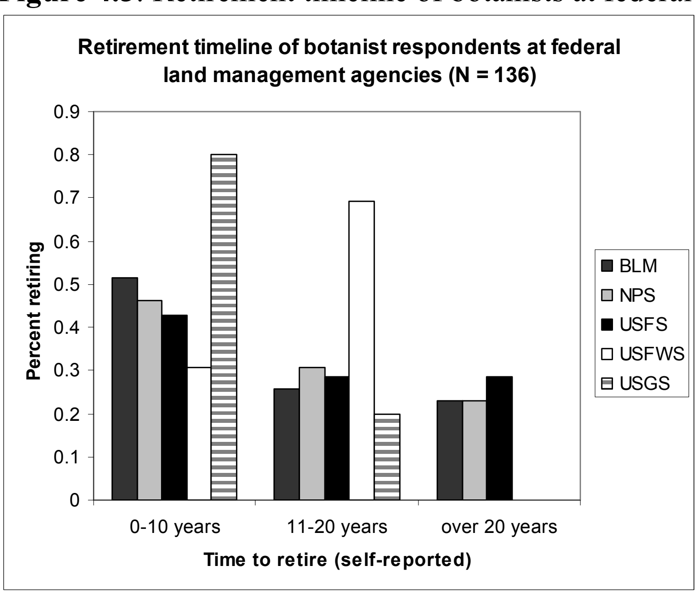
4.3.4 Workforce planning to sustain critical levels of botanical capacity

RECOMMENDATION 13

All federal land management and research agencies should ensure new hires have appropriate botanical training, and that monitoring and reporting mechanisms are in place to avoid a similar decay in botanical capacity in the future. Specifically, all new federal hires recommended here should be employed under the US Office of Personnel Management employment code 0430 (Botany), rather than the more general code of 0400 (Natural resource management / general biology), as it does not effectively capture required botanical expertise.

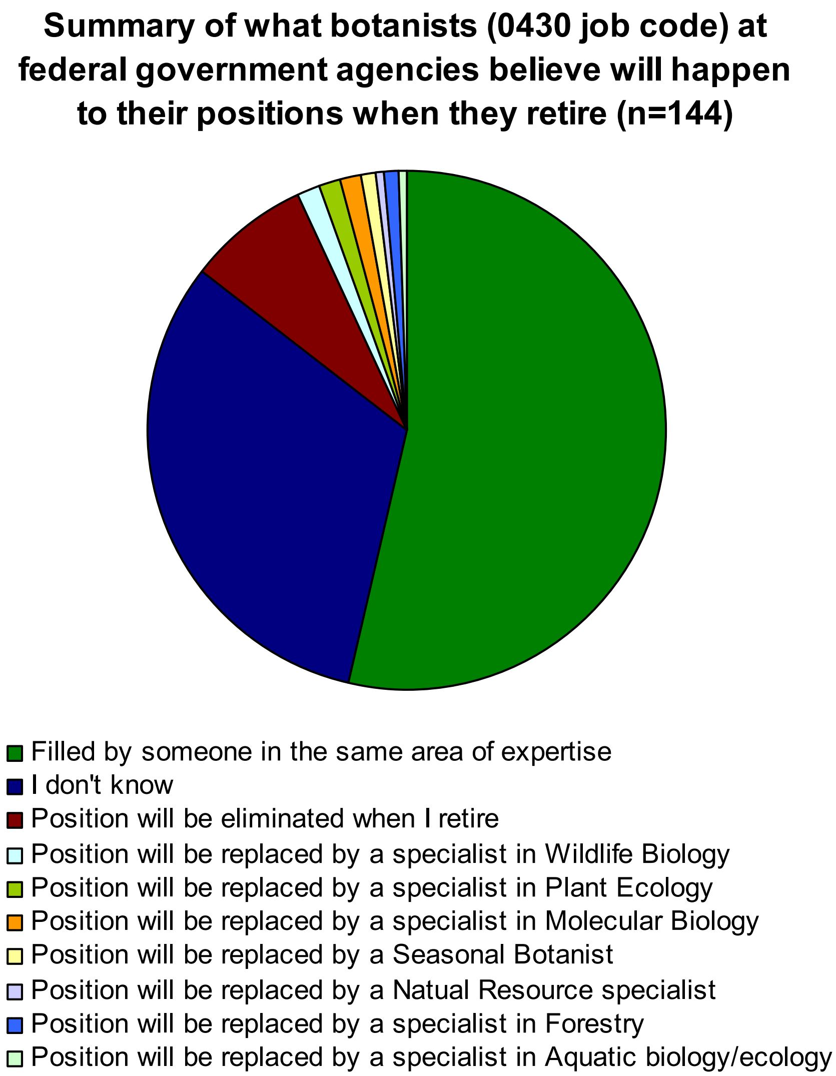
Survey results show that the significant gaps in current botanical capacity at government agencies responsible for managing nearly 1/3 of the nation's landmass will only continue to grow in the coming decade, as botanists are poised to retire at record numbers between 2010 and 2020 (Figure 4.5). Retirement of botanists at federal land management agencies is particularly high at the Bureau of Land Management and the U.S. Geological Survey in the coming decade.

Figure 4.5: Retirement timeline of botanists at federal land management agencies.



It is unsettling that a large number of retiring botanists are unsure whether that their position will be refilled by someone with botanical expertise (eight percent believed their position would be eliminated; see Figure 4.6). Indeed, a few retiring botanists, already considered to be a limiting resource at federal agencies, even indicated their position would be replaced by someone specializing in wildlife biology, or that the position would require less botanical expertise in the future (e.g. a seasonal botanist or natural resource specialist would be hired instead).

Figure 4.6: Projected replacement of federal botanist positions following retirement, as indicated by survey respondents employed as federal botanists.



4.3.5 Partnering to fill gaps in botanical research and management capacity

RECOMMENDATION 14

Cross-sector communication and partnership should be enhanced to pool existing resources, maximize efficiency, and more rapidly address and fill critical gaps in botanical capacity. Additional resources are needed to facilitate partnerships among government, academic, and private sectors, ensuring long-term sustainability of programs necessary for science-driven management of the nation's biological resources. The Plant Conservation Alliance provides an effective vehicle for multi-sector partnerships, and examples of programs built around public-private partnerships include the national Seeds of Success program and regional programs such as the New England Plant Conservation Program and the Georgia Plant Conservation Alliance.

Given that botanically trained individuals as well as funding to support research and management are limiting throughout the botanical sector, among the most effective and immediate ways to fill gaps in capacity and maximizing efficiency is to collaborate within and among sectors. All sectors are utilizing partnerships to varying degrees, with the most common partners being academic institutions and the federal government (Table 4.10).

Table 4.10: Partnerships utilized by different sectors to meet botanical research and management needs.

Partnerships in Botanical Research and Management

Partners	Federal Government (%) n=488	State/Local Government (%) n=73	State Natural Heritage (%) n=33	Non-Profit Organization (%) n=199	For-Profit/ Self-Empl. (%) n=47
Academic Institutions	**72.7**	**64.4**	**75.8**	**75.4**	**51.1**
Federal Government	**60.7**	**54.8**	**81.8**	**68.3**	**44.7**
State/Local Government	**55.3**	45.2	60.6	62.8	36.2
Native Plant Societies	52.0	41.4	57.6	57.3	**53.2**
Conservation Organizations	45.1	**56.2**	57.6	**70.9**	**44.7**
Botanic Gardens/Arboreta	44.9	34.2	45.5	51.8	29.8
Citizen Scientists	42.4	43.8	**69.7**	45.2	23.4
For-Profit / Self-Employed	29.7	30.1	24.2	30.2	31.9
Museums	< 1.0	28.8	42.4	36.7	8.5
Zoos	3.3	12.3	6.1	19.6	4.3
Our organization doesn't have any partnerships or provide services	< 1.0	2.7	0	1.0	6.3

Private organizations and businesses are generally less likely to be included in cross-sector partnerships than academic institutions and government agencies, yet the services they are providing to partners (Table 4.11) match closely with research and management needs identified by all sectors (Table 4.7). Future growth in these cross-sector partnerships will be critical to maximizing limited resources and addressing current and future grand challenges of this century.

Identified gaps in botanical capacity: management and research

Private sector's valuable but under supported role: businesses and non-profit organizations are beginning to fill key gaps in government and academic botanical capacity through cross-sector partnerships. Botanical services most commonly contributed to these partnerships match up with top needs for research and management, including invasive species identification and monitoring, botanical training, and rare species monitoring and conservation. Additional support is needed to ensure botanical capacity in the private sector is in place and able to help the nation address these current and future grand challenges

Table 4.11: Services contributed to partnerships by the private botanical sector.

Contribution/Service	Non-Profit Organization (%) n = 190	Businesses and Self-Employed (%) n =39
Invasive species identification/monitoring	52.1	53.8
Environmental consulting	------	51.3
Botanical training	48.4	46.2
Sensitive species conservation	44.7	43.6
Population habitat monitoring	44.2	35.9
Science consulting	41.6	33.3
Seed collection and storage	38.9	23.1
Ecological training	32.6	38.5
Outreach community gardening programs	30.5	------
Plant phenology data collection/interpretation	28.9	------
Habitat restoration training	27.9	28.2
Teacher training	27.4	------
Outreach urban greening programs	26.3	------
Botanical appreciation programs	21.1	------
Certificate based courses	20.5	------
Degree based courses	13.7	------
Laboratory services and analyses	12.1	15.4
Sustainable harvest of non-timber products	------	10.3

Respondents were asked whether they believed their partnerships were successful in meeting mutual goals of all partners, and results indicate that mutual goals are least often accomplished when working within sectors (Appendix 26 and 27) and that reasons for limited successes include funding issues, administrative/logistical difficulties, and unrealistic expectations (Appendix 28). While there is clearly more to be done, these survey results indicate that there are strong foundations to build on for future work.

4.4 Vision for the future

Workshop participants outlined a common goal based upon the results of this report, with the aim that it would lead to *A coalition of individuals and organizations from academic institutions, non-profit and for-profit organizations, professional societies, and government agencies that will work together to ensure that the nation's policies and practices are based on the best plant science, that people understand the importance of plants in their lives, and that the diversity of plants is protected for future generations*.

References

2010. Invaders of Texas: A citizen science program to detect and report invasive species. A partnership between the Lady Bird Johnson Wildflower Center, the US Forest Service, Texas Forest Service, HARC, NBII, and Texas Parks and Wildlife. Available at www.texasinvasives.org/invaders/index.php (Accessed February 12, 2010).

ABRS. 2006. Survey of Australian Taxonomic Capacity. Australian Government: Department of the Environment, Water, Heritage and the Arts, Australian Biological Resources Study. Available at www.environment.gov.au/biodiversity/abrs/publications/other/taxonomy-survey-2003/pubs/taxonomy-survey-2003.pdf (Accessed Feb 24, 2010).

AFFOLTER, J. 2003. Botanical gardens and the survival of traditional botany. *Public Garden* 18: 17-22.

ANDERSEN, C. J. 1984. Plant biology personnel and training at doctorate-granting institutions. Higher Education Panel Report No. 62. American Council on Education, Washington, D.C.

APGA. 2010. American Public Gardens Association. Available at www.publicgardens.org (Accessed July 2010).

BARNEY, J. N., AND J. M. DITOMASSO. 2008. Nonnative species and bioenergy: Are we cultivating the next invader? *BioScience* 58: 64-70.

BGCI. 2010a. Botanic Gardens Conservation International - Education Portal. Available at www.bgci.org/education (Accessed July 2010).

BGCI. 2010b. GardenSearch database. Botanic Gardens Conservation International, U.K. www.bgci.org/garden_search.php (Accessed April 2010).

BLM. 2000. The Great Basin: Healing the Land. Bureau of Land Management.

BLS. 2010. Occupational Outlook Handbook, 2010-11 Edition, Biological Scientists. Bureau of Labor Statistics, U.S. Department of Labor. Available at www.bls.gov/oco/ocos047.htm and www.bls.gov/data/#projections (Accessed March 29, 2010).

BOWERS, J. E. 2007. Has climatic warming altered spring flowering date of Sonoran desert shrubs? *The Southwestern Naturalist* 52: 347-355.

BRADLEY, B. A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology* 15: 196-208.

BREDENKAMP, C. L., AND G. F. SMITH. 2008a. Perspectives on botanical research publications in South Africa: An assessment of five local journals from 1988 to 2002, a period of transition and transformation. *South African Journal of Science* 104: 473-478.

BREDENKAMP, C. L., AND G. F. SMITH. 2008b. Botanical research in South Africa: A questionnaire assessment of opinions of South African botanists. *South African Journal of Science* 104: 97-100.

BREITHAUPT, H. 2008. Up to the challenge? Rising prices for food and oil could herald a renaissance of plant science. *EMBO reports* 9: 832.

BSA. 2010. The Botanical Society of America. Available at www.botany.org/ (Accessed July 2010).

CALLMANDER, M. W., G. E. SCHATZ, AND P. P. LOWRY. 2005. IUCN Red list assessment and the Global Strategy for Plant Conservation: Taxonomists must act now. *Taxon* 54: 1047-1050.

CANTINO, P. D. 2004. Combining breadth with specialization to build a strong botany department. *Plant Science Bulletin* 50: 38-40.

CARTER, J. L. 2004. Developing a curriculum for the teaching of botany. *Plant Science Bulletin* 50: 42-48.

CBD. 2010. Global Biodiversity Outlook 3. Secretariat of the Convention on Biological Diversity, Montréal. Available at www.cbd.int/gbo/gbo3/doc/GBO3-final-en.pdf (Accessed May 2010).

CBG. 2010a. Academic programs at Chicago Botanic Garden. Available at www.plantbiology.northwestern.edu/ (Accessed July 2010).

CBG. 2010b. Training programs at Chicago Botanic Garden. Available at www.clminternship.org (Accessed July 2010).

CHANEY, B., E. FARRIS, AND P. WHITE. 1990. Plant biology personnel and training at doctorate-granting institutions. National Science Foundation, Directorate for Biological, Behavioral, and Social Sciences, Washington, DC. Available at www.eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/23/e0/3d.pdf (Accessed May 2010).

CLARK, D. J. 2003. Summary of the interagency rare plant inventory project, 1999-2002. *SegoLily* 26: 1.

CLINTON, W. 1999. Presidential Documents - Executive Order 13112 of February 3, 1999: Invasive Species. *Federal Register* 64: 6183-6186.

CNPS. 2010. California Native Plant Society. Available at www.cnps.org (Accessed July 2010).

CPC. 2010a. Center for Plant Conservation. Available at www.centerforplantconservation.org/welcome.asp (Accessed July 2010).

CPC. 2010b. CPC by the numbers. Center for Plant Conservation, St. Louis, MO.

CPC. 2010c. National Plant Conservation Directory. Available at www.centerforplantconservation.org/Directory/Directory.asp (Accessed May 2010).

CURTIS, J. T., AND B. BELL. 2004. Botany program at the University of Wisconsin-Stevens Point. *Plant Science Bulletin* 50: 40-42.

DAISEY, P. 1996. Promoting interest in plant biology with biographies of plant hunters. *The American Biology Teacher* 58: 396-406.

DALTON, R. 1999. US universities find that demand for botanists exceeds supply. *Nature* 402: 109.

DALTON, R. 2003. Natural history collections in crisis as funding is slashed. *Nature* 423: 575.

DARNELL, R. L., AND J. G. CHEEK. 2005. Plant science graduate students: demographics, research areas, and recruitment issues. *HortTechnology* 15: 677-681.

DBG. 2010. Internship program at Denver Botanic Garden. Available at www.botanicgardens.org/content/internship-opportunities (Accessed July 2010).

DITOMASSO, J. M., J. K. REASER, C. P. DIONIGI, O. C. DOERING, E. CHILTON, J. D. SCHARDT, AND J. N. BARNEY. 2010. Biofuels vs. bioinvasions: seeding policy priorities. *Environmental Science and Technology* in press.

DOI. 2009. Interior's plan for a coordinated, science-based response to climate change impacts on our land, water, and wildlife resources. U.S. Department of the Interior. Available at www.doi.gov/whatwedo/climate/strategy/upload/Detailed-CSC-LCC-Information.pdf (Accessed May 2010).
DONALDSON, J. S. 2009. Botanic gardens science for conservation and global change. *Trends in Plant Science* 14: 608-613.
DUKE. 2010. Education programs at the Sarah P. Duke Gardens. Available at www.hr.duke.edu/dukegardens/education.htm (Accessed July 2010).
DUKES, J. S., J. PONTIUS, D. ORWIG, J. R. GARNAS, V. L. RODGERS, N. BRAZEE, B. COOKE, K. A. THEOHARIDES, E. E. STANGE, AND R. HARRINGTON. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research* 39: 231-248.
DUNCAN, C. A., AND J. K. CLARK. 2005. Invasive plants of range and wildlands and their environmental, economic, and societal impacts. Weed Science Society of America, Lawrence, KS.
ELISENS, W. J. 2004. "SUPPORT YOUR LOCAL HERBARIUM" A plea for increased appreciation and activism for Oklahoma's herbaria. *Oklahoma Native Plant Record* 4: 55-56.
ENGER, T. 2006. Usage of plant examples in New Jersey secondary biology classrooms. Masters of Subject Matter Teaching: Biology Degree Thesis, Rowan University.
EWERS, R. M. 2000. Growing an undergraduate program in botany. *Plant Science Bulletin* 46: 4-6.
FASTS. 2007. Proceedings of the National Taxonomy Forum, Australian Museum, Sydney.
FNPS. 2010. Florida Native Plant Society. Available at www.fnps.org (Accessed July 2010).
FTBG. 2010. Academic programs at Fairchild Tropical Botanical Garden. Available at www.fairchildgarden.org/education/graduatestudies/ (Accessed July 2010).
GNPC. 2010. Internship program at Greenbelt Native Plant Center. Available at www.nycgovparks.org/sub_about/parks_divisions/gnpc/internships.html (Accessed July 2010).
GOINS, S. L. 2004. Botany in children's literature: A content analysis of plant-centered children's picture books that have a plot and characters. Ph.D. Thesis, Louisiana State University.
GPCA. 2010. Georgia Plant Conservation Alliance. Available at www.uga.edu/gpca/ (Accessed July 2010).
GRANT, J. B., J. D. OLDEN, J. J. LAWLER, C. R. NELSON, AND B. R. SILLIMAN. 2007. Academic institutions in the United States and Canada ranked according to research productivity in the field of conservation biology. *Conservation Biology* 21: 1139-1141.
GREENFIELD, S. S. 1955. The challenge to botanists. *Plant Science Bulletin* 1: 1.
GROPP, R., AND M. A. MARES. 2009. 2008 Natural Science Collections Alliance economic impacts survey. *CLS Journal of Museum Studies* 3: 1-17.
GROPP, R. E. 2003. Are university natural science collections going extinct? *BioScience* 53: 550-550.
GROPP, R. E. 2004. Perspectives - Threatened species: university natural science collections in the United States. *Systematics and Biodiversity* 1: 285-286.
HALLÉ, F. 2002. In praise of plants. Timber Press, Inc., Cambridge, U.K.
HAVENS, K., P. VITT, M. MAUNDER, E. O. GUERRANT, AND K. DIXON. 2006. *Ex situ* plant conservation and beyond. *BioScience* 56: 525-531.
HAWKINS, B. A., S. SHARROCK, AND K. HAVENS. 2008. Plants and climate change: which future. Botanic Gardens Conservation International, Richmond, Surrey, United Kingdom. Available at www.bgci.org/usa/PlantsClimateChange/ (Accessed May 2010).
HERSHEY, D. R. 1996. A historical perspective on problems in botany teaching. *The American Biology Teacher* 58: 340-347.
HERSHEY, D. R. 2002. Plant blindness: We have met the enemy and he is us. *Plant Science Bulletin* 48: 78-85.
HL. 2008. Fifth report of session 2007–08, systematics and taxonomy: follow-up report with evidence (HL Paper 162). House of Lords, Science and Technology Committee. Available at www.publications.parliament.uk/pa/ld200708/ldselect/ldsctech/162/16202.htm (Accessed May 15, 2010).
HOOT, S. B. 2009. Charles Darwin: Botanist. *Reports of the National Center for Science Education* 29: 19-21.
HORTON, D., A. ALEXAKI, S. BENNETT-LARTEY, K. N. BRICE, D. CAMPILAN, F. CARDEN, J. D. S. SILVA, L. T. DUONG, I. KHADAR, A. M. BOZA, I. K. MUNIRUZZAMAN, J. PEREZ, M. S. CHANG, R. VERNOOY, AND J. WATTS. 2003. Evaluating capacity development: experiences from research and development organizations around the world. The Netherlands: International Service for National Agricultural Research (ISNAR); Canada: International Development Research Centre (IDRC), the Netherlands: ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA). Available at www.idrc.ca/en/ev-31556-201-1-DO_TOPIC.html (Accessed May 2010).
HOWE, H. F., B. ZORN-ARNOLD, A. SULLIVAN, AND J. S. BROWN. 2006. Massive and distinctive effects of meadow voles on grassland vegetation. *Ecology* 87: 3007-3013.
IAE. 2010. Ecological Education Programs at the Institute for Applied Ecology. Available at www.appliedeco.org/ecological-education (Accessed July 2010).
INOUYE, D. W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology* 89: 353-362.
ISSSSP. 2010. Interagency Special Status / Sensitive Species Program (ISSSSP): The Pacific Northwest Regional Office of the U.S. Forest Service and Oregon/Washington State Office of the Bureau of Land Management Available at www.fs.fed.us/r6/sfpnw/issssp/ (Accessed July 2010).
JIAO, L. 2009. China searches for an 11th-hour lifesaver for a dying discipline. *Science* 325: 31.
KELLER, M., D. S. SCHIMEL, W. W. HARGROVE, AND F. M. HOFFMAN. 2008. A continental strategy for the National Ecological Observatory Network. *Frontiers in Ecology and the Environment* 6: 282-284.

KELLY, A. E., AND M. L. GOULDEN. 2008. Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences* 105: 11823-11826.
KENNEDY, K. L. 2008. The Center for Plant Conservation: twenty years of recovering America's vanishing flora. *In* R. A. Askins, G. D. Dreyer, G. R. Visgilio, and D. M. Whitelaw [eds.], Saving Biological Diversity: Balancing Protection of Endangered Species and Ecosystems Pp. 47-58.
KRAMER, A. T., AND K. HAVENS. 2009. Plant conservation genetics in a changing world. *Trends in Plant Science* 14: 599-607.
KUZEVANOV, V., AND S. SIZYKH. 2006. Review - Botanic garden resources: Tangible and intangible aspects of linking biodiversity and human well-being. *Hiroshima Peace Science* 28: 113-134.
LAWLER, J. J., J. E. AUKEMA, J. B. GRANT, B. S. HALPERN, P. KAREIVA, C. R. NELSON, K. OHLETH, J. D. OLDEN, M. A. SCHLAEPFER, B. R. SILLIMAN, AND P. ZARADIC. 2006. Conservation science: a 20-year report card. *Frontiers in Ecology and the Environment* 4: 473-480.
LAWLOR, D. 2008. Botany program thrives at HSU. Humboldt State University, California. Available at www.humboldt.edu/~biosci/documents/BOTANY.pdf (Accessed March 28, 2010).
LBJWF. 2010. Lady Bird Johnson Wildflower Center: Native Plant Suppliers Directory. Available at www.wildflower.org/suppliers/ (Accessed July 2010).
LINK-PÉREZ, M. A., V. H. DOLLO, K. M. WEBER, AND E. E. SCHUSSLER. 2009. What's in a Name: Differential labelling of plant and animal photographs in two nationally syndicated elementary science textbook series. *International Journal of Science Education* 31: online early.
LIU, X., Y. GAO, S. KHAN, G. DUAN, A. CHEN, L. LING, L. ZHAO, Z. LIU, AND X. WU. 2008. Accumulation of Pb, Cu, and Zn in native plants growing on contaminated sites and their potential accumulation capacity in Heqing, Yunnan. *Journal of Environmental Sciences* 20: 1469-1474.
LOARIE, S. R., B. E. CARTER, K. HAYHOE, S. MCMAHON, R. MOE, C. A. KNIGHT, AND D. D. ACKERLY. 2008. Climate change and the future of California's endemic flora. *PLoS ONE* 3: e2502.
LONGCORE, T., R. MATTONI, G. PRATT, AND C. RICH. 1997. On the perils of ecological restoration: lessons from the El Segundo blue butterfly. 2nd Interface Between Ecology and Land Development in California, Occidental College.
LOUV, R. 2008. Last child in the woods: Saving our children from nature-deficit disorder. Algonquin Books.
MARRIS, E. 2009. Planting the forest of the future. *Nature* 459: 906-908.
MEA. 2005. Millennium ecosystem assessment synthesis report. Millennium Ecosystem Assessment, Island Press, Washington, D.C.
MILLER, B., W. CONWAY, R. P. READING, C. WEMMER, D. WILDT, D. KLEIMAN, S. MONFORT, A. RABINOWITZ, B. ARMSTRONG, AND M. HUTCHINS. 2004. Evaluating the conservation mission of zoos, aquariums, botanical gardens, and natural history museums. *Conservation Biology* 18: 86-93.
MILLER, J. R. 2008. Conserving biodiversity in metropolitan landscapes. *Landscape Journal* 27: 1-8.
MLOT, C. 1995. Botany for the next millennium. Botanical Society of America. Available at www.botany.org/bsa/millen/ (Accessed May 2010).
MOBOT. 2010. Academic programs at Missouri Botanical Garden. Available at www.mobot.org/gradstudents/ (Accessed July 2010).
MORTON. 2010. College programs at The Morton Arboretum. Available at www.mortonarb.org/adult-programs/college-courses.html (Accessed July 2010).
MUIR, M. J., AND M. W. SCHWARTZ. 2009. Academic research training for a nonacademic workplace: a case study of graduate student alumni who work in conservation. *Conservation Biology* 23: 1357-1368.
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, C. O. S., INTERAGENCY WORKING GROUP ON SCIENTIFIC COLLECTIONS. 2009. Scientific collections: mission-critical infrastructure of federal science agencies. Office of Science and Technology Policy, Washington, DC. Available at www.whitehouse.gov/files/documents/ostp/NSTC%20Reports/Revision_1-22_09_CL.pdf (Accessed July 2010).
NATURA. 2007. Managing plant diversity via the Natura 2000 network. *Natura 2000* 23: 7.
NATURESERVE. 2009. Predicting future change: a climate change vulnerability index. NatureServe, Arlington, VA. Available at www.natureserve.org/prodServices/climatechange/pdfs/fact%20sheet%20CCVI.pdf (Accessed May 2010).
NATURESERVE. 2010. NatureServe Explorer Online Database. NatureServe. Available at www.natureserve.org/explorer.
NCBG. 2010. The North Carolina Botanical Garden at the University of North Carolina, Chapel Hill. Available at http://ncbg.unc.edu/about-us/ (Accessed July 2010).
NCES. 2009. ONLINE DATABASE: Digest of education statistics: bachelor's, master's, and doctor's degrees conferred by institutions of higher education, by sex of student and field of study (1991 - 2008). U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), "Completions" survey. Available at www.nces.ed.gov/programs/digest/ (Accessed May 8 2010). .
NEC. 2009. A strategy for American innovation: driving towards sustainable growth and quality jobs. The White House, National Economic Council, Washington, D.C. Available at www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation/ (Accessed April 13, 2010).
NEPCOP. 2010. New England Plant Conservation Program. Available at www.newfs.org/protect/rare-plants-and-conservation/nepcop.htm (Accessed July 2010).
NESOM, G., AND A. S. WEAKLEY. 2009. Learning about other species: an updated component of a liberal arts education. *Journal of the Botanical Research Institute of Texas* 3: 1-2.
NEWFS. 2010. Internship programs at the New England Wildflower Society. Available at www.newfs.org/jobs/internships (Accessed July 2010).
NISC. 2010. National Invasive Species Council. Available at www.invasivespecies.gov (Accessed July 2010).

NOWAK, D. J., R. E. HOEHN, D. E. CRANE, J. C. STEVENS, AND J. T. WALTON. 2006. Assessing urban forest effects and values, Washington, D.C.'s urban forest. http://www.treesearch.fs.fed.us/pubs/18406.
NRC. 1992. Plant biology research and training for the 21st century. Committee on an Examination of Plant-Science Research Programs in the United States, Natural Resources Council, National Academy Press, Washington, DC. Available at www.nap.edu/openbook.php?isbn=0309046793 (Accessed May 2010).
NRC. 2001. Grand Challenges in Environmental Sciences. National Research Council, National Academy, Washington, D.C. http://www.nap.edu/catalog.php?record_id=9975.
NRC. 2008. Ecological impacts of climate change. Committee on Ecological Impacts of Climate Change, National Research Council Available at www.nap.edu/catalog.php?record_id=12491 (Accessed May 2010).
NRC. 2009. A new biology for the 21st Century: ensuring the United States leads the coming biology revolution. National Research Council, National Academy, Washington, D.C. Available at www.nap.edu/catalog.php?record_id=12764 (Accessed May 2010).
NSF. 1990. Plant Biology Personnel and Training at Doctorate-Granting Institutions. National Science Foundation, Directorate for Biological, Behavioral, and Social Sciences, Washington, DC. Available at http://www.eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/23/e0/3d.pdf.
NSF. 1999. Science and engineering doctorate awards: 1997 (NSF 99-323). National Science Foundation, Division of Science Resources Studies, Arlington, VA.
NSF. 2009. Federal science and engineering support to universities, colleges, and nonprofit Institutions: FY 2006 (Detailed Statistical Tables NSF 09-310). National Science Foundation, Division of Science Resource Statistics, Arlington, VA. Available at www.nsf.gov/statistics/nsf09310/ (Accessed May 2010).
NSN. 2010. Native Seed Network. Available at www.nativeseednetwork.org (Accessed July 2010).
NYBG. 2010a. Academic programs at New York Botanical Garden. Available at http://sciweb.nybg.org/science2/GraduateStudies.asp (Accessed July 2010).
NYBG. 2010b. Index Herbariorum: A Global Directory of Public Herbaria and Associated Staff Available at http://sciweb.nybg.org/science2/IndexHerbariorum.asp (Accessed July 2010).
OPM. 2005. Professional work in the natural resources management and biological sciences group, 0400. U.S. Office of Personnel Management, Washington, D.C. Available at www.opm.gov/fedclass/gs0400p.pdf (Accessed May 1, 2010).
PCA. 2010. Plant Conservation Alliance. Available at www.nps.gov/plants (Accessed July 2010).
PCAST. 1998. Teaming with life: Investing in science to understand and use America's living capital. Available at www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf (Accessed April 15, 2010).
PELTZER, D. A., R. B. ALLEN, G. M. LOVETT, D. WHITEHEAD, AND D. A. WARDLE. 2009. Effects of biological invasions on forest carbon sequestration. *Global Change Biology*: online early.
PIMENTEL, D. 2009. Invasive plants: their role in species extinctions and economic losses to agriculture in the USA. *In* Inderjit [ed.], Management of Invasive Weeds. Pp. 1-7. Springer, Netherlands.
PIMENTEL, D., R. ZUNIGA, AND D. MORRISON. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52: 273-288.
PLANTLIFE. 2009. Ghost orchid declaration: saving the UK's wildflowers today. PlantLife International. Available at www.plantlife.org.uk/campaigns/ghost_orchid_declaration/ (Accessed May 2010).
POLICANSKY, D. 1999. Interdisciplinary problem solving: The National Research Council. *Policy Sciences* 32: 385-391.
POLLAN, M. 2002. The botany of desire: a plant's eye view of the world. Random House, Inc.
PPS. 2009. Where the jobs are: mission-critical opportunities for America (Biological Sciences). Third edition. Partnership for Public Service, Washington, DC. Available at http://data.wherethejobsare.org/wtja/field/1484 (Accessed 29 March 2010).
PRATHER, L. A., O. ALVAREZ-FUENTES, M. H. MAYFIELD, AND C. J. FERGUSON. 2004a. Implications of the decline in plant collecting for systematic and floristic research. *Systematic Botany* 29: 216-220.
PRATHER, L. A., O. ALVAREZ-FUENTES, M. H. MAYFIELD, AND C. J. FERGUSON. 2004b. The decline of plant collecting in the United States: a threat to the infrastructure of biodiversity studies. *Systematic Botany* 29: 15-28.
PRIMACK, D., C. IMBRES, R. B. PRIMACK, A. J. MILLER-RUSHING, AND P. DEL TREDICI. 2004. Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. *American Journal of Botany* 91: 1260-1264.
ROBERSON, E. 2002. Barriers to native plant conservation in the United States: funding, staffing, law. Native Plant Conservation Campaign, California Native Plant Society, Sacramento, CA and Center for Biological Diversity, Tucson, AZ. Available at www.plantsocieties.org/PDFs/BarriersToPlantConservation.pdf (Accessed February 15 2010).
RPCI. 2010. Colorado Rare Plant Conservation Initiative. Available at www.conserveonline.org/workspaces/corareplantinitiative (Accessed July 2010).
RSABG. 2010. Academic programs at Rancho Santa Ana Botanic Garden. Available at www.rsabg.org/research/graduate-program (Accessed July 2010).
RUBIN, E. M. 2008. Genomics of cellulosic biofuels. *Nature* 454: 841-845.
SALT, D. E., M. BLAYLOCK, N. P. B. A. KUMAR, V. DUSHENKOV, B. D. ENSLEY, I. CHET, AND I. RASKIN. 1995. Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants. *Nature Biotechnology* 13: 468-474.
SCHATZ, G. E. 2009. Plants on the IUCN Red List: setting priorities to inform conservation. *Trends in Plant Science* 14: 638-642.
SCHERRER, W. 1999. Celebrating Wildflowers across the nation: How to develop a regional native plant education program, how to develop a native plant curriculum guide and how to organize and conduct teacher training workshops. North Cascades Institute, Sedro-Woolley, WA. More information at www.ncascades.org/more_info/resources/publications.html (Accessed May 2010).
SCHERRER, W., AND T. JOHANNESSEN. 1996. Celebrating Wildflowers: Educator's guide to the appreciation and conservation of native plants of Washington (native plant education, field and classroom activities, grades 4 - 8). North Cascades Institute, Sedro-Woolley, WA. More information at www.ncascades.org/more_info/resources/publications.html (Accessed May 2010).

SCHULTZ, C. B., AND K. M. DLUGOSCH. 1999. Nectar and hostplant scarcity limit populations of an endangered Oregon butterfly. *Oecologia* 119: 231-238.
SCHUSSLER, E. E., AND L. A. OLZAK. 2008. It's not easy being green: student recall of plant and animal images. *Journal of Biological Education* 42: 112.
SCHWENK, K., D. K. PADILLA, G. S. BAKKEN, AND R. J. FULL. 2009. Grand challenges in organismal biology. *Integrative and Comparative Biology* 49: 7-14.
SENCHINA, D. S. 2008. The students were right all along…plants really are BORING. *Plant Science Bulletin* 54.
SIEBERT, S. J., AND G. F. SMITH. 2004. Lessons learned from the SABONET Project while building capacity to document the botanical diversity of southern Africa. *Taxon* 53: 119-126.
SIMPSON, A., C. JARNEVICH, J. MADSEN, R. WESTBROOKS, C. FOURNIER, L. MEHRHOFF, M. BROWNE, J. GRAHAM, AND E. SELLERS. 2009. Invasive species information networks: collaboration at multiple scales for prevention, early detection, and rapid response to invasive alien species 10: 5-13.
SITES. 2009. The Case for Sustainable Landscapes. The Sustainable Sites Initiative. Available at http://www.sustainablesites.org/report.
SMALLIDGE, P. J., AND D. J. LEOPOLD. 1997. Vegetation management for the maintenance and conservation of butterfly habitats in temperate human-dominated landscapes. *Landscape and Urban Planning* 38: 259-280.
SMITH, G. F., C. K. WILLIS, AND M. MOSSMER. 1999. Southern African herbarium needs assessment (Southern African Botanical Diversity Network Report No. 6). SABONET, Pretoria.
SMOCOVITIS, V. B. 2006. One hundred years of American botany: a short history of the Botanical Society of America. *American Journal of Botany* 93: 942-952.
SNOW, N. 2005. Successfully curating smaller herbaria and natural history collections in academic settings. *BioScience* 55: 771-779.
SOS. 2010. Seeds of Success. Available at www.nps.gov/plants/sos/ (Accessed July 2010).
STEENKAMP, Y., AND G. F. SMITH. 2003. Needs of users of botanical information in South Africa: outcomes of a national workshop for the stakeholders and end-users of botanical information and herbaria. *Taxon* 52: 303-306.
STEIN, B. A., AND K. GRAVUER. 2008. Hidden in plain sight: The role of plants in State Wildlife Action Plans. NatureServe, Arlington, Virginia. Available at www.natureserve.org/publications/hidden_in_plain_sight.pdf (Accessed February 18 2010).
STEIN, B. A., C. SCOTT, AND N. BENTON. 2008. Federal lands and endangered species: The role of military and other federal lands in sustaining biodiversity. *BioScience* 58: 339-347.
SUAREZ, A. V., AND N. D. TSUTSUI. 2004. The Value of Museum Collections for Research and Society. *BioScience* 54: 66-74.
SUNDBERG, M. D. 2004. Where is botany going? *Plant Science Bulletin* 50: 2-6.
SUTHERLAND, W. J., W. M. ADAMS, R. B. ARONSON, R. AVELING, T. M. BLACKBURN, S. BROAD, G. CEBALLOS, I. M. CÔTÉ, R. M. COWLING, G. A. B. D. FONSECA, E. DINERSTEIN, P. J. FERRARO, E. FLEISHMAN, C. GASCON, J. M HUNTER, J. HUTTON, P. KAREIVA, A. KURIA, D. W. MACDONALD, K. MACKINNON, F. J. MADGWICK, M. B. MASCIA, J. MCNEELY, E. J. MILNER-GULLAND, S. MOON, C. G. MORLEY, S. NELSON, D. OSBORN, M. PAI, E. C. M. PARSONS, L. S. PECK, H. POSSINGHAM, S. V. PRIOR, A. S. PULLIN, M. R. W. RANDS, J. RANGANATHAN, K. H. REDFORD, J. P. RODRIGUEZ, F. SEYMOUR, J. SOBEL, N. S. SODHI, A. STOTT, K. VANCE-BORLAND, AND A. R. WATKINSON. 2009. One hundred questions of importance to the conservation of global biological diversity. *Conservation Biology* 23: 557-567.
TALLAMY, D. 2007. Bringing nature home: how you can sustain wildlife with native plants. Timberland Press, Portland, OR.
UNO, G. E. 1988. Teaching college and college-bound biology students. *The American Biology Teacher*: 213-216.
UNO, G. E. 1994. The state of precollege botanical education. *The American Biology Teacher* 56: 263-267.
UNO, G. E. 2002. The future of botany at the undergraduate level. *Plant Science Bulletin* 48: 4-5.
UNO, G. E. 2007. The struggle for botany majors. *Plant Science Bulletin* 53: 102-103.
UNO, G. E. 2009. Botanical literacy: What and how should students learn about plants? *American Journal of Botany* 96: 1753 - 1759.
UWBG. 2010. Academic programs at University of Washington Botanic Gardens. Available at http://depts.washington.edu/uwbg/education/academic.shtml (Accessed July 2010).
WANDERSEE, J. H., AND E. E. SCHUSSLER. 1999. Preventing plant blindness. *The American Biology Teacher* 61: 82-86.
WILLIS, C. K., AND B. J. HUNTLEY. 2001. SABONET: Developing capacity within Southern Africa's herbaria and botanical gardens. *Systematics and Geography of Plants* 71: 247-258.
WYSE JACKSON, P., AND K. KENNEDY. 2009. The Global Strategy for Plant Conservation: a challenge and opportunity for the international community. *Trends in Plant Science* 14: 578-580.
YOON, C. K. 2009. Reviving the lost art of naming the world, New York Times, August 11, 2009.
ZEITER, M., AND A. STAMPFLI. 2008. Long-term assessment of seed provenance effect on the establishment of the perennial grass Bromus erectus. *Journal of Vegetation Science* 19: 821-830.
ZISKA, L. H., P. R. EPSTEIN, AND W. H. SCHLESINGER. 2009. Rising CO2, climate change, and public health: exploring the links to plant biology. *Environmental Health Perspectives* 117: 155-158.
ZORN-ARNOLD, B., AND H. F. HOWE. 2007. Density and seed set in a self-compatible forb, *Penstemon digitalis* (Plantaginaceae), with multiple pollinators. *American Journal of Botany* 94: 1594-1602.
ZORN-ARNOLD, B., H. F. HOWE, AND J. S. BROWN. 2006. Obvious and cryptic vole suppression of a prairie legume in experimental restorations. *International Journal of Plant Science* 167: 961-968.

Assessing botanical capacity to address grand challenges

Summary of gaps identified and recommendations made

EDUCATION AND TRAINING

GAPS IDENTIFIED

Loss of botanical degree programs: In 1988, 72% of the nation's top 50 most funded universities offered advanced degree programs in botany. Today, more than half of these universities have eliminated their botany programs and many, if not all, related courses. Statistics from the U.S. Department of Education reveal that undergraduate degrees earned in botany are down 50% and advanced degrees earned in botany are down 41%. During the same time, undergraduate degrees awarded in general biology have increased 17% and advanced degrees earned in general biology have grown by 11%.

Decline in botanical course offerings: Nearly forty percent of the over 400 university faculty who completed the survey said botany courses in their department had been cut in the past 5-10 years. The courses eliminated tend to be from among those required for the 0430 (botanist) federal job code. A majority of faculty and graduate student respondents were dissatisfied with botany courses offered by their college or university.

Preparation for employment at federal agencies: Neither students or faculty were aware of the coursework requirements for employment as a federal botanist (24 credit hours in botany). Given course offerings at many academic institutions, it is likely that many students considering careers as federal botanists will graduate without meeting coursework requirements for federal hiring.

RECOMMENDATIONS MADE

Recommendation 1: Faculty and administration involved in college and university biology education should ensure plant science is appropriately incorporated in annual course offerings for undergraduate and graduate students to ensure they are employable both within and outside the academic sector. This includes offering courses that meet requirements for employment as a federal botanist (such as botany, plant anatomy, morphology, taxonomy and systematics, mycology, ethnobotany, and other plant-specific courses), and encouraging interdisciplinary research programs to train students in both basic research and applied science.

Recommendation 2: Faculty and administration at the nation's academic institutions should ensure plant science, including basic organismal expertise, is strongly represented within interdisciplinary departments, particularly as staff with botanical expertise retires in the coming decade. Accreditation bodies should develop recommendations and criteria for monitoring and evaluation to support adequate representation of botanical disciplines in biology departments and interdisciplinary study programs nationally.

Recommendation 3: Non-profit organizations play an increasingly critical role in filling gaps in botanical education and training. They contribute to course development and classroom education while providing amplification and practical experience, particularly for subjects that are most in demand for the nation's botanical workforce outside of academia. Because demand will likely only increase in this area, non-profit organizations should take strategic steps to increase their ability to fill this gap in capacity in this area. Leadership to recognize, support and sustain the ability of non-profit organizations to fill this role is needed from private foundations as well as academic and government sectors.

Recommendation 4: A full-time liaison position should be established between the Botanical Society of America and federal land management and research agencies to ensure botanical education and practical training needs for expert resource management are met. Similar to the current liaison position between the Bureau of Land Management and the Society for Range Management, this position would strengthen collaboration and workforce building through avenues such as quick-hire programs as well as the Office of Personnel Management's Student Educational Employment Program and Presidential Management Fellows Program.

Recommendation 5: Academic, government and private sectors should work collaboratively to strategically strengthen botanical education and training at all age levels. This includes curriculum development that recognizes the central role plants play in biological systems and human life, and better integration of plant science into biology standards and textbooks. Work through the STEM Education Coalition as well as organizations like the Botanical Society of America, the American Institute of Biological Sciences and the National Association of Biology Teachers is needed to build support for and better integration of plant science education and training in biology coursework.

COMMUNICATION AND OUTREACH

GAPS IDENTIFIED

Private sector: Respondents in this sector provide the greatest outreach to government agencies and private citizens, but more is needed. While 50% of respondents from this sector consulted with government agencies on botanical matters from 2007 - 2009, over 70% consulted with private citizens, and non-profit respondents gave on average 2.3 media interviews during the same timeframe.

Academic sector: While outreach within the academic sector is strong, there is a need for greater outreach to government agencies and private citizens: fewer than 37% of respondents reported consulting with government agencies on botanical matters, only 2.2% consulted with private citizens, and each respondent gave an average of 1.3 interviews to the media from 2007 - 2009.

RECOMMENDATIONS MADE

Recommendation 6: All sectors should work both individually and collaboratively to strategically increase outreach efforts to different audiences, and to monitor the effectiveness of this work. Action is needed to create appropriate materials and deliver information that increases the level of botanical literacy and appreciation among policy makers, other scientific disciplines, and the general public. The private sector should build on current outreach efforts to the government and general public, the government sector should ensure outreach efforts to the public effectively include plants as well as the wildlife that depends upon them, and the academic sector should make a commitment to increase outreach efforts beyond the academic sector.

RESEARCH AND MANAGEMENT

GAPS IDENTIFIED

Demand for research not being met: Survey respondents were unanimous in selecting invasive species control as the top management issue requiring additional research, yet very few faculty or graduate students reported undertaking research that was applicable to invasive species control.

Plants are being left out of climate change planning and action: Planning and policy actions within federal and state government agencies focused on climate change adaptation and mitigation are not incorporating botanical expertise. This is likely due at least in part to a false perception that plants are not being impacted by climate change, when in reality they will often be more impacted than the wildlife and people who depend upon them.

Private sector's valuable but under-supported role: businesses and non-profit organizations are beginning to fill key gaps in government and academic botanical capacity through cross-sector partnerships. Botanical services most commonly contributed to these partnerships match up with top needs for research and management, including invasive species identification and monitoring, botanical training, and rare species monitoring and conservation. Additional support is needed to ensure botanical capacity in the private sector is in place and able to help the nation address these current and future grand challenges.

Bureau of Land Management (BLM) — charged with managing biological resources on 40% of all public land, but employ just over one botanist per 4 million acres (equivalent to having one person responsible for all of Connecticut). Of the 95 BLM survey respondents, 97% said their agency did not have enough botanically trained staff to meet current needs.

US Geological Survey (USGS) — provides the science to guide management of nearly 400 million acres of public lands. All USGS survey respondents said their agency did not have enough botanically trained staff to meet current needs. A preliminary assessment of USGS scientists at science centers in the western U.S., where most public lands are located, shows that wildlife scientists outnumber botanical scientists by over 20 to 1.

RECOMMENDATIONS MADE

Recommendation 7: The significant impacts of climate change on plants, as well as the people, wildlife, and ecosystem services that are dependent upon plants for survival and well-being, should be recognized. Appropriate botanical expertise should be incorporated into climate change planning and policy efforts in all sectors to ensure appropriate proactive research efforts are initiated, and collaborative partnerships are encouraged to support effective, efficient, and economically defensible solutions. This includes ongoing work by the Department of Interior in developing and managing Climate Science Centers and Landscape Conservation Cooperatives, where botanical capacity is currently greatly underrepresented.

Recommendation 8: Public and private funding should be directed to help all sectors close key gaps identified in plant science research that are directly linked to top needs and applications identified by this survey. This includes identified research needs in invasive species control, climate change mitigation and adaptation, habitat restoration, and the preservation of ecosystem services.

Recommendation 9: The nation's five federal land management agencies* should increase the number of trained, full-time botanists on staff. *At minimum, each agency should have at least* (a) one full-time botanist working collaboratively at the national level to address critical climate change issues facing plants on public lands, and (b) one full-time botanist with appropriate training on staff at all regional, state, and field offices.

*Bureau of Land Management (BLM), Department of Defense (DOD), National Park Service (NPS) US Forest Service (USFS), and US Fish and Wildlife Service (USFWS), which are collectively responsible for managing nearly 1/3 of the nation's landmass.

Recommendation 10: The US Geological Survey, responsible for carrying out research to guide management of Department of Interior lands** should have *at least* five full-time botanists with a range of appropriate training on staff at each of its regional science centers.

**US Geological Survey (USGS) is the research arm of the BLM, NPS, and USFWS National Wildlife Refuge system, therefore charged with research on the native plant communities comprising almost 400 million acres of public lands.

Recommendation 11: Administrators and decision-makers at federal and state land management and research agencies should engage full-time staff botanists and work collaboratively with academic and private sector expert advisors in developing land-use plans, and in planning and implementing responses to key challenges (including climate change mitigation planning, habitat restoration and invasive species control strategies). This will lead to more successful, efficient, and economical outcomes.

Recommendation 12: Federal and state land management and research agencies should provide support for full-time staff botanists to identify and prioritize plant-related issues, and ensure these priorities are clearly and consistently communicated to the academic and private sector to allow for effective and efficient action. Once identified and communicated, management and funding decisions in the private and public sectors should ensure that capacity and resources are focused on the highest priority issues (such as invasive species) and/or taxa (such as those most critically threatened).

Recommendation 13: All federal land management and research agencies should ensure new hires have appropriate botanical training, and that monitoring and reporting mechanisms are in place to avoid a similar decay in botanical capacity in the future. Specifically, all new federal hires recommended here should be employed under the US Office of Personnel Management employment code 0430 (Botany), rather than the more general code of 0400 (Natural resource management / general biology), as it does not effectively capture required botanical expertise.

Recommendation 14: Cross-sector communication and partnership should be enhanced to pool existing resources, maximize efficiency, and more rapidly address and fill critical gaps in botanical capacity. Additional resources are needed to facilitate partnerships among government, academic, and private sectors, ensuring long-term sustainability of programs necessary for science-driven management of the nation’s biological resources. The Plant Conservation Alliance provides an effective vehicle for multi-sector partnerships, and examples of programs built around public-private partnerships include the national Seeds of Success program and regional programs such as the New England Plant Conservation Program and the Georgia Plant Conservation Alliance.

Appendix A: Full text of defined grand challenges (see Table 1.1)

Grand Challenge Identified
Biological Diversity and Ecosystem Functioning [a] The challenge is to improve understanding of the factors affecting *biological diversity and ecosystem structure and functionin*g, including the role of human activity. Important research areas include improving tools for rapid assessment of diversity at all scales; producing a quantitative, process-based theory of biological diversity at the largest possible variety of spatial and temporal scales; elucidating the relationship between diversity and ecosystem functioning; and developing and testing techniques for modifying, creating, and managing habitats that can sustain biological diversity, as well as people and their activities. [b] Understand and sustain *ecosystem function and biodiversity in the face of rapid change*. Fundamental advances in knowledge and a new generation of tools and technologies are needed to understand how ecosystems function, measure ecosystem services, allow restoration of damaged ecosystems, and minimize harmful impacts of human activities and climate change. What is needed is the New Biology, combining the knowledge base of ecology with those of organismal biology, evolutionary and comparative biology, climatology, hydrology, soil science, and environmental, civil, and systems engineering, through the unifying languages of mathematics, modeling, and computational science. This integration has the potential to generate breakthroughs in our ability to monitor ecosystem function, identify ecosystems at risk, and develop effective interventions to protect and restore ecosystem function.
Sustainable Food Production [b] Generate *food plants* to adapt and grow sustainably in changing environments. The New Biology could deliver a dramatically more efficient approach to developing plant varieties that can be grown sustainably under local conditions. The result of this focused and integrated effort will be a body of knowledge, new tools, technologies, and approaches that will make it possible to adapt all sorts of crop plants for efficient production under different conditions, a critical contribution toward making it possible to feed people around the world with abundant, healthful food, adapted to grow efficiently in many different and ever-changing local environments.
Biogeochemical Cycles [a] The challenge is to further our understanding of the Earth's major biogeochemical cycles, evaluate how they are being perturbed by human activities, and determine how they might better be stabilized. Important research areas include quantifying the *sources and sinks* of the nutrient elements and gaining a better understanding of the biological, chemical, and physical factors regulating transformations among them; improving understanding of the interactions among the various biogeochemical cycles; assessing anthropogenic perturbations of biogeochemical cycles and their impacts on ecosystem functioning, atmospheric chemistry, and human activities, and developing a scientific basis for societal decisions about managing these cycles; and exploring technical and institutional approaches to managing anthropogenic perturbations.
Climate Variability [a] The challenge is to increase our ability to predict climate variations, from extreme events to decadal time scales; to understand how this variability may change in the future; and to *assess realistically the resulting impacts*. Important research areas include improving observational capability, extending the record of observations back into the Earth's history, improving diagnostic process studies, developing increasingly comprehensive models, and conducting integrated impact assessments that take human responses and impacts into account.
Optimized (or carbon-neutral) fuel production [b] The challenge is to expand sustainable *alternatives to fossil fuels*. Making efficient use of plant materials—biomass—to make biofuels is a systems challenge, and this is another example of an area where the New Biology can make a critical contribution. At its simplest, the system consists of a plant that serves as the source of cellulose and an industrial process that turns the cellulose into a useful product. There are many points in the system that can be optimized. The New Biology offers the possibility of advancing the fundamental knowledge, tools, and technology needed to optimize the system by tackling the challenge in a comprehensive way. [c] The challenge is to harness science and technology to develop *biological systems that can turn sunlight into carbon-neutral fuel.*

[a] Taken from (NRC, 2001) Italics added.
[b] Taken from (NRC, 2009) Italics added
[c] Taken from (NEC, 2009) Italics added

Appendix 1: Summary responses to survey question ***In which state do you reside?.*** (All sectors)

State	Number of Respondents	State	Number of Respondents
AK	22	MT	31
AL	6	NC	46
AR	10	ND	5
AZ	38	NE	14
CA	200	NH	6
CO	63	NJ	22
CT	15	NM	19
DC	42	NV	20
DE	2	NY	48
FL	37	OH	39
GA	27	OK	11
HI	29	OR	72
IA	20	PA	32
ID	20	PR	2
IL	82	RI	3
IN	30	SC	9
KS	7	SD	14
KY	6	TN	27
LA	19	TX	45
MA	33	UT	37
MD	42	VA	48
ME	3	VT	10
MI	19	WA	43
MN	14	WI	30
MO	40	WV	7
MS	18	WY	46

Appendix 2: Summary responses to survey question ***What is your gender?*** (All sectors)

	Female (%)	Male (%)	Prefer not to answer (%)
Academic institutions			
Graduate students (n = 192)	67.2	32.8	0
Faculty and administration (n = 403)	46.4	52.6	1
Government agencies			
Federal agencies (n = 485)	54.8	42.3	2.9
Regional/local government (n = 85)	56.5	42.4	1.2
State natural heritage (n = 35)	48.6	51.4	0
Private organizations and businesses			
Non-profit organizations (n = 234)	53.4	44.4	2.1
For-profit business (n = 61)	50.8	47.5	1.6
TOTAL (n = 1495)	**53.7**	**44.6**	**1.7**

Appendix 3: Summary responses to survey question ***Please tell us about your highest completed degree.*** (All sectors) The degree with the greatest percent representation for each survey type is indicated in bold.

	Academic Institutions		*Government Agencies*			*Private Organizations/Businesses*		***Total***
Highest Earned Degree	**Graduate students (%) n=196**	**Faculty / admin. (%) n=410**	**Federal gov. (%) n=529**	**State/ local gov. (%) n=87**	**State nat'l heritage (%) n=35**	**Non-profit organization (%) n=227**	**For-profit business (%) n=63**	**Total (%) n=1547**
High School	0	0	0.8	1.1	0	4.4	6.3	1.2
AAS	0	0.2	0	0	0	0	0	0.1
BS/BA	**57.1**	0.5	34.0	29.9	20.0	30.0	38.1	27.1
MS/MA	42.9	12.0	**42.7**	**62.1**	**62.9**	**40.1**	**31.7**	35.3
PhD	0	**87.3**	22.5	6.9	17.1	25.6	23.8	**36.3**

Appendix 4: Summary responses to survey question ***How often is botanical knowledge needed as part of your daily work activities?*** (Government sector)

Frequency of Botanical Knowledge Used	Federal Gov. (%) n=505	State/Local Gov. (%) n=74	State Natural Heritage (%) n = 34
Every Day	46.7	48.1	67.6
Most Day	36.6	21.6	29.4
Some Days	15.2	15.1	2.9
Very Few days	1.4	5.1	0

Appendix 5: Summary responses to survey question ***Please indicate which of the following areas are directly related to your daily work activities. (Please check all that apply)*** (Government and private sectors) OR ***In which areas do you believe your research has direct or indirect application(s)? (Please check all that apply)*** (Academic sector). Top five selections for each sector are identified in bold. Response totals tally beyond 100% because the question allowed for several responses. Each response indicates the percent of participants that selected a choice as one of their answers. Blank spaces indicate non-applicable selections in a sector.

	Research applications		***Daily activities***				
Identified activity	**Faculty (%) n = 368**	**Graduate Student (%) n = 179**	**Federal Gov. (%) n = 481**	**Regional/ Local Gov. (%) n = 79**	**State Nat'l Heritage (%) n = 35**	**Non-Profit Org. (%) n = 228**	**For-profit (%) n = 57**
Understanding fundamental plant biology	**46.5**	**42.5**				20.2	19.3
Understanding native habitats & populations	**44.8**	**53.1**		**46.8**	**71.4**	**53.5**	**49.1**
Diversity maintenance & management	**40.5**	**40.8**	32.5	34.2	31.4		21.1
Habitat restoration	35.1	**43.6**	**57.0**	**57.0**	**40.0**	**46.5**	**49.1**
Invasive species management	37.8	35.2	**60.7**	**57.0**	34.1	**45.2**	**42.1**
Rare species conservation	**40.8**	37.4	**59.9**	**55.7**	**88.6**	**50.0**	**49.1**
Habitat and species monitoring	**41.3**	**44.7**	**62.4**	**64.6**	**74.3**	**53.1**	**59.6**
Native seed selection & storage	13.0	12.3	38.5	20.3	17.1	36.8	15.8
Native plant selection for restoration	23.9	31.8	39.9	34.2	22.9		
Land management	21.5	**40.8**	**50.9**	44.3	37.1	35.5	28.1
Climate change effects/mitigation	31.0	37.4	23.7	11.4	20.0	18.9	3.5
Threatened/endangered plant recovery	29.9	24.0	36.8	36.7	**45.7**	33.3	33.3

Appendix 6: Summary responses to survey question ***Which one of the following best describes the way you identify yourself? (Please select all that apply.)*** (Academic and private sector) Top three responses for each group are indicated in bold.

	Academic Respondents		*Private Sector Respondents*	
Identity	**University Faculty and Staff (%) n = 230**	**Graduate Students (%) n = 185**	**Non-Profit Org. (%) n = 230**	**Business/Self -employed (%) N = 58**
Botanist	**26.0**	**23.2**	**36.1**	**50.0**
Ecologist	**19.7**	**33.5**	27.8	**36.2**
Plant Conservation Biologist	4.2	4.0		**25.9**
Educator	7.1	------	**19.6**	19.0
Taxonomist	6.6	2.2	8.3	19.0
Administrator	1.5	------	**23.5**	17.2
Restoration ecologist	0	0	2.2	17.2
Horticulturist	2.9	3.2	14.8	13.8
Science Writer	------	------	8.3	12.1
Environmental Scientist	------	------	2.2	12.1
Herbalist	------	------	0	12.1
Land manager	------	------	10.4	8.6
Medicinal plant specialist	------	------	0	6.9
Evolutionary Biologist	**11.3**	**9.7**	3.5	5.2
Aquatic Biologist/Ecologist	------	------	1.7	5.2
Wildlife Biologist	0	0.5	2.2	5.2
Curator	------	------	12.6	1.7
Communications/outreach	------	------	10.9	------
Fundraiser	------	------	9.1	------
Interpretive/display staff	------	------	3.9	------
IS/IT specialist	------	------	1.3	0
Forester	0.5	1.6	1.7	1.7
Plant Physiologist	3.4	2.2	0.9	1.7
Soil Scientist	0	0.5	0.4	1.7
Zoologist	0	0	1.7	1.7
Climate Change Scientist	0.2	0	2.2	0
Geologist	0	0	0	0
Hydrologist	0	0	0	0
Mycologist	0.7	0.5	0.4	0
Plant Geneticist	2.5	3.8	0	0
Plant Pathologist	0	0	0.4	0
Theoretical/Mathematical Ecologist	0	0.5	0	0

Appendix 7: Summary responses to survey question ***Please indicate the number of full-time faculty, students, and postdoctoral fellows in your plant science program(s). If your institution does not offer any plant science or related degree(s), please skip to the next question.*** (Academic sector, faculty only) Response counts that make up the majority are shown in bold.

Academic Staff and Faculty Assessment of Their Department Sizes

Counts	Full-Time Faculty (%) n = 239	Undergraduate Students (%) n = 209	Master's Program (%) n= 226	PhD Program (%) n = 226	Post-Doctoral (%) n = 220
0	2.5	**18.6**	**24.8**	**35.0**	**36.4**
1 to 3	**29.7**	**7.2**	**13.3**	**8.4**	**25.5**
4 to 6	**19.7**	5.7	**15.0**	**6.2**	9.5
7 to 9	**9.2**	**7.7**	6.6	**7.1**	4.5
10 to 12	6.3	**8.6**	10.2	7.5	4.1
13 to 15	7.5	5.3	4.4	4.4	< 1.0
16 to 18	4.6	5.7	1.4	3.1	1.4
19 to 21	1.7	3.8	1.4	2.2	< 1.0
22 to 24	1.7	3.5	1.8	1.3	< 1.0
25 to 27	1.4	1.9	1.3	3.1	< 1.0
28 to 30	< 1.0	3.3	2.7	1.8	< 1.0
31 to 33	< 1.0	1.4	< 1.0	1.8	< 1.0
34 to 36	< 1.0	< 1.0	1.3	< 1.0	< 1.0
37 to 39	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
40 to 42	< 1.0	2.0	< 1.0	1.8	< 1.0
43 to 45	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
46 to 49	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
50 to 52	< 1.0	1.4	< 1.0	< 1.0	1.4
53 to 55	< 1.0	1.4	< 1.0	< 1.0	< 1.0
56 to 58	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
59 to 61	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
62 to 64	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
65 to 67	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
68 to 70	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
71 to 73	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
74 to 76	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
77 to 79	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
> 80	3.3	**13.9**	3.1	2.2	1.4
I don't know	7	16.3	10.6	10.6	12.7

Appendix 8: Summary responses to survey question ***How many students are you currently advising/training? If advising students is not part of your job role, then please skip to the next question.*** (Academic sector, faculty only) Majority responses given in bold.

Number of students advised	Associates (%) N=158	BS/BA (%) N=260	MS/MA (%) N=231	PhD (%) N=230
0	**95.6**	16.2	**52.8**	**54.1**
1 to 3	1.3	**30.1**	40.3	37.1
4 to 6	< 1.0	15.1	5.2	7.4
7 to 9	< 1.0	6.6	< 1.0	< 1.0
10 to 12	< 1.0	4.6	< 1.0	< 1.0
> 12	3.1	**27.0**	< 1.0	< 1.0

Appendix 9: Summary responses to survey question ***Which of the following represent your research areas? (Please check all that apply)*** (Academic sector) Majority responses given in bold.

Research Area	**Faculty Response (%) n = 406**	**Graduate Student Response (%) n = 185**
Agronomy/Crop Science	3.7	5.9
Aquatic Biology/Ecology	6.2	4.9
Behavioral Ecology	1.7	2.2
Botany	**54.9**	**51.4**
Bryology	2.2	2.7
Desert Ecology	6.2	6.5
Diversity Mechanisms	2.2	2.2
Diversity & Stability in Ecosystems	4.9	7.6
Ecology	**40.6**	**57.8**
Ecosystem physiology	4.9	4.9
Ecosystem Processes & Services	5.4	13.0
Ecosystem Primary Productivity	2.7	0
Environmental Science	8.6	14.1
Ethnobotany/Economic Botany	4.7	3.2
Evolutionary Biology	**32.0**	**24.9**
Fire Ecology	5.9	11.4
Foraging/Predation Behavior	1.5	1.6
Forest Ecology	13.5	14.6
Grassland Ecology	9.4	10.3
Herbivory/Granivory	6.9	5.4
Invasive Sp Biology/Ecology	18.7	19.5
Landscape Ecology	6.7	13.5
Mycology	3.7	3.2
Paleobotany	5.2	4.8
Plant Anatomy	11.1	4.9
Plant Biology	20.0	20.0
Plant Biotechnology	3.7	1.1
Plant Cellular/Molecular Biology	6.4	3.8
Plant Community Ecology	14.5	21.1
Plant Conservation	24.6	**22.7**
Plant Development	7.9	3.2
Plant Genetics	13.1	12.4
Plant Morphology/Plant Kingdom	11.3	4.3
Plant Pathology	1.5	0.5
Plant Physiology	13.1	11.4
Plant Population Biology	14.0	6.5
Plant Population Ecology	17.2	13.5
Plant Population Genetics	14.5	12.4
Plant Propagation/Horticulture	7.6	4.9
Plant Reproductive Biology	18.7	9.7
Plant Systematics	**27.8**	19.5
Plant Taxonomy	**25.1**	18.9
Plant-Animal Interactions	13.3	16.2
Pollination Ecology	15.3	15.7
Population Genetics	9.4	7.6
Pollution abatement/bioremediation	1.0	1.6
Rangeland Ecology	3.2	4.3
Restoration Ecology	12.8	**24.9**
Seed Biology/Ecology	7.1	8.1
Seed Dispersal	6.2	7.0
Soil Ecology	4.2	9.2
Spatial Ecology	5.7	6.5
Species Coexistence	3.2	7.0
Stress Physiology	6.9	3.8
Successional Processes/Outcomes	1.5	2.7
Theoretical/Mathematical Ecology	2.5	3.2
Tropical Ecology	8.9	6.5
Weed Science	5.2	5.3
Wetland Ecology	7.6	8.6

Appendix 10: Summary responses to survey question ***Which of the following do you use, or have you used, as financial support while in Graduate School? (Please check all that apply)*** (Academic sector, graduate students only)

Financial Support	**Graduate Student Response (%)**
University teaching assistantship	61.9
University tuition waiver	55.8
Support from advisor's funding	46.4
Personal savings	43.1
University fellowship	36.5
Student loans	34.4
University research grant	33.7
Part time employment	27.6
Funding from non-profit group	26.5
Government research grant	24.3
Support from family	21.0
Government sponsored fellowship	17.7
Support from spouse	11.0
Full time employment	9.9
Employer reimbursement	4.4
University clerical assistantship	0.6

Appendix 11: Summary responses to survey question ***Please indicate the number of full-time and seasonal/part-time staff (including yourself) at your organization. Please respond by considering an individual's primary duty.*** (Private sector, non-profit organizations only). Greatest response for each job category is indicated in bold.

Number of Staff	Full-time Research Staff (%) n = 166	Part-time Research Staff (%) n = 151	Horticulture Staff (%) n = 148	Herbarium Staff (%) n = 143	Data Information Staff (%) n = 158	Administrative Staff (%) n = 192	Education Staff (%) n = 167	Post Doctoral Associates Staff (%) n = 141	Interns (%) n = 164	Volunteers (%) n = 170
0	**27.7**	**35.8**	**22.3**	**33.7**	12.7	2.6	12.0	**51.1**	13.4	4.1
1-3	25.3	31.1	20.9	28.7	**46.8**	**48.4**	**41.9**	19.9	**40.2**	8.8
4-6	13.9	6.0	7.4	8.4	12.7	15.6	12.0	5.7	11.6	5.9
7-9	5.4	2.6	9.5	2.1	4.4	7.3	6.0	0.7	7.3	2.9
10-12	4.8	0.7	0.7	1.4	4.4	4.2	4.8	2.1	4.9	4.7
13-15	1.8	0.7	4.7	0.7	1.3	2.6	1.2	0	1.8	3.5
16-18	1.8	0.7	2.0	0	0	0.5	1.2	0	1.2	1.8
19-21	0.6	0	1.4	0	0.6	2.1	0.6	0	0.6	2.9
22-24	1.2	0	2.7	0	0	0.5	0.6	0.7	2.4	4.1
25-27	0	0	1.4	0.7	0	0	0	0	0	1.2
28-30	0.6	0	2.0	0.7	1.3	0	1.8	0	1.8	1.2
31-33	0	0	0	0	0	0.5	0	0	0	0
34-36	1.2	0	0	0.7	0	0	0	0	0	0
37-39	0.6	0	0.7	0	0	0	0	0.7	0.6	0.6
>40	6.0	4.0	8.8	3.5	1.3	2.6	2.4	0	2.4	**45.9**
I don't know	3.6	11.3	5.4	2.8	8.2	10.9	10.2	11.3	8.5	7.1
Does not apply	5.4	7.3	10.1	16.8	6.3	1.6	5.4	7.8	2.4	1.2

Appendix 12: Summary responses to survey question ***Which of the following are part of your organization's mission statement? (Please select all that apply.)*** (Private sector, non-profit organizations only). The top two activities most reported by organization type are shown in bold.

Activity incorporated in non-profit organization's mission	**Conservation/ Research Organization % (n=97)**	**Botanic Garden/ Arboretum % (n=86)**	**Museum % (n=11)**	**Zoo % (n=10)**
Education	64	**94**	**82**	**90**
Training	20	41	27	30
Research	47	76	**73**	50
Plant/Habitat Conservation	**89**	**80**	55	70
Native Habitat Management	**66**	48	27	**80**

Appendix 13: Summary responses to survey question ***Please indicate the number of full-time and seasonal/part-time staff (including yourself) at your organization. Please respond by considering an individual's primary duty.*** (Private sector, for-profit business or self-employed only). Greatest response for each job category is indicated in bold.

Number of Staff	**Full-time Research Staff (%) n = 34**	**Full-time Land Management Staff (%) n = 34**	**Part-time Research Staff (%) n = 33**	**Part-time Land Management Staff (%) n = 36**	**Data Information Staff (%) n= 34**	**Horticulture Staff (%) n = 33**	**Administrative Staff (%) n = 42**	**Education Staff (%) n = 33**	**Post Doctoral Associates (%) n = 29**	**Interns (%) n = 31**	**Volunteers (%) n = 30**
0	32.4	20.6	**36.4**	22.2	14.7	33.3	9.5	**30.3**	**55.2**	**35.5**	**50.0**
1-3	**38.2**	**26.5**	24.2	**33.3**	**50.0**	**42.4**	**42.9**	27.3	0	29.0	10.0
4-6	2.9	11.8	0	5.6	11.8	0	9.5	0	0	0	3.3
7-9	0	5.9	3.0	0	5.9	3	0	3.0	0	0	0
10-12	0	2.90	0	2.8	0	0	4.8	0	0	0	0
13-15	0	2.9	0	2.8	0	0	7.1	0	0	0	0
16-18	0	0	0	0	0	0	0	0	0	0	0
19-21	0	0	0	0	0	0	2.4	0	0	0	0
22-24	0	0	0	0	0	0	0	0	0	0	0
25-27	0	0	0	0	2.9	0	0	0	0	0	0
28-30	0	0	0	0	0	0	0	0	0	0	0
31-33	0	2.0	0	0	0	0	0	0	0	0	0
34-36	0	0	0	0	0	0	0	0	0	0	0
37-39	0	0	0	0	0	0	0	0	0	0	0
>40	2.9	0	0	0	0	0	2.4	0	0	0	3.3
I don't know	2.9	2.9	6.1	5.6	2.9	0	4.8	6.1	6.9	6.5	3.3
Does not apply	20.6	23.5	30.3	27.8	11.8	21.2	16.7	33.3	37.9	25.8	26.7

Appendix 14: Summary responses to survey question ***Which of the following plant-related services do you/your company provide? (Please select all that apply.)*** (Private sector, for-profit business and self-employed only).

Business Services Provided	**Business/Self-employed Response (%) N=59**
Native plant & habitat surveys	59.3
Native habitat monitoring	47.5
Native habitat restoration	42.4
Science Writing/Report Preparation	42.4
Plant science education/training	35.6
Native habitat management	33.9
Environmental compliance guidance and implementation	30.5
Greenhouse/nursery production of native species for restoration/revegetation/reintroduction	25.4
Data Analysis	23.7
Basic plant science research	23.7
Sustainable production/harvest of medicinal or other non-timber plant species	18.6
Applied plant science research	16.9
Renewable Energy Research/Environmental Effects	5.1
Biofuel selection/environmental effects	3.4

Appendix 15: Summary responses to survey questions ***Please check the plant science and related courses that you teach at least every two years.*** (Academic sector, faculty only AND Private sector, non-profit organizations only) OR ***Please check the plant science and related courses that you completed while in college and/or graduate school.*** (Government sector and academic sector, graduate students only).

	Courses Taught		*College-Level Courses Taken*			
Plant Science Courses	**Non-Profit Org. (%) n=55**	**Faculty (%) n=262**	**State Natural Heritage (%) n=34**	**State/Local Gov. (%) n=74**	**Federal Gov.(%) n=496**	**Graduate Students (%) n=181**
Botany	72.4	44.3	91.2	82.4	89.5	61.5
Bryology	< 1.0	1.9	26.5	< 1.0	14.1	9.5
Diversity & Stability in Ecosystems	13.8	3.1	14.7	13.5	19.0	5.6
Ecology	37.9	29.0	88.2	82.4	87.5	81.0
Ethnobotany/Economic Botany	< 1.0	12.2	20.6	14.9	16.3	15.1
Evolutionary Biology	3.4	22.9	38.2	27.0	33.7	46.9
Field botany (incl. plant ID)	75.9	31.3	---	---	73.4	61.5
Fire Ecology	< 1.0	< 1.0	14.7	20.3	21.8	1.1
Forest Ecology	< 1.0	< 1.0	47.1	31.1	36.7	<1.0
Horticulture/Plant Propagation	31.0	7.3	14.7	14.9	18.1	14.0
Invasive Species Biology/Ecology	6.9	3.4	2.9	9.5	13.7	14.5
Landscape Ecology	< 1.0	< 1.0	23.5	20.3	22.6	20.7
Mycology	< 1.0	2.7	20.6	10.8	22.0	12.3
Plant Anatomy	6.9	9.5	52.9	39.2	47.2	33.0
Plant Biology	20.7	15.3	55.9	52.7	54.8	35.2
Plant Cellular/Molecular Biology	0	2.7	23.5	24.3	23.0	15.6
Plant Community Ecology	13.8	3.1	58.8	50.0	48.4	22.9
Plant Conservation	27.6	3.1	14.7	10.8	18.3	12.8
Plant Genetics	6.9	3.4	23.5	20.3	32.3	17.9
Plant Morphology/Plant Kingdom	27.6	11.8	35.3	23.0	33.7	22.3
Plant Pathology	0	1.1	11.8	9.5	21.2	11.7
Plant Physiology	20.7	12.2	55.9	40.5	52.8	41.3
Plant Systematics	24.1	23.7	67.6	36.5	40.7	39.7
Plant Taxonomy	20.7	19.8	67.6	55.4	68.1	41.9
Pollination Ecology	10.3	1.5	8.8	9.5	8.9	10.6
Population Genetics	6.9	2.3	23.5	17.6	28.2	23.5
Rangeland Ecology/Management	< 1.0	1.9	11.8	9.5	24.2	6.1
Restoration Ecology	20.7	4.6	2.9	23.0	14.3	18.4
Seed Biology/Ecology	< 1.0	< 1.0	5.9	4.1	5.0	1.7
Soil Ecology	6.9	1.5	35.3	23.0	32.1	20.7

Appendix 16: Summary responses to survey question ***How have faculty openings in the plant sciences changed at your institution over the last 5 to 10 years?*** (Academic sector, faculty only)

Changes in Faculty Opening in the Plant Sciences (5-10 years)

Changes in Openings	**Faculty Response (%) n = 329**
Full-time	
Increased	14.6
Decreased	39.0
Remained Steady	46.6
Part-time	
Increased	9.8
Decreased	23.3
Remained Steady	67.2

Appendix 17: Summary responses to survey questions ***In which of the following areas have full-time faculty positions been advertised at your institution in the last 5 to 10 years?*** AND ***Please select the top three (3) areas that represent a need for faculty positions at your academic institution.*** (Academic sector, faculty only) Top three areas are indicated in bold.

	Areas Searched	*Reported Areas Needed*
Specialty	**Faculty (%) n = 330**	**Faculty (%) n = 348**
Ecology	**47.9**	**21.3**
Molecular Biology	**39.4**	8.0
Evolutionary Biology	**32.4**	14.7
Cell Biology	28.8	6.9
Botany	28.2	**21.0**
Developmental Biology	22.4	11.2
Zoology	21.5	3.4
Plant Physiology	17.6	12.9
Plant Systematics	16.7	**19.0**
Biochemistry	16.4	3.4
Plant Genetics	15.5	9.8
Wildlife Biology	13.3	5.2
Agronomy/Crop Science	12.7	2.9
Horticulture	10.9	6.9
Forestry	9.1	3.4
Soil Science	8.2	9.2
Pathology	8.2	2.0
Climate Change	7.9	16.7
Plant Conservation Biology	4.2	16.1
Plant Taxonomy	< 1.0	12.9
Mycology	< 1.0	17.2
No need for Additional Faculty	------	8.0

Appendix 18: Summary responses to survey question ***Please select your top three (3) preferences for an employer.*** (Academic sector, graduate students only)

Employer	Graduate Student Response (%) n = 172
University	53.5
Conservation based agency	50.6
Botanic garden/arboretum	43.0
Federal government agency	41.3
Four-year college	31.4
State/Local government	27.9
Other non-profit organization	16.9
Museum	14.5
Community college	9.9
Self-employed	8.1
For-profit business	5.2
Zoo	2.9

Appendix 19: Summary responses to survey question ***Which of the following continuing education programs or classes/seminars does your organization offer?*** (Private sector, non-profit organizations only).

Courses & Seminars Offered	Non-profit organization (%) n = 178
Adult Courses	
Local Flora & Natural Areas	57.3
Plant Identification Classes	53.4
Gardening Classes	50.0
Native Plant Gardening	48.9
Plant Propagation	45.5
Natural History Ecology	45.0
Plant Information Hotline	36.5
Plant Conservation	29.2
Plant-Animal Interactions	23.0
Master Gardener Certification	20.8
Master Naturalist Certification	9.0
Children & Family Courses	
Summer Science Programs (grades K-8)	45.5
Summer Science Programs (high school)	36.5

Appendix 20: Seminars given to different audiences in 2008, faculty. Majority responses are given in bold.

Percent Faculty Giving Seminars by Audience per Year

Number of Seminars	University n = 229	Societal Meeting n = 294	Non-Profit Organization n = 265	Special Interest n = 256	Local Interest n = 218	Local Government n = 210	State/Federal Government n = 210
0	**34.9**	**24.5**	**44.9**	**48.4**	**72.5**	**82.3**	**72.4**
1	**46.7**	**34.7**	**26.8**	**28.9**	18.3	9.5	15.4
2	29.7	26.5	16.7	12.5	6.4	7.1	7.0
3	10.5	7.5	6.0	2.7	< 1.0	< 1.0	3.3
4	4.4	3.7	2.3	3.5	< 1.0	< 1.0	1.4
5	1.7	1.7	2.3	1.5	< 1.0	< 1.0	< 1.0
6	< 1.0	< 1.0	< 1.0	1.5	< 1.0	< 1.0	< 1.0
7	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
8	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
9	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
>10	< 1.0	< 1.0	< 1.0	< 1.0	1.4	< 1.0	< 1.0

Appendix 21: Seminars given to different audiences in 2008, non-profit organizations. Majority responses are given in bold.

Percent Non-Profit Staff Giving Seminars by Audience during 2008 (n = 212)

Number of Seminars	University	Societal Meeting	Non-Profit Organization	Special Interest	Local Interest	Local Government	State/Federal Government
0	**47.5**	32.5	20.1	23.6	**43.3**	**54.3**	**51.4**
1	24.1	**35.6**	**24.2**	**24.7**	24.1	15.2	15.3
2	8.9	12.3	20.6	17.4	10.6	5.1	9.0
3	5.7	4.9	11.9	10.1	3.5	4.3	4.9
4	3.2	3.7	3.6	4.5	2.1	5.1	1.4
5	2.5	1.2	6.7	2.8	3.5	2.2	3.5
6	0	1.8	2.6	0.6	0.7	0.7	1.4
7	1.3	0	1.0	1.7	0	0	0
8	0	0	1.0	1.7	0	0	2.8
9	0	0	0.5	0.6	0	0	0
10	0	1.2	0.5	1.1	0	0	0.7
>10	0	0.6	1.5	4.5	4.3	4.3	2.1

Appendix 22: Seminars given to different audiences in 2008, for-profit business. Majority responses are given in bold.

Percent Business Employees Giving Seminars by Audience per Year (n = 52)

Number of Seminar Talks	University n = 36	Society Meeting n = 38	Non-Profit Org. n = 40	Special Interest Groups n = 40	Local Interest Groups n = 35	Local Government n = 33	State Government n = 36
0	**50.0**	**34.2**	**27.5**	**32.5**	**45.7**	**63.6**	**58.3**
1	16.7	**34.2**	25.0	17.5	**31.4**	12.1	11.1
2	11.1	15.8	25.0	15.0	5.7	3.0	13.9
3	2.8	5.3	5.0	10.0	2.9	3.0	0
4	2.8	0	2.5	5.0	2.9	3.0	0
5	0	0	0	0.0	0	0	2.8
6	2.8	0	5.0	5.0	0	3.0	2.8

Appendix 23: Number of media interviews reported by different respondent groups as given between 2007 and 2009.

Number of Media Interviews (2007 – 2009)	Faculty Response (%) n = 331	Non-Profit Organization Response (%) n = 185	For-profit / Self-Employed Response (%) n = 49
0	40.2	29.2	48.8
1	23.3	12.4	24.4
2	17.2	18.3	14.6
3	7.9	8.1	0
4	4.5	7.6	4.9
5	2.1	5.4	2.4
6	1.8	4.3	0
7	< 1.0	2.7	0
8	< 1.0	1.6	0
9	< 1.0	< 1.0	0
10	< 1.0	1.6	0
>10	1.8	8.1	4.9

Appendix 24: Online outreach by non-profit organizations to reach their audiences.

Online Tools	**Non-Profit Org. (%) n = 210**
Web Page with Programs, Projects & Events	89.5
Staff Contact Web Pages	51.0
Twitter/Face Book	38.6
Teacher Activities	34.3
Blogs	33.8
Plant Collections Database	32.9
Plant Image Database	30.0
Herbarium	17.6
Rare Books Database	11.9
Botanical Art Database	6.7
Virtual Courses	3.3

Appendix 25a: Answer to question ***Please indicate how much of an impediment, if at all, you think the following are to effectively managing native habitats.*** (Government sector)

	Federal Government Response (%) n = 498				State & Local Government Response (%) n = 76				State Natural Heritage Program Response (%) n =33			
Impediments	Very Serious	Serious	Not too Serious	Not Serious at All	Very Serious	Serious	Not too Serious	Not Serious at All	Very Serious	Serious	Not too Serious	Not Serious at All
Lack of Scientific Knowledge	25.4	**49.1**	21.1	3.2	28.9	**38.2**	26.3	5.3	21.2	**57.6**	15.2	3.0
Lack of Botanical Expertise	23.4	**42.3**	28.9	3.7	25.3	**42.7**	24.0	5.3	30.3	**48.5**	18.2	3.0
Unclear Management Objectives	38.7	**43.8**	14.0	1.2	**41.3**	**41.3**	14.7	0.0	24.2	**60.6**	12.1	3.0
Lack of Research Funding	**40.9**	**40.9**	12.8	2.4	28.9	**53.9**	14.5	1.3	27.3	**54.5**	18.2	0.0
Lack of Management Funding	**52.2**	35.4	9.6	1.2	**57.3**	40.0	1.3	0.0	**54.5**	36.4	9.1	0.0
Lack of Scientists	17.6	**39.9**	32.0	7.0	22.7	25.3	**37.3**	10.7	15.2	**42.4**	24.2	6.1
Improperly Trained Plant Scientists	13.3	29.4	**33.3**	15.1	14.7	30.7	**37.3**	12.0	9.1	**36.4**	**36.4**	3.0
Government Inefficiency	28.3	**39.0**	22.6	5.1	28.0	**40.0**	21.3	4.0	18.2	33.3	**39.4**	3.0
Poorly Enforced Environmental Laws	**33.9**	33.7	21.6	5.9	**40.0**	32.0	20.0	1.3	27.3	**45.5**	15.2	3.0
Lack of Environmental Laws	20.0	27.0	**34.2**	12.7	25.3	29.3	**36.0**	4.0	27.3	**33.3**	27.3	0.0

Appendix 25b: Answer to question ***Please indicate how much of an impediment, if at all, you think the following are to effectively managing native habitats.*** (Private sector)

Impediments	**Non-Government Organization Response (%) n = 204** Very Serious	Serious	Not too Serious	Not Serious at All	**Business and Self-Employed Response (%) n = 50** Very Serious	Serious	Not too Serious	Not Serious at All
Lack of Scientific Knowledge	26.9	**45.8**	20.9	3.0	28.0	**46.0**	20.0	2.0
Lack of Botanical Expertise	31.2	**43.7**	17.1	4.5	28.6	**44.9**	18.4	4.1
Unclear Management Objectives	32.7	**46.7**	16.1	1.5	28.6	**55.1**	8.2	0.0
Lack of Research Funding	**44.9**	38.9	9.6	1.5	**46.0**	36.0	12.0	0.0
Lack of Management Funding	**55.8**	33.7	6.0	0.0	**58.0**	22.0	10.0	4.0
Lack of Scientists	18.7	**41.4**	30.3	4.5	20.0	**36.0**	30.0	6.0
Improperly Trained Plant Scientists	21.0	22.1	**36.9**	10.8	22.0	**30.0**	**30.0**	8.0
Government Inefficiency	34.0	**40.0**	16.0	3.0	**36.0**	**36.0**	20.0	2.0
Poorly Enforced Environmental Laws	**49.5**	31.0	13.0	2.5	**54.0**	24.0	18.0	0.0
Lack of Environmental Laws	35.9	**37.4**	15.7	7.1	**46.0**	28.0	16.0	4.0

Appendix 25c: Answer to question ***Please indicate how much of an impediment, if at all, you think the following are to effectively managing native habitats.*** (Academic sector)

Impediments	**Academic: Faculty & Staff Response (%) n = 354**				**Academic: Graduate Student Response (%) n = 171**			
	Very Serious	Serious	Not too Serious	Not Serious at All	Very Serious	Serious	Not too Serious	Not Serious at All
Lack of Scientific Knowledge	29.8	**46.7**	17.8	1.4	**37.6**	35.3	21.2	4.1
Lack of Botanical Expertise	36.4	**41.5**	17.0	2.0	22.2	**41.5**	26.3	4.1
Unclear Management Objectives	25.0	**53.8**	11.9	1.2	35.1	**43.3**	17.5	1.2
Lack of Research Funding	**44.0**	42.5	8.0	0.6	**48.2**	38.8	10.6	0.0
Lack of Management Funding	**44.1**	39.4	7.8	1.2	**58.8**	32.9	6.5	1.2
Lack of Scientists	21.2	**38.3**	31.3	4.1	14.8	37.3	**38.5**	7.1
Improperly Trained Plant Scientists	10.4	26.7	**38.8**	12.8	11.8	28.8	**38.2**	10.6
Government Inefficiency	26.2	**36.7**	24.2	3.5	**39.4**	35.9	18.2	2.9
Poorly Enforced Environmental Laws	**39.7**	33.8	15.2	2.6	**48.0**	40.4	10.5	0.0
Lack of Environmental Laws	28.2	**38.1**	21.6	3.9	37.1	**38.8**	22.4	0.6

Appendix 26: Response to the question ***In general, do you believe your partnerships are effective in meeting mutual goals?*** (All sectors except academic institutions)

Level of Goal Effectiveness	Federal Government (%) n = 484	State/Local Government (%) n = 72	State Natural Heritage (%) n = 33	Non-Profit Organization (%) n = 193	Businesses and Self-Employed (%) n = 46
Our Goals					
Our goals are met	4.5	2.8	**21.2**	3.1	21.7
Sometimes our goals are met, sometimes they are not	**50.6**	**31.9**	**63.6**	**34.7**	**26.1**
I don't know if our goals are met	6.6	4.2	12.1	4.7	4.3
Partners' Goals					
Partners' goals are met	3.3	4.2	------	3.6	**32.6**
Sometimes partners' goals are met, sometimes not	**27.3**	**6.9**	------	**21.2**	19.6
I don't know if our partner's goals are met	12.4	4.2	12.1	7.8	4.3
Mutual Goals					
Both our partners' goals and our goals are met	**31.6**	**26.4**	------	**45.6**	**43.5**
Prefer not to answer	1.9	6.9	0	3.1	0

Appendix 27: Response to the question ***Please indicate which, if any, of the following partnerships were unsuccessful.***

Partners	Federal Government (%) n = 322	State & Local Government (%) n = 44	State Natural Heritage (%) n = 19	Non-Profit Organization (%) n = 89	Business/Self-Employed (%) n = 31
Academic Institutions	**17.7**	**11.4**	5.3	**14.6**	12.9
Federal Government	**12.7**	2.3	5.3	**14.6**	**16.1**
State/Local Government Agencies	**12.1**	**15.9**	**35.9**	**11.2**	**19.4**
Native Plant Societies	8.4	6.8	**26.3**	4.5	3.2
Conservation Organizations	8.4	9.1	10.5	7.9	9.7
Botanic Gardens/Arboreta	7.1	2.3	**15.8**	7.9	9.7
Citizen Scientists	9.6	**18.2**	**15.8**	6.7	0
Businesses and Self-Employed	8.7	9.1	10.5	3.4	**25.8**
Museums	< 1.0	0	0	1.1	0
Zoos	< 1.0	0	0	1.1	0
Prefer not to Answer	37.0	52.3	31.6	33.7	19.4

Appendix 28: Response to the question ***Please indicate why you think any partnerships were unsuccessful.***

Reasons for Ineffective Partnerships	**Federal Government (%) n = 367**	**State/Local Government (%) n = 54**	**Non-Profit Organization (%) n = 115**	**Businesses and Self-Employed (%) n = 30**
Insufficient funding	**20.4**	13.0	**23.5**	**30.0**
Insufficient staff for workload	**19.9**	**18.5**	13.9	10.0
Goals were unclear	**19.1**	9.3	8.7	**20.0**
Unrealistic goals	------	9.3	8.7	**13.3**
Administrative/logistical difficulties	17.4	**16.7**	**16.5**	**13.3**
Did not deliver what was agreed upon	16.9	------	------	------
Asked for more than what was agreed	------	6.4	4.3	3.3
Our partnerships have been successful	15.0	9.3	23.5	6.7
Improperly trained staff for the project	8.9	9.3	10.4	3.3
Did not meet deadlines	10.9	------	------	------
Unrealistic Timeline		7.4	7.0	10.0
Changed deadlines	------	1.9	2.6	3.3
Partner did not fulfill duties	10.4	7.4	8.7	16.7
Unrealistic expectations	------	**14.8**	**14.8**	**20.0**
Change in project leadership	10.1	9.3	9.3	3.3
Poor quality work	10.1	------	------	
Change in goals	6.3	5.6	4.3	**13.3**
Personality conflict	5.2	5.6	4.3	3.3
Partner treated our employees poorly	2.7	1.9	4.9	0
I don't know	19.3	18.5	17.4	3.3
Prefer not to answer	10.9	24.1	10.4	10.0

Appendix 29: Responses to the question ***Do you think your program will utilize partnerships with outside organizations to meet its botanical research/management needs in the future?***

Future Partnerships	**Federal Government (%) n = 486**	**State/Local Government (%) n = 72**	**State Natural Heritage (%) n = 33**	**Non-Profit Organization (%) n = 197**	**Business/Self-Employed (%) n = 47**
Yes					
With the same and other partners	**74.9**	**75.0**	**90.9**	**86.3**	**74.5**
But with different partners	2.3	0	3.0	< 1.0	2.1
No					
Because of lack of funding	2.1	1.4	3.0	0	2.1
Because botanical management will be reduced	1.4	1.4	0	------	------
Because we will increase within-agency spending and staffing	0	0	0	------	------
Because we have not been satisfied	0	0	0	0	0
I don't know	12.0	16.7	3.0	4.6	14.9